Proceedings of the 10th INTERNATIONAL CONFERENCE ON APPROPRIATE TECHNOLOGY

10th ICAT

22 – 25 November 2022
Khartoum, Sudan

Enhancing Peace and Governance through Appropriate Technology: Reimagining Sustainable Community Wellbeing in an Era of Global Climate Change

EDITORS

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Taurai Mutanda
Amged O. Abdelatif
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INAT. INTERNATIONAL NETWORK ON APPROPRIATE TECHNOLOGY

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@10thICAT

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10TH ICAT

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KHARTOUM, SUDAN

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University of Khartoum
Sudan University of Science and Technology

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DECLARATION

All the work that is published in this book was double-blind peer reviewed by the 10th ICAT Panel of Reviewers. This process entailed detailed reading of the abstracts, reporting of comments to authors. The authors of submitted abstracts (those that were accepted by the reviewers) were further invited to make their full submissions for consideration for the Proceedings Book. These submissions were further meta-reviewed by the co-editors of this proceedings. The full papers, poster abstracts, and workshop and tech-fair proposals that are included in the Proceedings Book are the only conference submissions to have been successfully accepted through the two-tiered, double-blind peer reviewed, and meta-reviewed, process.

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SUSTAINABILITY, SOCIAL INEQUALITY, AND HUMAN WELLBEING | GREEN ECONOMY AND INNOVATION

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GADA KADODA
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JEPHIAS GWAMURI
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In response to the first call for participation, we received a total of 190 abstract submissions for the different presentation types, full papers, poster papers, workshops and tech-fair proposals.

These abstracts went through a double-blind review process and 177 submissions were accepted. The authors of accepted submissions were invited to make their full submission.

Once we launched the call for full submissions based on the outcome of the abstract review process coupled with a second call for participation, we received 106 full submissions. These submissions went through a double-blind review process and 97 were accepted to proceed to the final submissions stage.

An additional quality assurance process of the final submissions was conducted by the chairs of the conference sections to ensure that reviewers' comments were addressed by the authors. This process generated the final set of 81 accepted submissions.

Of the 190 abstracts originally received, which included 168 papers, only 59 papers were accepted for inclusion in the proceedings, representing an acceptance rate of 35%.

The meta-review process also generated a set of 12 best papers that were selected for publication in a special issue of the African Journal on Science, Technology, Innovation and Development (AJSTID).

Only the abstracts of these selected papers, are published in this book of proceedings. An additional 3 papers will be selected during the conference based on best presentations to make the set 15 papers to be published in the journal.

This is the 3rd time in the ICAT series, since the 5th and 6th ICAT, in 2012 and 2014, to produce a journal publication. An independent process for preparing the special issue for AJSTID will start after the conference. Congratulations to their authors!

Abstracts of accepted posters, and descriptions of accepted workshops and tech-fair presentation categories are included in the proceedings.

The work published in the final book of proceedings are from the following countries: Australia, Belgium, Benin, Ethiopia, Germany, India, Italy, Japan, Kenya, Netherlands, Nigeria, Norway, Oman, Puerto Rico, South Africa, Saudi Arabia, Sudan, United Kingdom, United States, and Zimbabwe.

This task would simply not have been possible without the commitment, professionalism and support of the Program Committee, 41 academics and professionals, who volunteered their services to ensure the success of the process. We salute them!

The process we followed has guaranteed the academic quality of scholarship delivered at the Conference and that which is published in the Proceedings. This is to comply with the requirements for accreditation and funding by the Gibela Research Chair, Tshwane University of Technology, South Africa.

This complete two-tiered, double-blind, peer-reviewed, meta-reviewed process demanded a rigorous peer review and entailed detailed reading of the manuscripts by reviewers and the 10th ICAT Proceedings Editors. We are continuing the legacy of the 9th ICAT as the first virtual ICAT conference as well as having produced the best-looking proceedings.

The sections of the Proceedings book are based on the sub-themes of the conference. The authors selected the themes/topics as part of their submission process.

A number of sub-themes did not receive many submissions, since the early calls, and they were combined with other themes after the final submissions phase. The final set of sub-themes is used for the topic sections in this book of proceedings. In being grounded in technology and local context, the conference theme and topics, are evolving and changing, with ICAT and time. We hope that you find much food for AT thought.

THE PEER REVIEW PROCESS

The process followed by the 10th ICAT COMMITTEES helped guarantee the academic quality of what is delivered at the event and what was published in the Proceedings. By and large, this process benefited from the high standards set by the 9th ICAT peer review process. We salute Prof. Amira Osman and her team.

For the 10th ICAT, an international POGRAMME COMMITTEE/PANEL OF REVIEWERS with expertise aligned with the sub-themes of the Conference, were appointed. All abstracts were double-blind, peer reviewed, and meta-reviewed. Authors of accepted abstracts were then invited to submit full papers, which were also double-blind, peer reviewed. This is to comply with the requirements for accreditation and funding by the Gibela Research Chair, Tshwane University of Technology, South Africa.

All submitted abstracts and papers were required to adhere to a format provided in the document titled: INSTRUCTIONS FOR AUTHORS. These papers were reviewed by the 10th ICAT EDITORS, who checked them against the themes of the conference and evaluated in terms of:

- Relevance to conference theme and objectives
- Originality of material
- Academic rigor
- Contribution to knowledge and
- Research methodology

Authors whose abstracts were accepted after the Stage One review process was completed were provided with anonymous reviewers' comments and requested to submit their full papers, noting and addressing these comments.

Authors were included in the Conference Presentation Program and the Conference Proceedings book only after evidence was provided that all comments were appropriately responded to during the last stage of the meta-review process.

None of the reviewers were involved in the review process related to their own authored or co-authored papers. This process was managed fully online on EASYCHAIR and authors who are also members of the 10th ICAT INTERNATIONAL ORGANIZING COMMITTEE, the LOCAL ORGANIZING COMMITTEE, and the PANEL OF REVIEWERS could not see their own papers.

The **International Organizing Committee (IOC)** – Members of the International Network on Appropriate Technology (INAT): *Brian Stephenson*, USA; *Cadena Bedney*, USA; *Charles Verharen*, USA; *Diran Soumonni*, South Africa; *Gada Kadoda*, Sudan; *Hattie Carwell*, USA; *Ilesanmi Daniyan*, South Africa; *Jephias Gwamuri*, Zimbabwe; *Jesse Bemley*, USA; *John Tharakan*, USA; *John Trimble*, South Africa; *Khumbulani Mpofu*, South Africa; *Mammo Muchie*, South Africa; *Marcel J. Castro-Sitiriche*, Puerto Rico; *Mjumbe Poe*, USA; *Olukorede Adenuga*, South Africa; *Taurai Mutanda*, South Africa; *Thierry Yonga Chuengwa*, South Africa.

The **Local Organizing Committee (LOC)** – Academics from the University of Khartoum (UofK); Sudan University of Science and Technology (SUST): *Aamir Dean*, SUST; *Akram A. Elkhalifa*, UofK; *Alla Isam Khidir*, UofK; *Alnema B. K. Eltom*, UofK; *Amel Bakhiet*, SUST; *Amged O. Abdelatif*, UofK; *Aya A. Abdalrahman*, UofK; *Safa Suliman*, UofK; *Sahl Yasin*, SUST; *Shaza M. H. Mohammed*, Uof K; *Yousif J. A. Osman*, SUST, *Zeinb Y. A. Mohamed*, SUST.

The **Panel of Reviewers/ Scientific Review Committee (SRC)**:

IOC Members: *Brian Stephenson*; *Charles Verharen*; *Diran Soumonni*; *Gada Kadoda*; *Ilesanmi Daniyan*; *Jephias Gwamuri*; *John Tharakan*; *John Trimble*; *Khumbulani Mpofu*; *Mammo Muchie*; *Marcel Castro-Sitiriche*; *Olukorede Adenuga*; *Taurai Mutanda, Thierry Yonga Chuengwa*.

LOC Members: *Aamir Dean*; *Akram Elkhalifa*; *Amged Abdelatif*; *Sahl Yasin*.

Other Colleagues: *Amira Osman*, South Africa; *Ammar Babiker*, Sudan; *Anas Showk*, Sudan; *Arig Bakhiet*, Sudan; *Christopher Papadopoulos*, Puerto Rico; *Corinthias P. M. Sianipar*, Japan; *Eitimad Ahmed*, Sudan; *Excellent Chireshe*, Zimbabwe; *Fatima Salaheldin Mohamad Ali*, Sudan; *Gamal Hamid*, Sudan; *Ibrahim Zakaria*, Sudan; *Iman Abdelrahman*, Sudan; *Joseph Thomas*, India; *Kelvin Willoughby*, Germany; *Malathe Gamal Mahmoud Hamid*, Sudan; *Marwan Adam*, Sudan; *Mohamed Chouikha*, USA; *Muna Eltahir*, Sudan; *Rami Zeinelabdein*, Sudan; *Rofaida El Zubair*, Sudan; *Safa Mohammed*, Sudan; *Tanzeil Hashim*, Sudan; *Xavier Poshiwa*, Zimbabwe.

Conference Chairs:

Gada Kadoda, International Organizing Committee and Scientific Review Committee; *Akram Elkhalifa*, Local Organizing Committee; *Amel Bakhiet*, Local Organizing Committee Co-Chair.

10th ICAT ORGANIZERS AND SPONSORS

International Network on Appropriate Technology (INAT)

Developing science and advancing engineering present opportunities to solve global health and education problems and to meet the basic water, food, and shelter needs of the world's population. Human-centered technologies can promote better health, better education, improved access to clean water, necessary shelter, and safe food, as well as transportation and energy solutions that do not cause ecological imbalance.

Today's world governments focus a disproportionate amount of our resources on war technology, policing, and security. Such control of the planet's natural and developed resources stands in the way of forwarding science, engineering and resource distribution to end poverty and human suffering.

"Appropriate Technology" (AT) is the technology to empower people. The more the world population is empowered, the more the world's human resources can be utilized, and the better equipped the mass of human society is to exercise democracy. Appropriate Technology is culturally sensitive yet ecologically sound and economically sustainable. It requires:

a. Compassion for humankind and Mother Earth,

b. Belief that humanism, collectivism and egalitarianism are abiding human characteristics, and

c. Commitment to replace unproductive and war-centered technologies with technology that focuses on human needs.

Public education on "what is appropriate technology" is central to the mission of the International Network on Appropriate Technology (INAT). Our ongoing work is to bring Appropriate Technology to the forefront of discussion and practice regarding science and technology—in education, policy, research, development, and deployment. INAT organized the 1st International conference on appropriate technology (1st ICAT) in July 2004, in Bulawayo Zimbabwe, hosted by the National University of Science and Technology (NUST). The theme was "A Knowledge Management Approach to the Development of Appropriate Technology, with a focus on sustainable land-based projects". Since then, every two years INAT has advanced this process, in 2006 again in Bulawayo, in 2008 in Kigali Rwanda, in 2010 in Accra Ghana, in 2012 in Pretoria South Africa, in 2014 in Nairobi Kenya, in 2016 again in Zimbabwe, in 2018 In Benin and our last ICAT was blended conference hosted in South Africa.

To fully embrace AT, one must be driven by compassion for humankind and Mother Earth and philosophically rooted in the belief that humanism, collectivism and egalitarianism are abiding human characteristics that heighten a collective conscience across human society. To fully embrace AT, one must be committed to organising for AT to replace unproductive and war centered technologies. This process will move AT from the pronouncement of the goal of AT advocates, to a reality where appropriate technology dominates in all realms of science, technology and education. We encourage all organisations to become signatories to our Appropriate Technology Declaration by visiting our website at www.appropriatetech.net. We look forward to sharing our vision in more detail in a full-length edited book *The Appropriate Technology Manifesto* due for release early 2023. INAT is pleased to be part of the team that is making the 10th ICAT in Sudan a success.

For more information visit:
https://www.appropriatetech.net/.

University of Khartoum (UofK)

The University of Khartoum is delighted to host, in collaboration with Sudan University of Science and Technology, the International Conference on Appropriate Technology in its 10th edition. We believe that the theme for this edition, enhancing peace and governance through appropriate technology, comes in great accordance with the prior issues that Sudan is now concerned with and the entire world indeed. Through this platform, the University of Khartoum is looking forward to seizing the opportunity for the establishment of solid connections with local and international participants, to exchange knowledge and experiences on the use and creation of appropriatetechnology that would serve the enhancement of peace and good governance in era of global instability, for the good of our nations and the globe.

The **University of Khartoum** (**UofK**) is a public university located in Khartoum, Sudan. It is the largest and oldest university in the country. In 1902, Lord Kitchener established Gordon Memorial College, which was upgraded in 1951 to become Khartoum University College. The present University of Khartoum is the result of the natural transformation of the aforementioned mentioned College when the country became independent in 1956. Since that date, the University of Khartoum has been recognized as a top university and a high-ranked academic institution in Sudan and Africa. UofK has been actively involved in education, research, and community services through its different faculties, schools, and institutes. It accommodates today more than 55,000 students both in the under-graduate and postgraduate programs that are delivered by the 22 Faculties and 14 institutes. The University has five campuses that are located in differentareas within the capital city.

Mission

The University of Khartoum - by virtue of its position as the 'mother' for all Sudanese universities is entrusted with:

- Providing a variety of high-quality programs both at undergraduate and postgraduate levels for all specializations and disciplines.
- Providing education and training services of the highest quality in accordance with international standards and with values that are derived from the Sudaneseculture.
- Embracing modern concepts in all the services it provides and nurturing research environments with the aim of raising the competence of students to high standards that would enable them to undertake the responsibility of work and interaction with the society at both national and international levels.
- As an intellectual reserve and stock of knowledge, the University aims at fulfillingthe needs of the society and the requirements for development and directing these needs and requirements.

Vision

The University vision is to participate, through its role in the field of higher education and scientific research, in the creation of a unified, developed and advanced Sudanese Nation. The University aspires to be independent both academically and financially, elevated in the different aspects of knowledge and to link the programs and research it offers with the requirements of permanent development in Sudan. While it maintains itsposition as a leading national institution, it also aspires to occupy a leading internationalposition.

For more information visit: https://www.uofk.edu/en/

Sudan University of Science and Technology (SUST)

Sudan University of Science and Technology (SUST) is one of the distinguished institutions of applied sciences in Sudan, and a center of scientific research which is committed to excellence and innovation, preparing students for leadership over the world, and community service.

SUST provides educational programs in applied knowledge in the fields of Basic, Engineering & Medical sciences, and humanities & natural resources, and keeps pace with modern programs. The university offers its programs through traditional methods and by affiliation (distanced). It also offers many programs based on e-learning methods.

SUST produces a great deal of original scientific research of practical nature that leads to sustained development and the ability to cope with new technology, thus leading to the emergence of prominent and distinguished scientists of high international caliber and reputation.

SUST accomplishes its share in the scientific, technological and industrial development and public services in Sudan, thus serving the community. Most of University's activities are carried out through its partnership with national and international bodies in various sectors that serve it mission and help achieve its objectives.

SUST graduates are distinguished by their possession of scientific knowledge in addition to possession of the required skills for applying knowledge, which made our graduates desirable and preferred in the labor market. The university has preserved this advantage through its educational traditions and components of its programs and its possession of the latest laboratories, workshops and technical frameworks, its training for faculty members and its permanent interaction with society.

SUST hosts the UNESCO Chair for Women, Science and Technology which provides an appropriate environment for transferring knowledge, conducting scientific research, projects, training, and transferring and exchanging regional and global experiences, and empowering women for scientific research, and application of science and technology to achieve sustainable development.

For more information visit: https://www.sustech.edu/

WELCOME FROM THE COMMUNITY OF THE 10TH INTERNATIONAL CONFERENCE ON APPROPRIATE TECHNOLOGY

On behalf of the International Network on Appropriate Technology (INAT), the University of Khartoum (UofK), and Sudan University of Science and Technology (SUST), we welcome all the participants to our first fully-blended onsite and virtual conference.

WELCOME FROM THE CHAIR OF THE 10TH ICAT INTERNATIONAL ORGANISING COMMITTEE (IOC) & SCIENTIFIC REVIEW COMMITTEE (SRC)

Dr. Gada Kadoda (INAT)

Although the idea of ICAT coming to Sudan goes back a long way to 2006 when I attended the 2nd ICAT in Zimbabwe and found the intellectual community that I wanted to be part of, the idea became stronger when I was elected to the INAT Board of Directors in March 2021 where my role was to lead the planning for the 10th ICAT. The first 10th ICAT International Organizing Committee (IOC) meeting was held on 14 April 2021 after much activity on email while we were drafting for the call for hosting.

The first mission that IOC embarked on was to distribute the call-to-host of the 10th ICAT through the various channels and networks that members have access to. My eyes were set on the University of Khartoum and Sudan University of Science and Technology, our top universities with a long track record in STEM fields. It was to my great delight that not only both universities responded positively to the call, but also decided to co-host it. I find it a good example of collaboration between Sudanese universities, and what we in Sudan strive for, and we in Africa know that such collaboration–transnational and regional, academics and research–will build equal partnerships and enhance all of us.

The first meeting of the 10th ICAT Organizing Bodies was on 27 July 2021, and the first joint meeting between international and local committees was on 4 August. The first call-for-participation went out on 9 August 2021, and the rest will be history by the time you read this book of proceedings. However, I want to share my top three notable moments in this journey.

When we started the planning, COVID-19 international travel restrictions were still in place. So, we followed in the footsteps of the 9th ICAT in 2020, the first virtual ICAT, but also kept the on-site modality in our planning, which was the wish of the two organizing committees. For INAT members, it was the legacy of face-to-face conferences they wanted to revive; and for the Sudanese, it was ideal in every sense. The decision was made to hold the 10th ICAT in a fully integrated virtual and onsite modality, and therefore, we can claim to be the first ICAT to do so.

Three months into the joint planning, on 25 October 2021, a military coup occurred in Sudan along with an internet blackout that lasted for over three weeks. Things suddenly stopped, and then dramatically changed in more ways than one. As a Sudanese was many things, but as a planner for an international conference, the first thought was what if this coup had happened, along with its consequences, at the very same time next year. We might not have known if the conference had taken place, or not, until the internet is back!

Thanks to INAT colleagues, especially those in South Africa, for exploring options and creating a back-up plan that should there be a need, the conference would be convened from South Africa. However, this would be an alternative, but not a desirable scenario, for a conference where more than 70% of its presenters live in Sudan and who were facing the same circumstances as they tenaciously went through the various submission phases. As expected, the conference planning over the following months was disrupted–the meetings, the fund raising, etc., along with significant changes at management-level at the two host universities. Nonetheless, here we are convening the conference in Sudan and over the internet.

The last moment I want to share was relatively recent. It is when the Ministry of Higher Education and Scientific Research granted the conference a generous amount that would allow us to convene it in the way it was originally planned. This was a notable moment because it followed months of fruitless searching for funds and lots of worry whether we will have to limit onsite activities to fit with the meager resources we had. We had just a few weeks to the conference. Thanks to the resilience of the local committee and the commitment of the host universities, as well as to the decision by the Ministry, that we now have this congregation of online and offline participants who can wholly engage with each other.

There is a close relationship between the Sudanese Revolution for "freedom, peace, and justice" and AT. The field of appropriate technology (AT) offers alternatives to capital-intensive technology that dominates national development plans and university curriculums fueled by the aspiration for industrialization. These alternatives come in the form of scalable solutions that aim to improve access to basic needs, strengthen self-reliance, reduce poverty, and protect the environment. AT is also considered a movement because it embodies a sustained effort in support of social and environmental goals. Whether AT roots lie in Ernest Schumacher's concept of "intermediate technology" for economic development or Mahatma Gandhi's approach to "self-sufficiency" and nonviolent resistance, its gist is about dismantling the status quo in technology choice and development thinking. By being people-centered and context-relevant, AT offers ways to work at injustices that create wars and calls for revolutions. The intrinsic link between development and freedom, pioneered by Amartya Sen and Julius Nyerere before him, is at the heart of the Sudanese revolution and AT. So, welcome to the 10th ICAT in Sudan!

Despite being experienced in organizing international events and coordinating complex programs, planning for this conference was exceptionally hard. Not only, it was a long-awaited for conference to come to my home country, but also because there was much uncertainty that multiplied after the coup. Yet, it has also been a truly rewarding effort, that had its moments of crisis and others of good fortune. I salute the Sudanese, for working under difficult conditions, and I salute our international participants and partners, fellow organizers and reviewers, for their unrelenting support. From our 20 countries represented in this conference, we did it! I hope that we will reflect further on pertinent matters, both in Sudan and globally, to achieve justice in all its forms and deal with the climate change crisis. One way, is to have this kind of conversation on Appropriate Technology across our places, fields, and age groups. Finally, I wish our conference was open access, just like it's proceedings, but we will make up for that, especially for the students!

WELCOME FROM THE CHAIR AND CO-CHAIR OF THE 10TH ICAT LOCAL ORGANISING COMMITTEE (LOC)

Dr. Akram Ahmed Elkhalifa (UofK)
Prof. Amel Bakhiet (SUST)

The Local Organising Committee would like to welcome the delegates to 10th ICAT (2022) which is hosted in Sudan for the first time jointly by the University of Khartoum (UofK) and Sudan University of Science and Technology (SUST). This conference culminates enormous collective efforts and activities that started two years ago. The journey of organizing this incredible event by the Local Organizing Committee (LOC) started in April 2021 when the Faculty of Architecture (FoA), Uofk received an invitation to apply for hosting the tenth version of ICAT conferences. Since the early stages of preparations, widening the pool of participation and collaboration between UofK faculties and institutes and among higher education institutes in Sudan has been a featuring character of all plans and arrangements undertaken.

Immediately after receiving the correspondence communicating the selection of UofK and SUST as host and co-host respectively, both universities started planning for the event jointly in all stages. Despite the challenges associated with the instability in the political and economic scene in the country, which makes proper planning a serious challenge, the LOC managed to overcome most of the obstacles that came along through flexible plans, interim and responsive actions, and good communication. In fact, not all milestones were delivered in accordance to the initial plan, however, the LOC team kept in mind the proper organization of the event as the ultimate goals which in turn was the key factor of success. Dedicating time, effort, and resources featured the performance of the LOC which held weekly meetings since early stages. Attracting fund to cover the financial resources needed for the realization of the conference was not an easy task, and continued to be a source of anxiety for the team especially when the event came closer and closer. The efforts of the LOC to provide in-kind support helped eliminating many items from the budget and paved the road for organizing the conference as planned for. We put ahead to allow as much participants as possible to participate, therefore, having the conference in a hybrid form – in person and online – maximized the level of participation and allowed many participants from around the globe to take part in the discussions.

Hosting the 10th ICAT conference initiates a global network and international exchange and cooperation in research and practice in the field of appropriate technology. The UofK and SUST are privileged to set the arena that discusses issues related to appropriate technology, in a mutli-national, multi-cultural, muti-institutional, and multi-generational environment.

The conference is addressing issues that many communities around the globe are facing and many scholars are investigating. These issues are in fact directly related to the human's wellbeing and prosperity of nations and communities. On the top of these issues comes peace in its different interpretations and forms as well as climate change. We hope that the discussions which will take place as part of the conference activities will reflect positively and effectively on these matters in the near future.

10th ICAT SPONSORS

Ministry of Higher Education and Scientific Research

(SUDAN)

The **Ministry of Higher Education and Scientific Research (MoHE)** was established in 1972 to be in charge of setting policies, plans and programmes for higher education and scientific research, and to coordinate among its institutions which consist of public and private universities, private colleges, institutes, and research centres. These institutions are established by their own laws and founding orders. These institutions have their scientific, administrative and financial independence and are supervised by their own boards and administrative bodies.

VISION

Advancing community, fulfilling its needs, with more emphasis on comprehensive development through qualifying an adept individual who has the ability to create, innovate and interact effectively with their community and who is able to promote the community's spiritual and human values and to lead to progress and development of the Sudanese nation.

MISSION

a. Providing world-class higher education according to the standards of quality and competence; where students are equipped with the appropriate knowledge and skills required for the labour market.
b. Offering higher education for all on the basis of capability and competence.
c. Preparing scientific and technical frameworks in various fields and disciplines that prepare highly trained cadres in different disciplines
d. Developing and spreading science and knowledge through scientific research and promoting local technology
e. Preserving community values.

GENERAL OBJECTIVE

The Ministry of higher education aims to develop the higher education (HE) and scientific research sector as a major contributor to achieving the development and prosperity of Sudanese community, so long as it is available for all citizens who are academically qualified to access this type of education, regardless of their social, economic, political, gender, geographic, religious and disability backgrounds. HE should be of multidisciplinary and diverse programmes within public and private institutions, and it should be of wide-ranging styles, flexible and of high quality, grounded on the Sudanese community values.

For more information on MoHE visit:
http://mohe.gov.sd/

Text for MoHE was prepared by Safa Suliman, and translated by Noureddin Ahmed Hashim.

Gibela Research Chair, Tshwane University of Technology, Pretoria

(SOUTH AFRICA)

The **Gibela Research Chair (GRC)** was established in 2016 and chaired from inception by Prof. Khumbulani Mpofu. The vision of the GRC is to pioneer innovative research in manufacturing technology development and manufacturing value chain skills development geared for the revitalisation of the South African railway-manufacturing sector. The GRC focuses on manufacturing in rail specific learning programmes, research, and development on rail. The mandate GRC is anchored on six desired outcomes as follows:

1. To create an enabling institutional environment for research to thrive
2. To develop areas of work in priority areas that provide Tshwane University of Technology (TUT) with a sustained reputation for a focused, user-friendly research.
3. To foster a critical mass of contended research leaders who inspire and mentor others.
4. To develop a well prepared of next generation researchers, postgraduate students, postdoctoral research fellows and young staff members.
5. To increase the income for and from research and innovation through a diversity of approaches, sources, partnership, alliances, nationally, regionally, continentally, and globally.
6. To foster effective leadership, governance, and management system.

HIGHLIGHTS

- Between 2020 and 2021 financial year the GRC attracted approximately R5million complimentary funding for research and innovation activities. The funding covers the localization project, merSETA projects, business incubator, future transport manufacturing technology, and TUT food support initiatives.
- The GRC is responsible for the funding of 11 postgraduate students, 5 postdoctoral research fellows and 2 junior lecturers.
- Facilitation of academic writing workshop to upskill students and researchers with academic writing skills.
- In 2022, 32 research publications has been credited to the GRC.

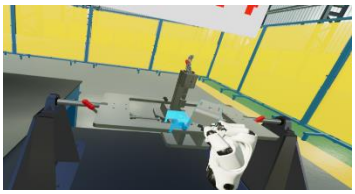
INNOVATION HUB

An innovation ecosystem has been built by the GRC through the partnership of SEDA, NRF and the partnerships that have been formulated around industrialisation of innovations, localisation, patents, and prototypes taking research outputs to the market for commercialisation.

For more information on GRC visit:
https://rmceri.org/index.php/about-us/

GRC BUSINESS INCUBATOR

The GRC supports the commercialization of research output through RMCERI, a business incubator located in Hatfield, Pretoria. The Incubator supports companies such as the X-Reality (XR) Lab and Ditau Advanced Manufacturing Technologies among others, specializing in the development of virtual educational environments and the design and fabrication of manufacturing technologies such as Intelligent Jigs, Reconfigurable Vibrating Screen, Energy Efficiency Technology, Reconfigurable Assembly Fixture, virtual reality technology and Simulation Plan A to promote the competitiveness of the SMMES etc. This is to assist small business in gaining access to enabling facilities, networks and markets that will accelerate their growth locally and globally.

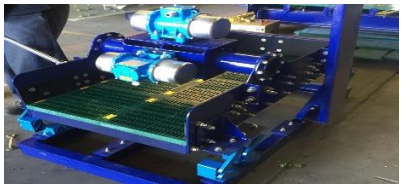


Virtual-Reality Experiences at the X-Reality (XR) Lab

Intelligent Jigs

Reconfigurable Assembly Fixture

Reconfigurable Guillotine Shear and Bending Press Machine (RGS&BPM)



Reconfigurable Vibrating Screen (RVS)

Gibela Plant exhibition

10th ICAT PRORAM PARTNERS

Sudanese Knowledge Society (SKS)

The **Sudanese Knowledge Society** (SKS) was established in 2012 as a cultural society and a free space for knowledge sharing. It comprises students, academics, professionals, from a wide array of educational, business, government, and civil society backgrounds. Our activities span a wide range of topics pertaining to knowledge, its management and production, focusing on innovation, ICT and development, as well as on factors that influence knowledge work such as politics, culture and pedagogy. Conferences, symposia, and workshops have been organized for various sectors including education, health, engineering, environment, media, as well as for civil society organizations. SKS's motto is "knowledge to empower people". While our vision is to foster a knowledge society in Sudan, we take an equitable and inclusive approach in thinking about society and knowledge.

For information, visit: https://www.facebook.com/sksociety.org

Joint Educational Facilities, Inc. (JEF)

The **Joint Educational Facilities, Inc.** (JEF) is a non-profit K-12 organization in Washington, DC USA with national and international impact. JEF works primarily with pre-college and undergraduate students and teaches them advanced computing, contemporary mathematics, robotics, research skills and oral and written communication skills with an emphasis on artificial intelligence (AI) and high-performance computing (HPC). These students participate at local, national, and international meetings, conferences and symposia to present the results of their research. Their papers are published in the proceedings of those conferences. Many JEF students have continued their education through the Masters and Doctoral levels. Representative program areas include Raspberry Pi, Robotics, HPC, Computer Gaming, and Geographic Information Systems (GIS).

For information, visit: https://www.facebook.com/JEFIncDMV/

Northern California Council of Black Professional Engineers (NCCBPE)

Established in 1970 by concerned engineers to form ties between the Black scientists and engineers in Northern California, the **Northern California Council of Black Professional Engineers** (NCCBPE) is a Professional Society that promotes technical professional development and encourages youth to enter STEM careers through programs such as the Museum of African American Technology Science Village, field trips, seminars and conferences. The purpose of the organization is to establish camaraderie, and to act as a pressure group as needed to enhance the professional opportunities of black engineers. Initially, emphasis was placed on becoming registered Professional Engineers. Later the number of disciplines represented in the organization began to diversify, with no one discipline having a clear majority, and more scientists joined. Today, the organization addresses the needs of scientists and engineers. Although professional development continues to be emphasized, the need to encourage more African Americans to enter technical fields has become a major priority.

For information go to http://www.nccbpe.org

Passion of Hope International (PHI)

Passion of Hope International (PHI) is a registered non-profit corporation in the state of Maryland, USA. With a focus on Africa, we purpose to lift and empower impoverished communities towards triple-bottom line (Planet-People-Productivity) resilience in the areas of food sovereignty, livelihoods, health, well-being, and education. Our feet on the ground are our hubs in Nakuru, Kenya and Kwara state, Nigeria. The vision of PHI is to collaboratively empower the most marginalized communities towards a sustainable future characterized by biodiverse-rich ecosystems and stewardship of one another.

You may find us on the web at: www.passionofhope.org

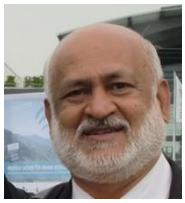
STEM Sudan

STEM Sudan is an NGO entity consisting of a number of science educators and professionals, working to promote science as key solution to solving many problems in the Sudanese communities, especially in education, peace, environment and development. STEM Sudan, in collaboration with its partners and donors, has been serving the community through the last five years, providing schools, kids and families with practical solutions in science education as tools for improving the abilities of school students, opening for them new horizons and assisting them to explore the world of science as a main tool towards innovation and creativity. Our priorities include children with disabilities, women and girls in science, and displaced children. STEM Sudan works among those communities to help in giving them the chance for equal opportunities and fair competition power with other children with better situations and educational environments. We promote peace, environment conservation, ethical values, and encourage children to continue their education by motivating them to achieve a better future for themselves, and for their families and communities.

For information, visit:
https://www.facebook.com/stemsudaninitiative

10th ICAT KEYNOTE SPEAKERS

Dr. Mohamed Abdelrahman Hassan is a writer, critic and graphic designer. He is as associate professor of criticism and human sciences in the College of Fine Art and Design at Al-Neelain University-Sudan. His work focuses on decoloniality of modern knowledge, and critique of modernity. Dr. Hassan's most recent published book is *Critique of the (Global) South Thought* (2022).



Mr. Deepak Gadhia is a leading technocrat and a pioneer in the field of Solar and Renewable Energy as well as Bio Gasification, and has earned international recognition for his accomplishments over the last 40 years. He started his career with Wacker Chemie GMBH in Germany but moved to India where he developed a number of world-renowned renewable energy projects. He is a popular speaker at International as well as National meetings and conferences on solar power, solar cooking, social techno-preneurship, community uplifment and sits on the board of advisors for a number of organisations. He is a Director of MSA Renewtech Foundation. Mr. Gadhia holds a degree in "Process and Environmental Engineering" from TFH Berlin, and has obtained his Post Graduate Degree from TU Berlin, Germany & MIT of USA.

Dr. Myron N.V. Williams is an Associate Professor of Chemistry, at Clark Atlanta University, Atlanta, GA, USA. In 1980, he earned a B.S. in Microbiology (magna cum laude), at Howard University, Washington, DC, and went on to complete a Ph.D. in Biology at the Massachusetts Institute of Technology, Cambridge, MA in 1989. He has held appointments as Adjunct Professor at the Winship Cancer Center at Emory University, and Mid-Career NHGRI Fellow at The Molecular Science Institute in Berkeley California. During the 2021-2022 academic year, he has been a Fulbright Fellow at the Institut International Ingénierie de Eau et de Environment in Ouagadougou, Burkina Faso, and at the Kwame Nkrumah University of Science and Technology, Kumasi, Ghana. His current research interests include appropriate technologies for improving biofuel production, waste disposal, climate smart agriculture, and use of low cost and local resources for education and industrial development in marginalized communities.

Dr. Lilia A. Abron, P.E., BCEE, the CEO/President and Founder of PEER Consultants, P.C. (PEER) is a trailblazer, a History Maker™, an entrepreneur. She is the first African-American woman in the nation to earn a Ph.D. in Chemical Engineering and the first African-American to start an engineering consulting firm focused on the environment and its environmental issues. To help advance the condition of the impoverished sector worldwide using sustainability measures, Lilia also founded PEER Africa Western Cape, CC in 1995. Most recently, Dr. Abron has been inducted to the prestigious National Academy of Engineering (NAE) - election to the National Academy of Engineering is among the highest professional distinctions accorded to an engineer. Dr. Abron has also been inducted into the notable American Academy of Arts & Sciences as an Eminent Engineer. She is a proud resident of the District of Columbia, a District-registered Professional Engineer (P.E.), and a Board-Certified Environmental Engineer (BCEE).

Ms. Sushma Patel is a South African registered professional architect, urban designer, lecturer and researcher. Sushma has a particular interest in the spatial fragmentation of South African cities and the need for increased density and integration close to the inner city. Since graduating as an architect, she acquired 16 years of practice experience mainly in Cape Town, South Africa, during the period 1998-2012. She has worked with prominent architects Jo Noero, Heinrich Wolff, Aaron Wegmann and Luyanda Mpahlwa on socially significant buildings. Her Masters in Urban Design dissertation and current Doctorate of Architecture proposal centres around these themes. She is also a published researcher in the field of the 'urban laboratory', a research field identified within the Department of Architecture and Industrial Design at the Tshwane University of Technology where she teaches and is head of post graduate studies.

Dr. Guma Kunda Komey is associate professor of Political Geography, Peace and Development Studies, consultant, and civic activist. His areas of research and activism include peace, conflict resolutions, land rights, natural resource governance, and state-society relations. He has carried research projects, consultancies, and publications on those issues, with special reference to the Nuba Mountains in South Kordofan. Komey obtained a B.A. (Honors) in Human Geography from the University of Khartoum in 1987; an MA in International Development Economics from the Graduate School of International Relations at the International University of Japan in 1991, a Ph.D. in Economic Geography from the University of Khartoum, Sudan. Dr Komey serviced as Peace Advisor in the Office of the Prime Minister Dr Abdalla Hamdok, 2020 -2021; and is currently the Head of Peace Programs Office of TCC in Khartoum, Sudan.

Dr. Nashwa Eassa is Associate Professor of Physics at Al Neelain University, Sudan. She is undertaking a post-doctoral fellow in Nanophotonics group at Nelson Mandela Metropolitan University (NMMU), funded by the department of Research Capacity Development (RCD) at NMMU. She holds a Ph.D. in physics from the Nelson Mandela Metropolitan University, South Africa and Master of Science in Material Physics and Nanotechnology from Linkoping University, Sweden. Dr. Eassa is Founder & President of Sudanese Women in Science Organization (SWSO), Vice- President of Arab Region of Organization for Women Scientists for the Developing World (OWSD) (2016-2020), and member of South African Institute of Physics (SAIP). She received many awards, more recent are Honored Doctorate, Linkoping University, Sweden, 2019; and Elsevier Foundation awards in Mathematics and Physics, 2015.

In 2021, **John Trimble** retired as a professor in Industrial Engineering at Tshwane University of Technology (TUT). From 2015-2016, he served as a Fulbright professor at TUT, while collaborating with the South African Post Office on postal innovation. In 2003-2004, he served as a Fulbright Professor in computer science in Zimbabwe. From 1996 to 2015, he worked in the Systems and Computer Science department at Howard University in Washington DC. He holds a Ph.D. in Industrial and Systems Engineering from Georgia Institute of Technology, a M.Sc. in Operations Research from UC Berkeley, a M.Sc. in Computer Science from Stanford University, and B.Sc. in Engineering from Northwestern University. He is the founding president of the International Network on Appropriate Technology (INAT) and has coordinated nine international conferences on appropriate technology (all in Africa).

10th ICAT PROCEEDINGS EDITORS, ORGANIZING COMMITEES AND PANEL OF REVIEWERS

AAMIR DEAN

Member, Local Organizing Committee and Panel of Reviewers

Aamir Dean is an Assistant Professor and Head of Material Testing Lab (MTLab) at the School of Civil Engineering, Sudan University of Science and Technology. He is also associated with the University of Seville, Spain, as a Visiting Professor. **Dr. Dean** received two doctorate degrees, in Mechanical Engineering from the University of Seville, Spain in 2020, and also in Civil Engineering from the Leibniz University Hannover, Germany in 2017.

AKRAM A. ELKHALIFA

Chair, Local Organizing Committee
Member, Panel of Reviewers

Dr. Akram Ahmed Elkhalifa is Associate Professor at the Department of Construction Management and Economics. He obtained a B.Sc. in Architecture from the Faculty of Engineering and Architecture, University of Khartoum, in 2000; an M.Sc. in Real Estate Management from KTH Royal Institute of Technology, Sweden, in 2004; and a Ph.D. in Architecture from the University of Camerino, Italy, in 2012. **Dr. Elkhalifa** acquired more than 20 years in teaching, research and practice in the field of architecture with specific focus on construction management and economics, technologies, and building materials. He was the former dean of the Faculty of Architecture, University of Khartoum during the period from Nov. 2019 to April 2022. Dr. Elkhalifa is very active in research and conducted several researches with many universities and research institutes locally an internationally.

ALLA ISAM KHIDIR

Member, Local Organizing Committee

Ala Isameldin Ali Khidir is lecturer at the Department of Political Science, University of Khartoum; and the Department of International Relations and Strategic Studies, University of Medical Sciences and Technology. She received her B.Sc. in Political Science and M.Sc. in International Relations from the University of Khartoum. **Alla** has an M.Sc. in Public Administration from the Doha Institute for Graduate Studies.

ALNEMA B. K. ELTOM

Member, Local Organizing Committee

Dr. Alnema Bakri Khorsahen Eltom is an assistant professor at the department of accounting and finance, University of Khartoum. She has more than 15 years of experience in teaching, research and consultation. **Dr. Eltom** holds a Ph.D. in Businesses Administration and her main research area is Banking Efficiency. She served as Deputy Dean for Administrative Affairs, and Coordinator for Post Graduate Studies Program, at the School of Management Studies; and was Financial Secretary for the Management Studies Graduate Association.

AMEL BAKHIET

Co-Chair, Local Organizing Committee

Amel Omer Bakhiet is a Professor of Veterinary Pathology and Dean of Scientific Research Deanship, Sudan University of Science and Technology. She has more than 100 scientific papers. **Professor Bakhiet** is a certified auditor for academic programs from the Association of Arab Universities and an ISO 22000 internal auditor.

AMGED O. ABDELATIF

Member, Local Organizing Committee
Co-Chair, Panel of Reviewers
Co-Editor, Proceedings

Amged Osman Abdelatif is an Associate Professor at the University of Khartoum, where he had BSc in Civil Engineering (2003), and MSc in Structural Engineering (2008). **Dr. Abdelatif** was awarded a Ph.D. in Civil Engineering at the University of Nottingham, UK (2013). Also, he is the owner of www.sudacon.net for construction news, Sudan.

AMIRA OSMAN

Member, Panel of Reviewers

Amira Osman is a Sudanese/South African architect, researcher, academic, activist, public speaker, and author. She is a Professor of Architecture at the Tshwane University of Technology and holds the position of SARChI: DST/NRF/SACN Research Chair in Spatial Transformation (Positive Change in the Built Environment). **Professor Osman** is a registered Professional Architect (SACAP 7267) and the editor of The Built Environment in Emerging Economies (BEinEE) Book Series.

AMMAR BABIKER

Member, Panel of Reviewers

Ammar Babiker is an Assistant Professor in the Department of Structural Engineering at Sudan University of Science and Technology. He received his Ph.D. in Structural Engineering from TU Dresden in 2021. **Dr. Babiker** is an active researcher on different aspects of structural analysis with a special focus on advanced computational methods.

ANAS SHOWK

Member, Panel of Reviewers

Dr. Anas Showk is associate professor at University of Khartoum. He was a senior development engineer in KROHNE Innovation GmbH, Germany. **Dr. Showk** received his Ph.D. in engineering from Ruhr-University Bochum, Germany in 2012. He completed M.Sc. at Munich University of Technology, in 2007 and B.Sc. at University of Khartoum in 2003. He published more than a dozen articles and papers in peer reviewed journals and international conferences. He is a member of IEEE, IEEE Young Professionals, and IEEE Communication Society.

ARIG BAKHIET

Member, Panel of Reviewers

Arig Bakhiet is Consultant Engineer, Accredited GHG inventory reviewer (UNFCCC) Energy, and Climate Change academic and working professional collaborating with different national and international bodies in terms of preparing technical studies and international reports. **Dr. Bakhiet** is collaborating lecturer and academic supervisor with different universities in subjects related to Energy, Environment and Development.

AYA A. ABDALRAHMAN

Member, Local Organizing Committee

Aya Abdalaziz Abdalrahman is a Teaching Assistant at the faculty of Arts, department of French. **Aya** has been awarded honor degree in French language at the University of Khartoum. She holds a master degree in French literature. She did her graduate studies in the field of Folk Tales in Sudan, Africa and Europe. She has been a member/ leader in media and communication teams in several local projects.

BRIAN STEPHENSON

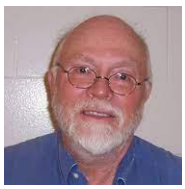
Member, International Organizing Committee
Co-Chair, Panel of Reviewers
Co-Editor, Proceedings

Brian Stephenson is the founder and President of Passion of Hope International - USA, a non-governmental organization operating in Africa with a vision to "collaboratively empower the most marginalized communities into a sustainable future characterized by biodiverse-rich ecosystems and stewardship of one another." An active advocate and practitioner of sustainable design and appropriate technology, **Dr. Stephenson** believes, "we all share a responsibility to be stewards of our planet and lifters up of the people communities that inhabit it." Brian a registered civil/structural engineer with over 40 years' experience in consulting engineering under his company, Qodesh CM. For over 25 years, he was adjunct professor of civil engineering at both Howard University (Washington, DC) and Morgan State University (Baltimore, MD). He is also a founding member of the International Network on Appropriate Technology and currently leads their Projects Committee.

CADENA BEDNEY

Member, International Organizing Committee

Cadena Bedney is a Registered nurse from California. She received her nursing degree from California State University in Los Angeles. While working as the Cancer and AIDS Pain Management Nurse for USC Medical Center, Los Angeles, California she participated in the research project: Multi-measure Pain Assessment in an Ethnically Diverse Group of Patients with Cancer and AIDS. **Ms. Bedney** presently works as a Nurse Consultant/Case Manager for the physically & mentally handicapped. She is a member of CASA [Court Appointed Special Advocates] of Los Angeles for juveniles and the League of Women Voters.



CHARLES VERHAREN

Member, International Organizing Committee
Co-Chair, Panel of Reviewers
Co-Editor, Proceedings

Charles Verharen has served for 55 years at Howard University, America's flagship historically black University. Specializing in philosophy of culture, **Professor Verharen** has traveled to 160 countries searching for ideas to support his philosophy of survival ethics: the values with the most promise to guarantee our continued existence in the face of climate change and other crises.

CHRISTOPHER PAPADOPOULOS

Member, Panel of Reviewers

Christopher Papadopoulos, PhD., is a Professor in the Department of Engineering Sciences and Materials at the University of Puerto Rico, Mayagüez Campus (UPRM), which he joined in 2009. He earned B.S. degrees in Civil Engineering and Mathematics from Carnegie Mellon University (1993) and a Ph.D. in Theoretical and Applied Mechanics at Cornell University (1999). Prior to joining the faculty at UPRM, **Professor Papadopoulos** had appointments at the University of Wisconsin, Milwaukee, first as a member of the faculty of the Department of Civil Engineering and Mechanics (2001-2006) and later as a research and instructional staff member in the College of Engineering (2007-2009).

CORINTHIAS P. M. SIANIPAR

Member, Panel of Reviewers

Dr. Sianipar is an Assistant Professor at Kyoto University, Japan. A versatile scholar trained in engineering and social science educations, he specializes in Appropriate Technology, Social/Life-Cycle Assessment, and Complex Systems within the science-to-policy-to-action framework. **Dr. Sianipar** has more than ten years of experience in delivering socio-technical solutions for different development contexts.

DIRAN SOUMONNI

Member, International Organizing Committee
Member, Panel of Reviewers

Dr. Diran Soumonni is a Senior Lecturer in Innovation Policy and Management, and Director of the Master of Management in Innovation Studies programme at the Wits Business School, University of the Witwatersrand, South Africa. He obtained his PhD in Public Policy from the Georgia Institute of Technology in Atlanta, Georgia, USA, where he focused on both innovation studies and energy policy. Diran's teaching and research interests include comparative innovation systems, energy innovation, nanotechnology innovation, and philosophical paradigms in scientific research. Diran also holds a master's degree in Materials Science and Engineering (Georgia Institute of Technology) and undergraduate degrees in Physics and Mathematics (Tuskegee University, USA). **Dr. Soumonni** is an active member of the Global Network for the Economics of Learning, Innovation and Competence Building Systems (GLOBELICS), the African Network for the Economics of Learning, Innovation and Competence Building Systems (AFRICALICS), the International Network on Appropriate Technology (INAT), and of the Society for the Social Studies of Science (4S).

EITIMAD AHMED

Member, Panel of Reviewers

Dr. Eitimad Hashim Abdel-Rahman Ahmed is a graduate of the Department of Zoology, Faculty of Science, University of Khartoum. She was employed by various universities in Sudan Khartoum University, South Africa Kwa-zulunal Duran, Pretoria and Lompopo universities in South Africa and Hail University in Saudi Arabia. She has provided consultancy, Research, workshop services to numerous environmental organizations and groups (South African National Biodiversity Institute, SANBI, Humanitarian Aid Commission, HAC and The German Biosecurity Programme GIZ Sudan Office). **Dr. Ahmed** belongs to numerous scientific societies (OWSD, STEM), has numerous published scientific and research articles, books and chapters.

EXCELLENT CHIRESHE

Member, Panel of Reviewers

Excellent Chireshe is an Associate Professor of Religion and Gender in the Department of Philosophy and Religious Studies of Great Zimbabwe University. She holds a PhD in Religious Studies from the University of South Africa. **Dr. Chireshe** has supervised, to completion, a number of undergraduate and postgraduate students. She is well-published in reputable outlets.

FATIMA S. M. ALI

Member, Panel of Reviewers

Fatima Salaheldin Mohamad Ali is doctoral candidate University of Bonn, Germany. Her current research focuses on Participatory Approaches to Valuing Forest in Sudan. **Fatima** worked as Researcher for the National Center for Research (NCR) in Sudan. Additionally, Fatima co-founded the Sudanese Knowledge Society. She holds a B.Sc. in Botany and an M.Sc. in Remote Sensing from the University of Khartoum. Fatima is doing research on nature valuation and conflicts in forest resources in Sudan. The research aims to know how the local communities value and use the forest. Furthermore, Fatima is studying higher diploma in folklore at Khartoum University.

GADA KADODA

Chair, International Organizing Committee
Chair, Panel of Reviewers
Managing Editor, Proceedings

Gada Kadoda received her Ph.D. in Software Engineering from Loughborough University, M.Sc. in Information Systems and Technology from City University, and B.Sc. in Computer Science from University of Khartoum. She is an independent scholar and civic activist. Her work experience includes research and teaching posts in the UK, Barbados, and Sudan. **Dr. Kadoda** is well published and received notable recognitions. Her most recent co-edited book is "Capturing Cultural Capital: A Step towards Propelling Sudanese Intellectuals into the Global Milieu (2022). She is founding president of the Sudanese Knowledge Society, as well as founding and executive board member of the International Network on Appropriate Technology.

GAMAL HAMID

Member, Panel of Reviewers

Dr. Gamal Mahmoud Hamid has a B.Sc. Arch., Khartoum University; S. M. Arch. S., Massachusetts Institute of Technology, and Ph.D. Urban Planning, University of California, Los Angeles. **Dr. Hamid** has been a teaching staff at Khartoum University since 1993. Served as Department Head (1995-1998), and as Faculty Dean (2010-2015). He has several published papers, books and book chapters.

HATTIE CARWELL

Member, International Organizing Committee

Hattie Carwell is a founding member of the International Network of Appropriate Technology and currently serves as Vice President. She is Co-founder and Executive Director of the Museum of African American Technology (MAAT) Science Village. **Ms. Carwell** is a retired health physicist with the US Department of Energy, and former nuclear safeguards group leader rat the International Atomic Energy Agency in Vienna, Austria. She is a graduate of Bennett College and Rutgers University.

IBRAHIM ZAKARIA

Member, Panel of Reviewers

Dr. Ibrahim Zakaria Bahreldin is an architect, urbanist, and educator with various educational backgrounds (architecture, human settlements, and urban design). He is currently an Associate Professor of Urban and Environmental Design, King Abdulaziz University, Saudi Arabia. **Dr. Bahreldin** served as Head of the Department of Urban Planning and Design, University of Khartoum (2015-2018), Director of Investment University of Khartoum (2017-2018), and the director of the Quality Assurance Unit at the Faculty of Architecture, the University of Khartoum (2013-2015). He is also a member of several academic and professional organizations in Sudan and worldwide. He is a co-founder of the Sudanese Urban Planning Association (SUPA).

ILESANMI DANIYAN

Member, International Organizing Committee
Member, Panel of Reviewers

Dr. Ilesanmi Afolabi Daniyan obtained both the Doctor of Philosophy and Masters of Engineering in Mechanical Engineering from the Federal University of Technology, Akure, Nigeria in 2017 and 2012 respectively. At present, **Dr. Daniyan** is a Researcher at the Department of Industrial Engineering, Tshwane University of Technology, Pretoria, South Africa. His research interests include: Production Engineering, Advanced Manufacturing and Automation/Robotics.

IMAN ABDELRAHMAN

Member, Panel of Reviewers

Iman Abuelmaaly Adelrahman (IEEE SM) is an Associate Professor of Digital Signal Processing at the University of Khartoum (U of K). She received her B.Sc. in Electronics and Telecommunication, from Cairo University (1982) and obtained her M.Sc. (1994) and her Ph.D. (1998) in Digital Signal Processing from U of K. **Dr. Adelrahman** has over twenty-two years of experience in teaching and research, eleven years in operation and maintenance of telecommunication systems. She was the founding CEO of the Sudanese Research and Education Network (SudREN). She has nine years of experience in regional organizations; positions included Vice Chair, and Board Member of the organizations.

JEPHIAS GWAMURI

Member, International Organizing Committee
Co-Chair, Panel of Reviewers
Co-Editor, Proceedings

Professor Gwamuri holds a PhD in Materials Science and Engineering from Michigan Technological University. He has partaken research and coordinated a number of projects including the International Atomic Energy Agency (IAEA) funded RAF-8040 Zimbabwe project, the DNV GL-NREL funded Snow Effect on PV Systems project and the Regional Environmental Initiative Network (REIN) – Africa's Biofuels Project. He has co-authored several research articles in international high impact journals such as; Scientific Reports, IEEE journal of Photovoltaics, Elsevier's Solar Energy materials and Solar Cells, and has contributed towards; technical reports, a book, a policy briefs and book chapters. His current research direction is informed experience in appropriate technologies (AT) in general, and Renewable Energies Technologies (RET) in particular, where technologies such as wind, hydro, geothermal, hydrogen, biofuels and solar energy are explored as alternatives energy sources for water abstraction, supply and energy particularly in rural communities.

JESSE BEMLEY

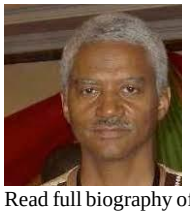
Member, International Organizing Committee

Dr. Jesse Bemley is the Director of Joint Educational Facilities (JEF) in Washington, DC., USA. He and the JEF CIO, Bryan Bemley, have initiated the shifted from PC platforms for projects to Raspberry Pi platforms for student projects in intelligent technologies, high performance computing and geographical information systems. **Dr. Bemley** is a lecturer at Bowie State University in the Department of Technology and Security.

JOHN THARAKAN

Member, International Organizing Committee
Co-Chair, Panel of Reviewers
Co-Editor, Proceedings

John Tharakan is Professor of Engineering in the Department of Chemical Engineering, Howard University. He has served as Chair, Director of Graduate Studies and is founding Faculty Adviser, Engineers Without Borders, HU Chapter. He received his BS (chemical engineering) at Indian Institute of Technology, Madras, MS and PhD in Engineering Science (Biochemical Engineering) from the University of California, San Diego. His research expertise is in environmental engineering and biotechnology, appropriate technology development, engineering education, sustainable development and ethics in science and engineering, with funding from US EPA, DOD and NSF. **Professor Tharakan** was Fulbright Senior Scholar to India ('06-'07), researching biological methods of waste treatment. With Engineers Without Borders, he has worked on clean water, sanitation and renewable energy technology implementation in Senegal, Kenya and El Salvador. He is founding and board member of the International Network on Appropriate Technology. Professor Tharakan has authored over 50 peer-reviewed papers and book chapters.



JOHN TRIMBLE

Member, International Organizing Committee
Member, Panel of Reviewers

Read full biography of **Professor Trimble** on 10th ICAT Keynote Speakers' pages.

JOSEPH THOMAS

Member, Panel of Reviewers

Joseph Thomas is an Aeronautical Engineer from Indian Institute of Technology, Madras (IITM) with 40 plus years of experience in the sustainable development sector with hands on experience in Sustainable Agriculture, Information and Communications Technology and Renewable Energy and Fund raising. **Dr. Thomas** is currently Vice President of the Office of Institutional Advancement at IIT Madras.

KELVIN WILLOUGHBY

Member, Panel of Reviewers

Kelvin Willoughby holds the Chair of Innovation Management and Entrepreneurship, at the HHL Leipzig Graduate School of Management, in Germany. **Professor Willoughby** is author of Technology Choice (Routledge 2019) and is an expert on the management of intellectual property, technology-based entrepreneurship, and strategic planning for technology-based industry development.

KHUMBULANI MPOFU

Member, International Organizing Committee
Member, Panel of Reviewers

Professor Khumbulani Mpofu is an established NRF rated researcher with an unstoppable appetite for industrialisation of his research activities, who has graduated over 8 doctoral and 30 Masters students in the last ten years. In the past years, he had published more than 150 articles in peer-reviewed journals, with over 130 conference proceedings and 20 book chapters, to date. He has 4 patents registered to his name continentally and globally. He has also been recognised 10 times at national awards (National Science and Technology Forum, Southern African Institute of Industrial Engineers, Standard Bank-Rising Star) and more than ten times in the university, for research excellence since the beginning of his career. To date he has been awarded funding to the tune of over R50 million rand ($US 5 million) for research, innovation, incubation, and commercialisation activities.

MALATHE G. M. HAMID

Member, Panel of Reviewers

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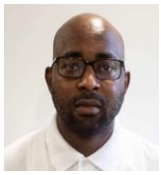

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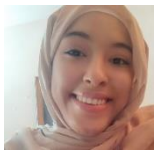

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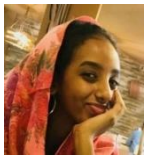

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WELCOME TO THE PROCEEDINGS OF THE 10TH INTERNATIONAL CONFERENCE ON APPROPRIATE TECHNOLOGY

PAPERS

CLIMATE CHANGE

PAPERS

INCREASE ATMOSPHERIC WATER GENERATING EFFICIENCY BY USING THERMOELECTRIC COOLERS CHIP AND ELECTROLYTE LIQUID

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Abstract
A tropical country with a latitude of zero degrees (Sudan is one of them) is known as a humid country; by 2030, almost half of the world's population will live in water-stressed conditions. Due to high average values of annual rainfall, relative humidity, solar irradiance, and ambient temperature. In this work, an atmospheric water generator (AWG) system was designed, fabricated, and will be tested at the Sudan University of Science and technology under the outdoor tropical climate conditions of Sudan to investigate the amount of freshwater production in successive periods of 24 h. AWGs have various components including thermoelectric coolers (TEC) units, internal and external finned heat sinks, direct current (DC) cooling fans, air-conditioner mesh air filters, and axial ventilation fans. A TEC unit is the main component of an atmospheric water generating (AWG) system, which works based on condensing the humid air and extracting water from the atmosphere.

Keywords: Atmospheric Water Generator, Thermoelectric Cooling, Water-Electrolyte, Air-Cooled Condenser Water Yield Rate.

INTRODUCTION

Aims and objectives:
This project achieves a number of sustainable development goals. The Sustainable Development Goals (SDGs) are a set of 17 UN Resolution “Global Goals” (Paragraph 54, Resolution: A/RES/70/1 of 25 September 2015) that were built on the principles of The Future.

We want to cover a wide range of social and economic development issues.
Goal 3: Good health and well-being: People in rural areas that cannot reach clean water face problems with diseases that are caused by polluted water, we provide them with reachable clean water.
Goal 6: Clean water and hygiene: In Sudan many states face difficulties in getting clean water, the device can help overcome this danger by providing clean fresh water 24/7.
Goal 9: Industry, Innovation, and Infrastructure: a new innovation was built that can reduce overall energy consumed by the TEC when used as a condenser.
Goal 17: As we mentioned above there is an integration between goals 3, 6, and 9 in the project.

RELATED STUDIES

An experimental study has been conducted by testing a novel water generator with only two thermoelectric coolers (Model A) for the extraction of water from atmospheric vapor under small inlet flow rates. The impact of operating conditions on surface temperatures of cold/hot sides and water yield are investigated, including the air flow rate and humidity (He, 2019).

The AWG converts water vapor into liquid water, mostly by condensation. Condensation-based AWGs operate on a vapor-compression refrigeration cycle. Its advantage is it can cool moist air below the dew point, causing a phase change from vapor to liquid water over the cooling surfaces. Despite relative humidity playing a crucial role in the AWG's efficiency, abiotic conditions like sky emissivity and wind speed are less of an impact. Therefore, it can be operated under a wider range of weather conditions. Moreover, the AWG can produce higher water yields than the passive method through additional energy inputs (Inbar, 2020). Figure 1 illustrates the process of the cooling cycle.

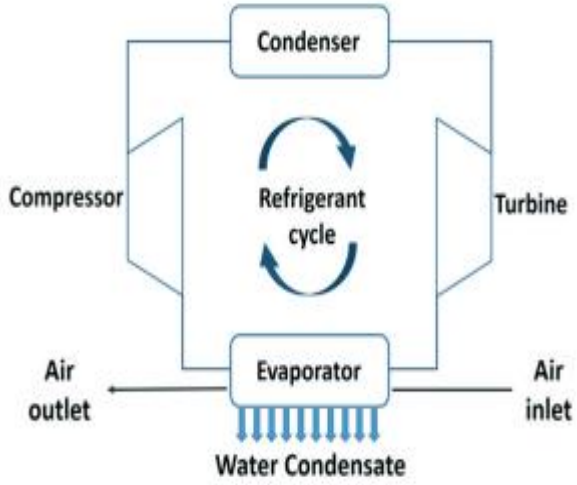


Figure 1: *Flow chart for the process of cooling cycle*

METHODOLOGY

The Atmospheric Water Generator is a humidity and temperature-driven Application Therefore, the device's ability to generate water is entirely depends on relative humidity and atmospheric temperature. For optimal performance, relative humidity must be at least 50%. In regions with lower humidity levels, the Appliance will produce water at a slower rate and with less volume than that of a higher humidity environment. In a residential environment, higher levels of humidity tend to be found in kitchen areas, near bathrooms used for bathing, near open windows (in warmer weather), or in more spacious rooms.

This unit also performs well in an air-conditioned room or homes. Because air-conditioning reduces relative humidity, it is recommended to open the window at night to increase the humidity in the room. By converting humidity in the air into water, the Atmospheric Water Generator can also function as a dehumidifier. To ensure high quality of the drinking water produced, the Atmospheric Water Generator utilizes multiple filtration technologies. When the air is dry and cold, water generation may become slow and inefficient. It is recommended that the Appliance be connected to a municipal water supply allowing the Appliance to serve as a water purifier using its filtration system.

Design theory

We purchase a new system for condensation in AWG. Our system has the ability to produce a large amount of water by using air cooled condenser that used in the Vapor compression Refrigeration system (VCRS). And the low power consumptions by using water electrolyte as

a refrigerant in a thermal isolated close that been cooled by a thermoelectric cooler (TEC).

Component of the AWG

*Microcontroller***:** The unit is fitted with a microcontroller, which ensures proper working of internal parts, regulates hot or cool water temperature settings, and supervises and controls the functionality of individual internal working parts.

Electrical Sensors: Various types of electronic sensors are mounted on different parts like the UV light, heating mechanism, and storage tank. These sensors will alert in the event of a malfunction or performance anomaly The sensors that was used are: temperature sensor, to check the temperature of the TEC, Water level sensor, to give a signal to control the valve when the pure water in the tank reach a certain level, and PH sensor, to make sure the water is pure enough for drinking. Figure 2 illustrates seniors with microcontroller connection.

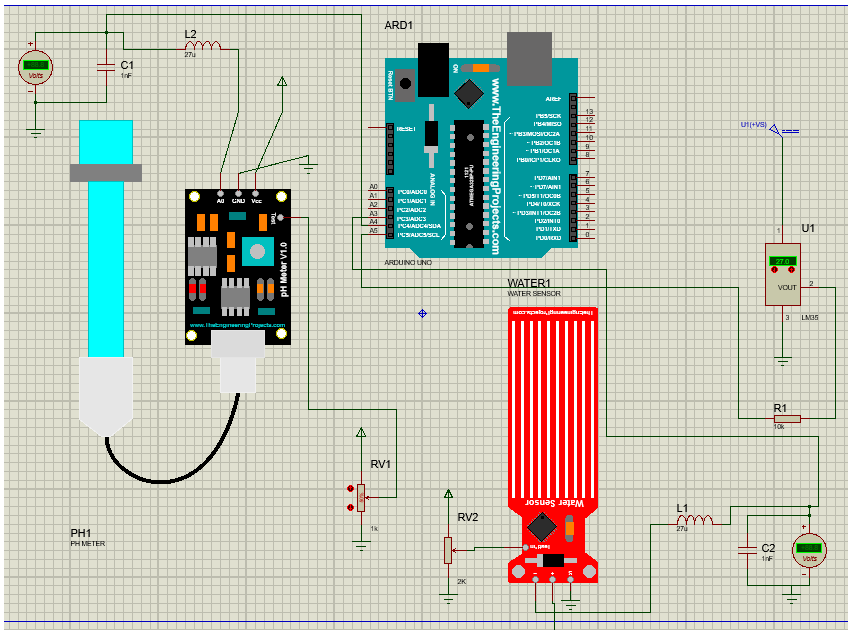


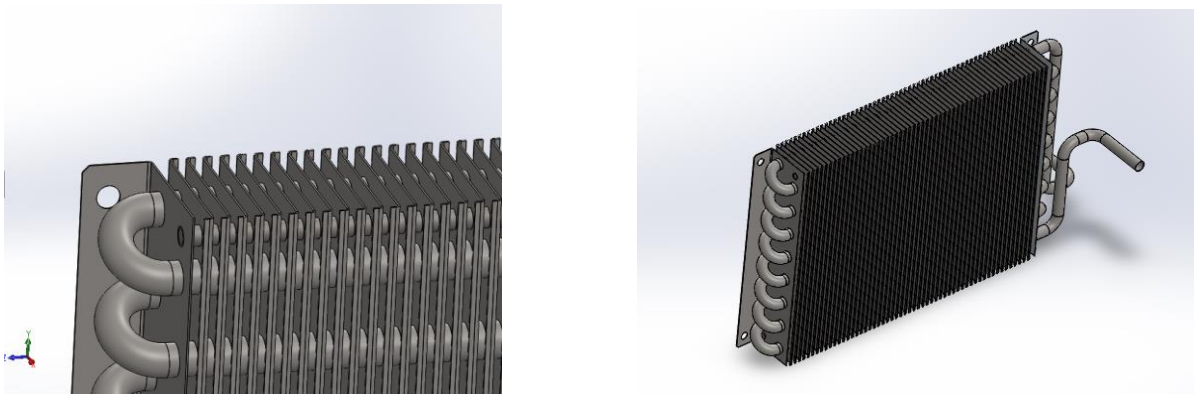
Figure 2: *seniors with microcontroller connection.*

*Energy Saving Features***:** The machine makes less water if the tank is full, and when hot or cold water reaches a preset temperature. An electronic sensor was installed in the tank to turn off the water-making function when the preset temperature has been reached.

Air suction Fan: a fan increases production efficiency by increasing the airflow rate that enters the condenser.

*Water Leakage Detector***:** In case of any unexpected situation of water leakage, the machine will stop working automatically. The shutdown is accompanied by a warning sound and flashing VFD.

*Condensing Coils***:** The condenser was designed like an air-cooled condenser with a special refrigeration fluid. We used water electrolytes as a cooling fluid which been cooled with a TEC system contacted with a tank. We use this new system to reduce the cooling energy that has been lost from the TEC when used as a condenser and to conduct water and improve water production efficiency. Figure 3(a) and (b) is the SolidWorks design.



(a) **(b)**

Figure 3: *Condenser* (a) and (b).

*Electrostatic Air Filter***:** The first filter that air passes through before being condensed and converted to water is electrostatic; our electrostatic air filter effectively prevents micro-particles and dust from entering the machine, as well as deterring slime and fungus growth.
UV Filter Treatment: An ultraviolet lamp that effectively eliminate bacteria and microorganisms from the water by sterilizing it. Sterilization Controlled by Microprocessor.
Multi-Stage Filtration System: Our multi-stage filtration system allows us to provide consumers with great tasting, high-quality water**.**

Software:
Design: SolidWorks has been used to design our devise. It is efficient 3D design tool using parametric design modular. We added the properties of the materials we used in our device.
Simulation: SolidWorks Flow simulation tool is an effective tool to simulate liquid and gas flows throw the condenser plates. It is intuitive Computational fluid dynamic (CFD) that represents the purpose of our study. Figure 4 is a simulation with SolidWorks that represent air filtration system, and Figure 5 is polyster filter that has been using in the air filtration system.

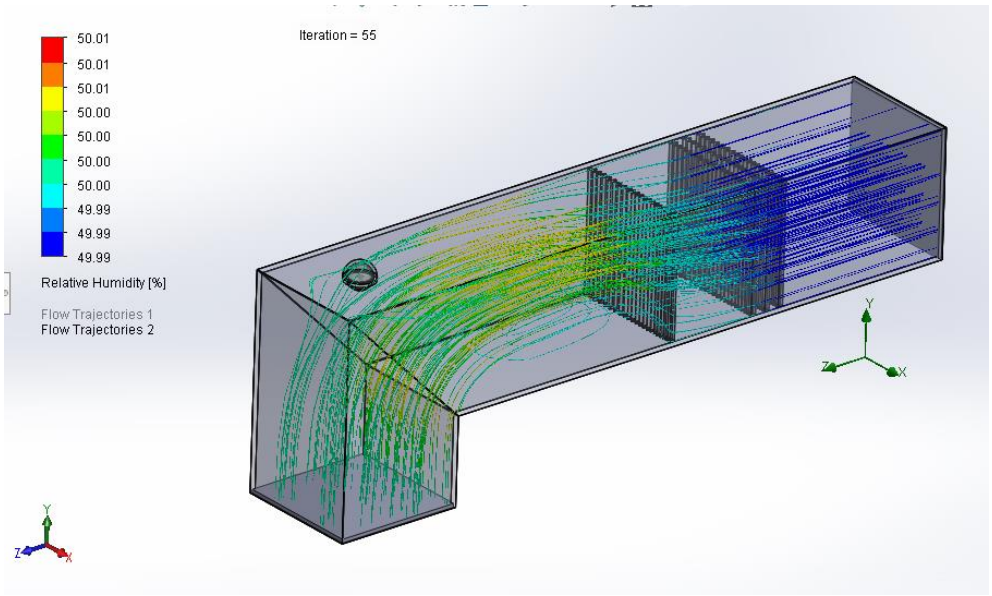


Figure 4: *Air filtration system*.

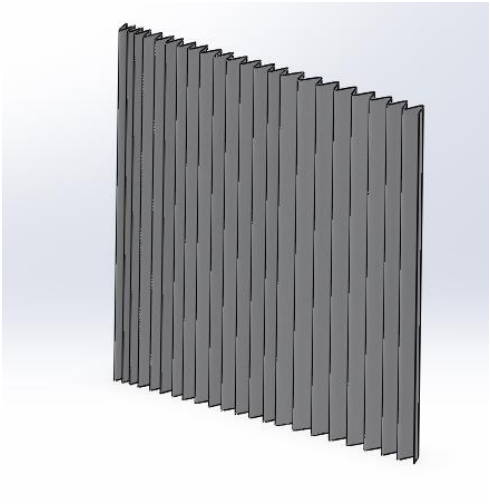


Figure 5: *Polyester filter.*

RESULTS AND DISCUSSION

In our method that has been used, Relative humidity will drop after air enters in first step, and the air temperature will also drop this means some of the relative humidity will been condensed. Figure 6 is diagram to illustrate the drop that happen from 50% to 23% in the air humidity.

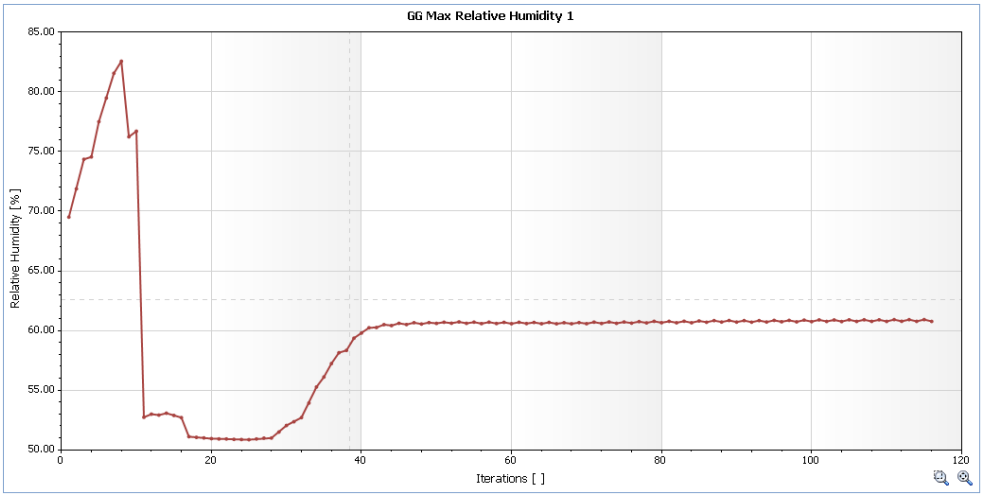


Figure 6: *The relative humidity with time (iterations) diagram.*

In the initial step the temperature (heat flux) is high then it drops when it goes through heat exchanger, the small increasing in the temperature that happen is due to incoming air mixing with air coming from the other side, Figure 7 is a diagram to illustrate this.

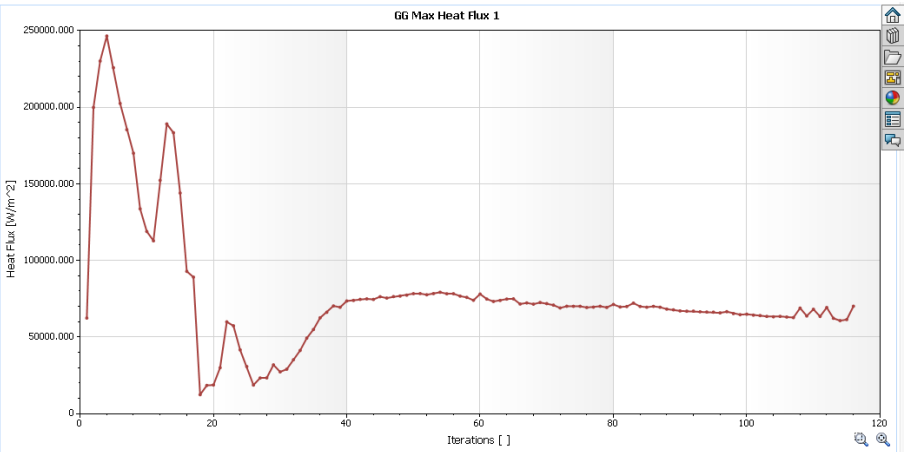


Figure 7: *The heat Flux with time (iterations) diagram.*

Fluid Flow Simulation

Initial Conditions: Ambient Conditions

Thermodynamic parameters	Static Pressure: 101325.00 Pa Temperature: 30.00 °C
Velocity parameters	Velocity vector Velocity in X direction: 0 m/s Velocity in Y direction: 0 m/s Velocity in Z direction: 20.000 m/s
Solid parameters	Default material: Aluminum Initial solid temperature: 20.05 °C
Turbulence parameters	

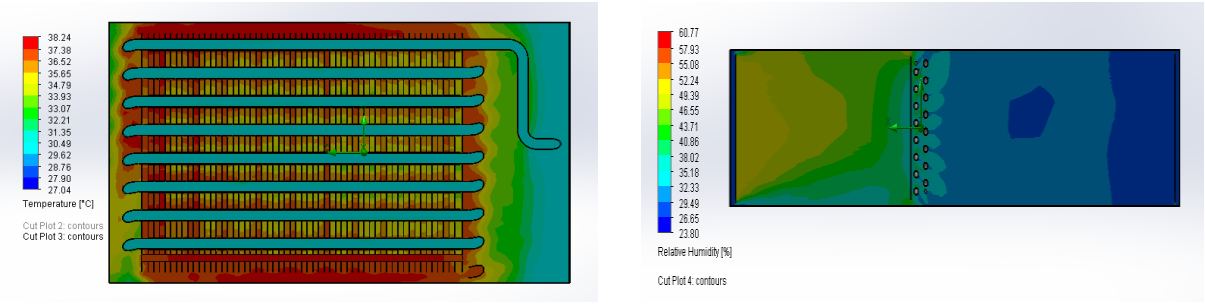
Boundary Conditions: Boundary Conditions, Inlet Volume Flow 1

Type	Inlet Volume Flow
Faces	Face<3>@LID8-1
Coordinate system	Face Coordinate System
Reference axis	X
Flow parameters	Flow vectors direction: Normal to face Volume flow rate: 1.9000 m^3/s Fully developed flow: No Inlet profile: 0
Thermodynamic parameters	Temperature: -5.00 °C
Turbulence parameters	
Boundary layer parameters	Boundary layer type: Turbulent

Environment Pressure 1

Type	Environment Pressure
Faces	Face<4>@LID7-1
Coordinate system	Face Coordinate System

The output relative humidity and the air temperature around the condenser in the humidity condensation, Figure 8 (a) and (b) are diagrams to illustrate the temperature cut plot (a) and the relative humidity at the output (b).



(a) *(b)*

***Figure 8**: temperature cut plot (a) and humidity at the output (b).*

CONCLUSION

After studying and investigations, we found that the annual average relative humidity in Khartoum is about 30%. The highest humidity occurs in August. Its monthly average is 50%, and the lowest humidity in April was about 15%. However, these percentages change over the course of 24 hours. Where the humidity is highest in the morning and lowest in the afternoon. Certainly, it changes according to the fluctuations of the weather, especially when it rains.

In Port Sudan, the average annual humidity is 63%. The highest humidity is in October and November, with an average humidity of about 70%. The lowest humidity occurs in June and is about 65%. Wind direction; and sea breezes affect the humidity in Port Sudan during the 24 hours. Therefore, the red sea state is better in terms of high humidity in Sudan, which enables us to produce a greater amount of water from the atmosphere. There is also a problem with fresh water, shortage, and difficulty in fresh water. Therefore, this project is to achieve one of the goals of sustainable development.

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MULTIPLE-CRITERIA DECISION ANALYSIS FRAMEWORK FOR WATER INFRASTRUCTURE DEVELOPMENT PRIORITIZATION IN SUDAN

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Abstract
Water does not respect administrative, domestic, or international boundaries. There is no development without secure and sustainable water sources which are assessed, managed, and developed along natural hydrological boundaries. Limited access to water resources is a pressing social and environmental issue that frequently causes conflicts, especially in the Least Developed Countries (LDCs). The water scarcity associated with water competition brings attention to sustaining national security through coordinated, integrated, and careful planning to support quests for poverty eradication, employment generation, rural development, and sustainable livelihoods. The aim of this paper is to propose and develop a process that can be followed in defining priorities for water infrastructure development in water catchments based on a Multiple-Criteria Decision Analysis (MCDA). The MCDA is based on economic, social, and environmental criteria that support envisaged outcomes from investing in infrastructure development to assisting decision-makers in prioritizing the use of limited financial resources and/or directing international support agencies. Climate-Responsive water infrastructure can be further explored in order to prioritize the water harvesting measures undertaken considering the Sustainable Development Goals (SDG). The paper also introduces MCDA as a tool to promote coordination between competing demands; irrigation, energy production, mining, industrial, etc. through dialogue between the respective priorities of the various stakeholders. In short, the Multiple-Criteria Decision Analysis can be used to analyze the forms of institutional arrangements and coordination mechanisms that will be dedicated to implementing the integrated prioritization plan with roll-out potential in a phased and incremental manner and based on a national master plan for water infrastructure development in this water-scarce country.

Keywords: Water Infrastructure Development, Multiple-Criteria Decision Analysis, Economic Development, Sustainable Development Goals.

INTRODUCTION

Providing access to water is a global challenge. Access to water provides quality of life and economic development. According to the UN progress report for 2020 of the SDG 6; “Water is essential not only to health, but also to poverty reduction, food security, peace, human rights, ecosystems, and education. Nevertheless, countries face growing challenges linked to water scarcity, water pollution, degraded aquatic ecosystems, and a lack of cooperative efforts to maintain transboundary water basins. In addition, funding gaps and weak government systems hold many countries back from making necessary advancements. Unless current rates of progress increase substantially, Goal 6 targets will not be met by 2030” (United Nations, Department of Economic and Social Affairs, Statistics Division, 2020). Accordingly, governments have the responsibility to provide reliable and safe drinking water and sanitation, as well as a sustainable supply of water for productive uses such as agriculture, energy production, and industrial production. Apart from the problems of availability of water, water

supply is also faced with socio-economic, institutional, and environmental limitations, in addition to the fact that Africa does not have its fair share of infrastructure development to enhance water supply (United Nations. Economic Commission for Africa, *et al.*, 2003).

Urbanization and population growth are fundamental in increasing water insecurity due to the increased demands on the resource, and hence the need for these resources to be adequately managed becomes central to sustained growth and development. This is a complex task of ensuring a continuous balance between these environmental, economic, and social drivers. The complexity of decision-making in water catchments and systems requires the integration of criteria, models, and data sources for achieving sustainable development through attaining the desired balance between these drivers (Barton, s.a.).

This paper is aimed at proposing a framework for integrating the above drivers when dealing with limited financial resources by prioritizing water infrastructure development projects. It is aimed to simplify and streamline a structured and consistent process for the evaluation of alternatives and as such allows governments to govern and decide on new infrastructure investments given their economic restrictions and preferences in an equitable, participative, and transparent manner.

During researching this paper, it was discovered that establishing a decision context should rely on the government's national objectives, which are typically found in a national development plan. Sudan does not have such a plan. The closest that could be found were the 10 transitional priorities plan (Forces of Freedom and Change Coordination Committee and Partners in Development (FFC, PDS), 2020). For this paper, the following relevant pillars are of relevance; strategic institutional building, economic reforms, constitutional reforms, and peace and stability. It was also discovered that decisions around water infrastructure development were largely triggered by international development agencies wishing to support projects predominantly based on cost-benefit analyses and not on the national intensity of need, although it might be a considered factor, therefore, this proposed Multi-Criteria Decision Analysis (MCDA) process can greatly enhance how such decisions are made.

WATER INFRASTRUCTURE DEVELOPMENT RATIONALE

Water Resources and Infrastructure for Sudan:

The Ministry of Irrigation and Water Resources is responsible for how water is used, managed, developed, and controlled in the country. The temporal and spatial distribution of water is the genesis of water insecurity in Sudan. The lacks of coordinated planning as well as the prevalence of seasonal variability and extreme events of droughts and floods which are on the increase, as well as population growth and urbanization are further stressors on available water resources. The need to sustain major economic developments in support of poverty eradication or reduction, employment generation, equity, and peace are major tasks for the new government in Sudan. Increasing the control and regulation of the flow of water can help in better utilization of the resources. This can happen either through the building of water retaining structures or weirs/barrages that regulate the flow; moving water from one region to the other in mega pipelines, subsurface retention, and green infrastructure potential. Whatever the case might be and in the absence of a water infrastructure development master plan, the need for developing a priority list is needed now, as Sudan steers towards an accelerated development trajectory (Karar, Mega Water Infrastructure Development Prioritization Listing for 2021-2030., 2021).

In Sudan, surface water consists primarily of rainfall, rivers, wadis, khors, lakes, and wetlands. Furthermore, groundwater is also extensively used, along with wastewater reuse and desalination as non-conventional resources. At the watershed level, Sudan comprises seven main basins and there are six dams across the Nile in Sudan. These are Sennar on the Blue Nile; Jebel Awlia on the White Nile; Khashm al-Girba on the Atbara; Roseires Dam on the Blue Nile; Merowe Dam on the Nile; and The Atbara/Setit Dam Complex. The only downstream areas with irrigation canals are those of Sennar and Khashm al-Girba. The Gezira Scheme is irrigated by a 10,000km-long intensive canalization network. Other major agricultural projects include Suki, Rahad, Bourgeig, Kennana, Geneid, Asalaya, White Nile, Mikabrab, Keiheila, and al-Multaga (Fanack Water, 2017). Figure (1) demonstrates the hydrological basins and the major agriculture schemes in Sudan.

The limited investments in the past have not adequately developed the available resources to meet current and future demands. The lack of an ambitious water master plan is particularly glaring now that the country is embarking on a development trajectory. The modest and incremental thinking of meeting water challenges by installing more hafirs and boreholes or water yards, which was perpetuated because of a lack of government investment, should be transformed into a 'can do' approach in which citizens benefiting from these developments receive services based on cost recovery. This implies a serious shift in citizen behavior. Awareness-raising campaigns about citizens' rights and obligations will need to accompany such developments. Special provisions are needed for households that are unable to pay for services, such as special coupons, social grants, stepped tariffs, and/or a free basic allowance. There is also a need to encourage and support the use of renewable energy in water resources development. (Karar, Water Management in Sudan: Contribution to the Sudan Water Strategy, 2021).

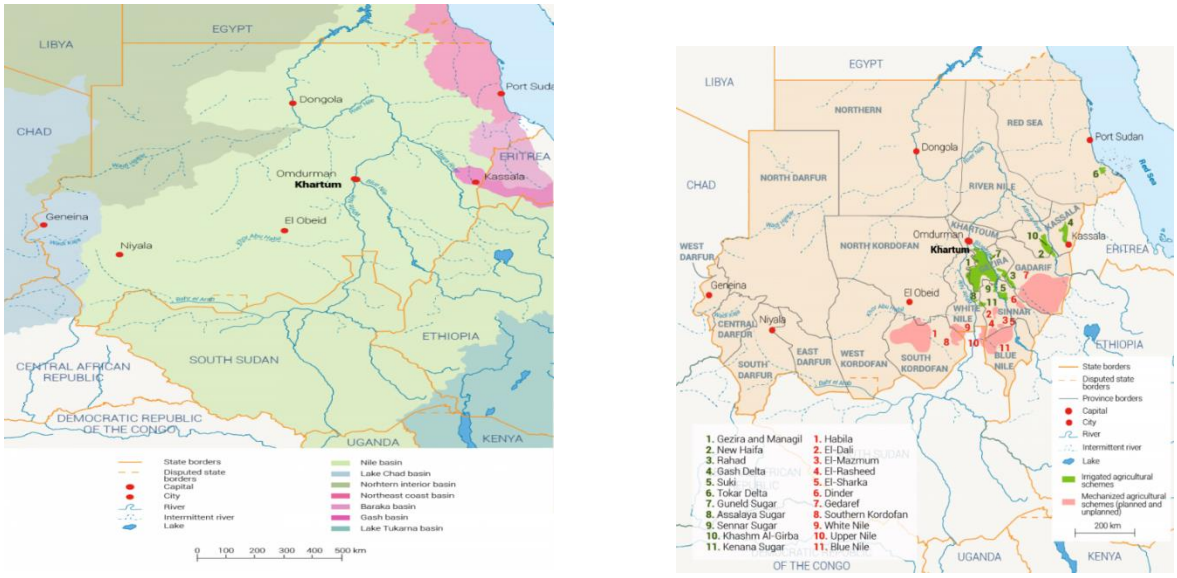

Figure 1: *Hydrological Basins and Major Agriculture Schemes in Sudan (Source: Water Fanack).*

Water infrastructure development in Sudan is primarily aimed at improving access to clean water and sanitation systems, as well as improving utility efficiency. The challenge is to develop usable water resources while simultaneously improving sanitation to decrease contaminants (Rafkin, 2017).

Human Resources Development and Capacity Building in the water sector:
The recent water sector livelihood transformation strategy (2021–2031) indicated that there is an acute shortage of staff with adequate skills, including technical and administrative qualifications, to design, implement, and manage water supply and resources services in the country. The water has experienced a significant "brain drain," with the loss of numerous qualified technical cadres. Political interference and appointments have also contributed to an increase in staff turnover and a lack of institutional memory and capacity to guide the sector. Thus, the water supply sector currently lacks sufficient technical capabilities to meet the increasing challenges, and it is dominated by administrative staff with very few technical staff at all levels (Ministry of Irrigation and Water Resources, 2021).

Institutional factors can relate to issues of policies and laws as well as the administrative processes for equitable allocations and water distribution to various sectors, on the one hand, and across geographic levels such as States, Localities, and Villages. The ability of institutions to provide access to water is another factor as well as how governance or decisions are made involving affected and influenced stakeholders. The environmental limitations prevail in the finite nature of the resource, its temporal and spatial natural distribution across the country as well as the prevalent climatic variability and uncertainty in space and time due to climate change (Ministry of Irrigation and Water Resources, 2021).

Water infrastructure development (WID) potential impacts for Sudan:
Arriving from the premise that water is the catalyst for national development, good water management can directly relate to sustainable development and enhanced community resilience to climate change and population growth. In Sudan, decisions around the prioritization of infrastructure development are done on a case-by-case basis mostly at the federal level. These decisions are not necessarily systematic, consistent, equitable, participative, or transparent. In the absence of an overarching National Development Plan, there is no broad national infrastructure development framework that could be applied to water, roads, energy, mining, etc. This paper explored the water infrastructure only. Probably this is not an exclusive attempt to this team; numerous versions were contemplated but were never adopted in the mainstream. The most widely known attempt is the Water Atlas which depicts prioritization based on demand, however, this Atlas focused on specific interventions such as hafirs and water yards for identifying urgent drinking water sources (Dams Implementation Unit, 2017).

Prioritizing water infrastructure requires a catchment scale perspective to capture future changes due to factors that vary rapidly, like climate change and socio-economic development in the catchment as well as the cumulative upstream/downstream or surface water and groundwater dynamics. The traditional approach in Sudan for deciding on infrastructure investments usually uses conventional economic methods like Cost-Benefit -Analyses (CBA), which allow project comparison based on a single monetized value. It is worth mentioning that it is particularly challenging to assess small and medium projects with limited government resources since the government has limited financial resources. (Marcelo, *et al.*, 2016).

RELATED STUDIES

In cities around the world, unprecedented levels of urbanization as well as deteriorating infrastructure have made it increasingly difficult to build sustainable forms of infrastructure with limited resources. One of the best ways to bridge enormous funding gaps has emerged as

prioritizing projects at the system level based on transparent and evidence-based decision-making processes. A scenario-based framework is proposed based on the MCDA to prioritize urban transportation projects in China. A two-year framework has been used to prioritize nine recent urban transportation projects in China's Tianjin Binhai New Area. Despite diverse perspectives among stakeholders, the proposed framework could serve as a consistent, robust, and comprehensive prioritization strategy for infrastructure projects. Moreover, it relates the prioritization process to the planning phase that precedes it and emphasizes sustainability in urban transportation decision-making (Liu, *et al*., 2015).

Since funding gaps have been projected for the coming decades, many governments decided to allocate limited resources for infrastructure development. A serious water supply problem is currently plaguing Santa Marta city in Colombia. Shortage of water supply is a result of problems such as watershed degradation - and its associated reduction in river flow - reduced rainfall, illegal water collection, and rapid population growth. By considering the preferences of stakeholders, MCDA supports the implementation of the best solution for solving the water supply problem. There are two groups of criteria to analyze the problem: non-economic criteria and economic criteria. According to the proposed methodology, non-economic criteria to be considered are operational time, infrastructure setup, operational risk, and socio-environmental parameters. Construction and operation costs of the system are included in the economic criteria. The proposed methodology supported the decision-making process that achieved the selection of the alternative that will address the water supply problem in Santa Marta. Santa Marta has used the recommended alternative since 2018 (Amorocho-Daza, *et al.,* 2019).

METHODOLOGY

The context, scope, boundaries, and indicators of water infrastructure development in Sudan are described. A group of experts evaluates the important criteria of the NWID. The purpose of the evaluation is to present descriptive statistics that consider current and future trends and assist in the further development of group decision-making. The proposed MCDA incorporates all important criteria that are necessary for prioritizing the NWID based on the above framework. These criteria will be operational and measurable in both qualitative and quantitative scoring, in which the performance of each criterion is independent. The time-differentiated impacts of the selected criteria are adequately addressed.

RESULTS AND ANALYSIS

NWID prioritization framework (NWID):

Demands on water resources can only be assessed within their natural catchment boundaries if sustainability is desired for fulfilling these demands. Since water is believed to be the driver of economic growth and prosperity in nations, planning is a critical part of the decision-making for how water is shared and allocated in various jurisdictions and between sectors. The need for harmonizing planning in terms of setting common developmental targets for expanding irrigation agriculture, hydro-energy production, industrial or mining expansions, etc. Figure (2) shows MCDA prioritization Framework and Tradeoffs for NWID.

Multi-Criteria decision analysis (MCDA) Process:

Multi-Criteria decision analysis (MCDA) is an approach that explicitly considers multiple factors in a complex decision-making environment; it is an umbrella term that seeks to develop

procedures and techniques by which concerns about multi-dimensional conflicting criteria can be formally incorporated into prioritization processes (Department for Communities and Local Government, 2009).

For the purposes of this paper, the MCDA will be guided by the following principles:

1. MCDA should be preceded by surveys and hydrological analysis in which all parameters (water scarcity, land capability, livelihood conditions, societal condition, and run-off) are prepared; to identify the suitable water infrastructure.
2. The implementation of a structured prioritization process requires the participation and buy-in of key stakeholders (Thokala & Madhavan , 2018).
3. MCDA should consider the limitation of financial resources by promoting the best use of available funds, either by phasing out the targeted demands and/or identifying the type of development needed.

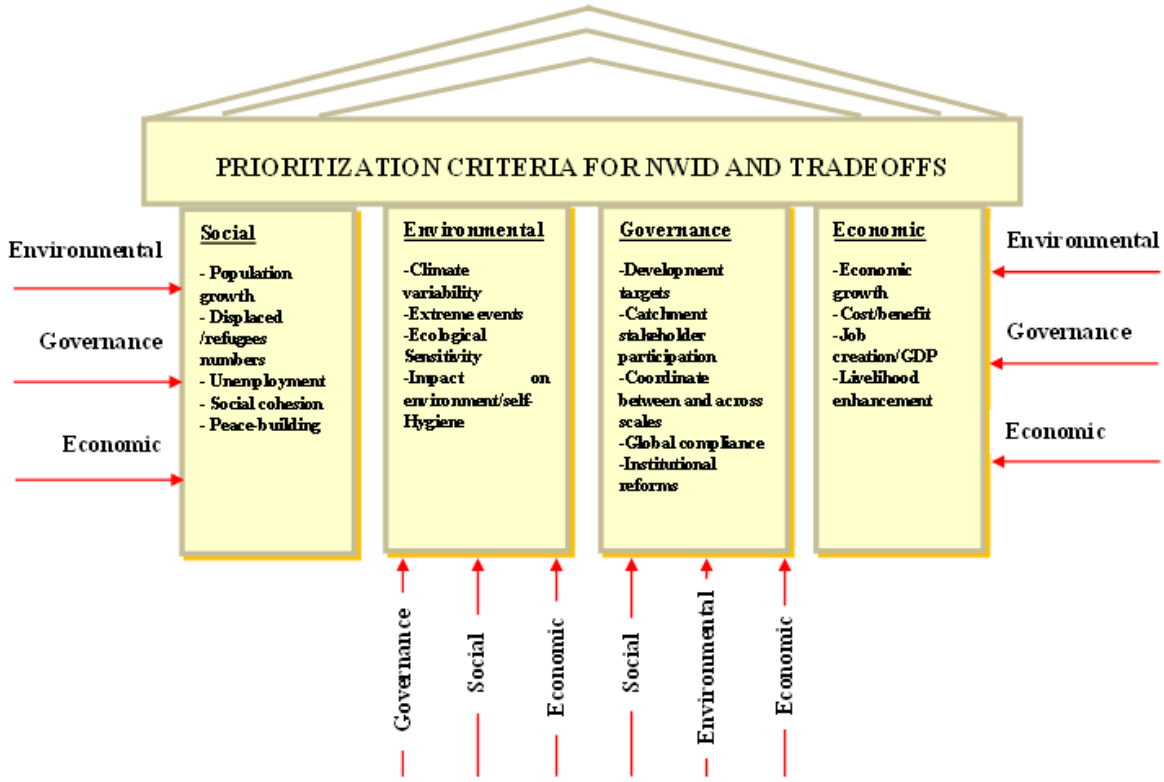

***Figure 2**: MCDA Prioritization Framework and Trade-offs.*

MCDA will be pursued to achieve several objectives which are; to contribute to peacebuilding, support sustainable growth in conflict-affected states, aid decision-making in the areas of climate change adaptation/mitigation and development, to contribute to reducing disparities in wealth and income by offering job opportunities, and generally enabling beneficiaries to have a sense that they are engaged in a common enterprise through supporting Community Based Management (CBM) of infrastructure and to support the local decision-makers to allocate their financial resources and aid the flow of these funds in a rational manner, based on explicit consideration of their priorities. The MCDA development process can have several stages as reflected in Figure (3) below:

1. Establish the decision context: What are the aims of the prioritization MCDA, and who are the decision-makers and other key stakeholders? The decision context involves the

establishment of a shared understanding of the administrative, political and social context for which the decision is needed. This includes the administrative and historical context, the set of people who may be affected by the decision, and an identification of those responsible for the decision. A clear understanding of purpose and objectives related to the overall ambition to which the prioritization decision will seek to contribute. A prioritization MCDA framework is all about multiple conflicting objectives for which trade-offs will be made. The use of MCDA allows for the identification of a single objective and some sub-objectives as part of a national framework. This paper will attempt the objectives based on Sudan Transitional Period Proposed Program Urgent Needs and Priorities; (Forces of Freedom and Change Coordination Committee and Partners in Development (FFC, PDS), 2020)

2. Identifying the options: There are a number of catchment assessments done in the past and for the Ministry of Irrigation and Water Resources (MIWR), often when starting this process; the easiest is to bring these assessments as a starting point. When contemplating water infrastructure, the main intention is to balance the capabilities of the catchment in terms of ecological limits with the social and economic gains needed. This does not mean that other catchments need to be ignored; however, detailed hydrological assessments will need to be completed for all the 12 catchments in Sudan to be able to prioritize across catchments. The role of the MCDA is to generate a shortlist of alternatives using basic data and quick procedures and provide a structured ranking of alternatives within a catchment.

3. Identify the objectives and criteria that reflect the value associated with the consequences or trade-offs of each option; a 'top-down' approach is mainly executed and validated by relevant experts. The criteria for prioritization are broken down into hierarchical structures, the main criteria are generic and the other sub-criteria are more specific and incorporate the initial brainstorming of experts based on objectives from catchment development targets. Water infrastructure projects that have been identified based on catchment assessments and have been subjected to feasibility studies will be used to undergo the ranking process by the identified stakeholders.

4. Describe the expected impact of each option against the criteria in which the expected performance of each option against the criteria and 'scoring' the options take place by the identified stakeholders (Sharma, *et al*., 2015).

5. Ranking of indicators and scoring**:** The indicators provide measurable parameters of the performance of the different development actions against the defined prioritization criteria. Indicators can be qualitative or quantitative. Stakeholders rank a number of (n) projects (P) as reflected in the following scoring matrix in Table (1), which can represent the proposed criteria (C_x) for water infrastructure development, (N) is the number of main criteria, (M) is the number of 1st level criteria and (m) is the number of second level criteria and (S) is the sub-criteria final scoring value.

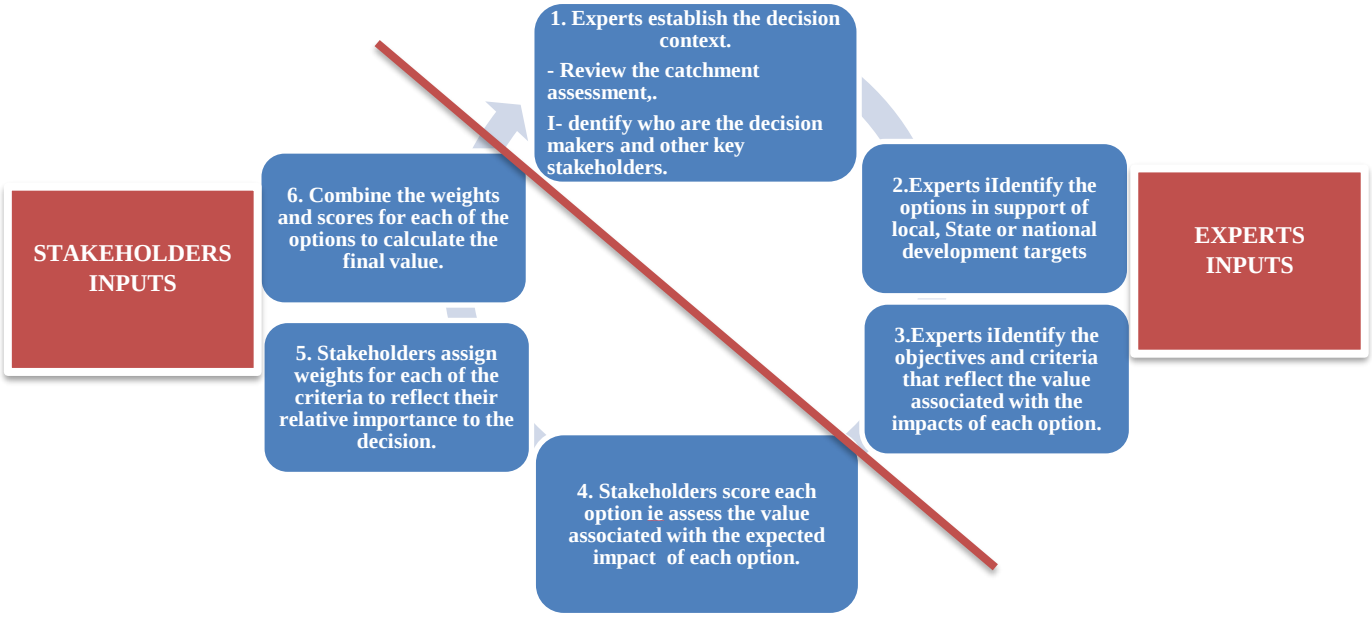

Figure 3: *MCDA Development Process.*

Hierarchy criteria			NWID Projects						
Criteria	**1st level sub-criteria**	**2nd level sub-criteria**	**P1**	**P2**	**P3**	**…**	**…**	**…**	**Pn**
C1	C1,1	C 1,1,1	$S_1^{1,1,1}$	$S_2^{1,1,1}$	$S_3^{1,1,1}$	…	…	…	$S_n^{1,1,1}$
		…	…	…	…	…	…	…	…
		C 1,1,m	$S_1^{1,1,m}$	$S_2^{1,1,m}$	$S_3^{1,1,m}$	…	…	…	$S_n^{1,1,m}$
	C1,2	C 1,2,1	$S_1^{1,2,1}$	$S_2^{1,2,1}$	$S_3^{1,2,1}$	…	…	…	$S_n^{1,2,1}$
		…	…	…	…	…	…	…	…
		C 1,2,m	$S_1^{1,2,m}$	$S_2^{1,2,m}$	$S_3^{1,2,m}$	…	…	…	$S_n^{1,2,m}$
	C1,3	C 1,3,1	$S_1^{1,3,1}$	$S_2^{1,3,1}$	$S_3^{1,3,1}$	…	…	…	$S_n^{1,3,1}$
		…	…	…	…	…	…	…	…
		C 1,3,m	$S_1^{1,3,m}$	$S_2^{1,3,m}$	$S_3^{1,3,m}$	…	…	…	$S_n^{1,3,m}$
	…	…	…	…	…	…	…	…	…
	…	…	…	…	…	…	…	…	…
	C1,M	C1,M,m	$S_1^{1,M,m}$	$S_2^{1,M,m}$	$S_3^{1,M,m}$	…	…	…	$S_n^{1,M,m}$
….	….	….	….	….	….	….	….	….	….
CN	CN,M	CN,M.m	$S_1^{N,M,m}$	$S_2^{N,M,m}$	$S_3^{N,M,m}$	…	…	…	$S_n^{N,M,m}$

Table 1: *MCDA Generic Scoring Matrix.*

Table (2) demonstrates the suggested criteria matrix for NWID as adjusted from the literature review References.

6. Weighting. Stakeholders assign weights possibly based on an online survey for each of the main criteria to reflect their opinions relative to the importance of the decision in the catchment. This can vary by location, stakeholder grouping, or time scale. Combining the weights and scores for each of the options can yield the overall value which reflects the judgments and is represented as a geometric mean of the overall response for each criterion. Table (3) shows the computed weights based on the online survey.

Decisions with weights from the two methods are an essential step that incorporates diverse views of those potentially impacted by these decisions. The structure afforded by the framework can ensure that decisions are made with common and agreed-on reference points as reflected in the criteria which could expand or collapse according to context.

Goal	Criteria	First Level Sub-Criteria	Second Level Sub-Criteria	Indicators
Prioritization of NWID in Sudan	Socio-economic	Social cohesion	Create an environment for settling or returning displaced/refugees	The number of citizens to be serviced; accommodation, jobs, livelihoods
			Projected demand for services	Differential rate of future growth
			Reduce rates of unemployment	The number of job opportunities The number of people will be trained to operate the infrastructure
			Establishment of Community-Based-Management projects	The number of proposed Community Based Management committees
			Displacement for mega projects	The number of people displaced
			Feasibility of compensation plans in Mega projects	Stakeholders consultation workshops
		Peace-building	Possibility of sharing the water infrastructure with surrounding localities	Demand gap in neighborhood localities (l/c/d)
			Reduce violence against women fetching water from scarce areas	Roundtrip to the new infrastructure (hours)
			Reduce potential ethnic/tribal clashes as well as transboundary conflicts	The number of ethnic groups/tribes served by the infrastructure
	Environmental	Combat climate change and water extremes	Minimize projected demand gaps due to climate shocks	Reliability of water supply during droughts
			Minimize natural hazards and floods	The capacity of infrastructure to retain floods
			Enhance natural infrastructure	The number of natural/green infrastructures proposed.
			Promote green infrastructure	How many green infrastructures are proposed within the project? What is the expected value for carbon footprint?
			Develop systematic catchment assessment	The number of catchments with systematic and completed assessments
			Rehabilitation of aging infrastructure and encouraging investments	The number of infrastructures that will be rehabilitated
	Governance	Global compliance	National (hard and soft) laws and regulations	Qualitative indicators
			International (hard and soft) laws and regulations (standards, recommendations, norms, guidelines etc.)	Qualitative indicators
			Procedural consistency and transparency including trust building between center and regions	Qualitative indicators
			SDG 6.5 indicators	Quantitative indicators
			Enforcement of regulations	Qualitative indicators
		Institutional reforms	Regional reforms (vertical); coordination between regions/ provinces, municipalities	Qualitative indicators
			Decentralization Re-allocation of resources including competence	Qualitative and quantitative indicators
			(Horizontal) coordination between sectors	Qualitative indicators
			Liberalization/ / privatization trends and private sector involvement	Quantitative indicators

Table 2: *Proposed MCDA criteria for NWID (Compiled by the Author).*

NO	Sub-Criteria	Critical	Important	Somehow important	Not important	Geometric mean	Weights
		4	3	2	1		
		Number of responses					
Socio economic criteria							
S1	Cost Benefit Ratio	3	5	0	0	3.34	0.039
S2	Economic crisis and fiscal consolidation measures	5	1	2	0	3.24	0.037
S3	Equity in regional distribution of fiscal allocations and international support	4	4	0	0	3.46	0.040
S4	Peace and social stability	3	5	0	0	3.34	0.039
S5	Population Growth and Migration	2	4	2	0	2.91	0.034
S6	Urban growth and spatial planning	3	3	2	0	3.02	0.035
S7	Job creation and social empowerment	0	6	1	1	2.49	0.029
S8	Continuity of supply	3	3	2	0	3.02	0.035
S9	Crisis / emergency-driven management (instability, fragility, conflicts, etc….)	6	1	1	0	3.54	0.041
Governance/Institutional Criteria							
S10	International (hard and soft) laws and regulations (standards, recommendations, norms, guidelines etc.)	0	6	1	1	2.49	0.029
S11	Procedural consistency and transparency, including trust building between center and regions	4	3	1	0	3.29	0.038
S12	National (hard and soft) laws and regulations	4	3	1	0	3.29	0.038
S13	Regional reforms (vertical coordination between regions/ provinces, municipalities)	2	4	2	0	2.91	0.034
S14	Decentralization / re-allocation of resources including competence	3	5	0	0	3.34	0.039
S15	Liberalization/privatization trends and private sector involvement	3	2	3	0	2.87	0.033
S16	Horizontal coordination between sectors	2	5	1	0	3.06	0.035
S17	Enforcement of regulations	6	2	0	0	3.72	0.043
Environmental/Water Related Criteria							
S18	Increased attention to water in the political agenda	5	2	1	0	3.41	0.039
S19	Implementation of the Human Right to Water & Sanitation (acceleration after COVID-19 crisis) and SDG targets	2	5	1	0	3.06	0.035
S20	Climate change adaptation	2	2	4	0	2.63	0.030
S21	Ageing, obsolete infrastructure/ Lack of infrastructure investments	4	4	0	0	3.46	0.040
S22	Sustainability of water resources	6	2	0	0	3.72	0.043
S23	Systematic catchment assessments such as those for Wadi Nyala, Tokar and Howar	4	3	1	0	3.29	0.038
S24	Competition / conflicts over water allocation (national/trans-boundary)	5	2	1	0	3.41	0.039
S25	Extreme events (e.g. floods, droughts)	4	2	2	0	3.13	0.036
S26	Over abstractions of groundwater	5	3	0	0	3.59	0.041
S27	Water pollution (e.g. contaminated surface /groundwater sources)	6	1	1	0	3.54	0.041

Table 3: *Computed Weights from experts using the geometric mean method.*

The pairwise comparison method is used to determine the relative priorities of each sub-criteria against others in each category separately (socio-economic, governance/institutional, and environmental water-related), to judge which sub-criteria are most weighted. The following matrices represent the pairwise comparison results.

	S1	S2	S3	S4	S5	S6	S7	S8	S9
S1	-	S2	S3	S1/S4	S1	S1/A6	S1	S1/A8	S9
S2	-	-	S2	S2	S2	S2	S2	A2	S9
S3	-	-	-	S3	S3	S3	S3	A3	S9
S4	-	-	-	-	S4	S4/S6	S4	S4/S8	S9
S5	-	-	-	-	-	S6	S5	S8	S9
S6	-	-	-	-	-	-	S6	S6/S8	S9
S7	-	-	-	-	-	-	-	S8	S9
S8	-	-	-	-	-	-	-	-	S9
S9	-	-	-	-	-	-	-	-	-

Ranking	
S1	5
S2	7
S3	6
S4	5
S5	1
S6	5
S7	0
S8	5
S9	8

	S10	S11	S12	S13	S14	S15	S16	S17
S10	-	S11	S12	S13	S14	S15	S16	S17
S11	-	-	S11/S12	S11	S11	S11	S11	S17
S12	-	-	-	S12	S12	S12	S12	S17
S13	-	-	-	-	A14	S15	S13/S16	S17
S14	-	-	-	-	-	S14/S15	S14	S17
S15	-	-	-	-	-	-	S15	S17
S16	-	-	-	-	-	-	-	S17
S17	-	-	-	-	-	-	-	-

Ranking	
S10	0
S11	**6**
S12	**6**
S13	2
S14	4
S15	4
S16	2
S17	**7**

	S18	S19	S20	S21	S22	S23	S24	S25	S26	S27
S18	-	S18	S18	S18	S22	S18	S18/S24	S18	S18/S26	S27
S19	-	-	S19/S20	S21	S22	S23	S24	S25	S26	S27
S20	-	-	-	S21	S22	S23	S24	S25	S26	S27
S21	-	-	-	-	S22	S21/S23	S24	S21/S25	S26	S27
S22	-	-	-	-	-	S22	S22	S22	S22	S22/S27
S23	-	-	-	-	-	-	S24	S23/S25	S26	S27
S24	-	-	-	-	-	-	-	S24	S24/S26	S27
S25	-	-	-	-	-	-	-	-	S26	S27
S26	-	-	-	-	-	-	-	-	-	S27
S27	-	-	-	-	-	-	-	-	-	-

Ranking	
S18	7
S19	1
S20	1
S21	4
S22	**9**
S23	4
S24	7
S25	4
S26	7
S27	**9**

LIMITATIONS

1. This proposed framework relies on a large amount of information that needs to be readily available. It also depends upon the adoption of this process at a high level for effective utilization and hence improved decisions made around prioritizing water infrastructure.
2. The framework will need to be tested in a case study based on existing catchment assessments. The sensitivity between the center and states on who makes infrastructure investment decisions will be tested by adopting this integrative, highly participative, coordinated process between various geographic scales.

3. The quick online experts' questionnaire conducted was for indicative purposes and is not expected to provide an accurate representation of views; therefore, the weights calculated by the geometric mean are demonstratively strengthened by the pairwise comparison to obtaining the required statistical significance.

CONCLUSIONS AND RECOMMENDATIONS

1. From the experts' online survey, it is found that the most weighted criteria are ranked as follows:
    i. Equity in regional distribution of fiscal allocations and international support.
    ii. Crisis / emergency-driven management (instability, fragility, conflicts etc.….).
    iii. Enforcement of regulations.
    iv. Sustainability of water resources.
    v. Over abstractions of groundwater.
    vi. Water pollution (e.g., contaminated surface /Groundwater sources).
2. Data collected from the online survey are analyzed using pairwise comparison for each criterion separately (Socio-economic, Governance, and Environmental Criteria), the most weighted criteria are:
    i. Economic crisis and fiscal consolidation measures.
    ii. Crisis / emergency-driven management (instability, fragility, conflicts etc.).
    iii. Procedural consistency and transparency, including trust building between the center and regions.
    iv. National (hard and soft) laws and regulations.
    v. Enforcement of regulations.
    vi. Sustainability of water resources.
    vii. Water pollution (e.g., contaminated surface /groundwater sources).
3. The demonstrative survey indicates that this framework can act as a start, a work-in-progress effort that can be further refined to a nationally adopted process for water infrastructure prioritization in Sudan.
4. Sensitivity/risk analysis is recommended to further assess the impact of uncertainty in the prioritization criteria.
5. The proposed prioritization framework, such as transportation, health, accommodation etc., obviously with adapted criteria.
6. The framework proposed is relevant to all water infrastructure relevant to all sectors including irrigation; to single out irrigation and elaborate on it might perpetuate the predominant thinking that the planning role in the Ministry of Irrigation and Water Resources is only for irrigation and drinking water, which needs to change by acknowledging and upholding the sole responsibility for overall planning and prioritization for water infrastructure development demands from all sectors.

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FACTORS AFFECTING SOLAR BOXCOOKER (SBC) TECHNOLOGY ADOPTION IN KHARTOUM STATE, SUDAN

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Abstract
This study was been conducted to investigate factors affecting solar cooker technology adoption in Khartoum State, Sudan.42 women from different localities who owned the SBC since 2000 were surveyed in 2013.The methodology is based on both qualitative and quantitative methods using Participatory Rapid Appraisal (PRA), a questionnaire and interview were used for data collection. The data were been analyzed considering solar box cooker accessibility, compatibility, and human perception. The results showed that SBC is compatible for women's use so 71% of them face no problem during utilization, while only 29% face some problems in tracking. Education affected positively perception, as most of the women that use the solar cooker based on positive judgment were educated. Fuel saving compared with other parameters is the weighty parameter, from the results it was found that 89.7% are aware of fuel saving, and this very high percentage.

Keywords: Solar Box Cooker; Adoption; Accessibility; Khartoum State; Sudan.

INTRODUCTION

Technological innovations in many cases remain in areas where they are been introduced, although these technologies may appear compatible with existing social, financial, and technical constraints and may nonetheless, remain practically unused, even after long periods of time (Reynolds, 1984). Solar cooking was one of the best alternatives for domestic use but is still not popularly used. The consumption of wood fuel in Sudan is high especially in remote areas; this has led to environmental degradation due to deforestation and scarcity of firewood. The use of fossil fuels such as kerosene and LPG for cooking is facing many challenges, mainly availability in remote areas and high prices. Solar energy for cooking is: i) a non-consumptive and non-polluting fuel, ii) can help in alleviating the problem of insecurity of cooking energy iii) solar cookers are introduced to mitigate CO2 emission at the household level. The above-mentioned factors are considered and applicable to all regions of Sudan. Fuel wood availability, and climatic conditions (amount and regularity of solar radiation) should be taken into account when assessing the potential for solar cooking (as well as for any other renewable energy applications) in a specific region in Sudan (Sudan Energy Hand Book, 2004). As the promotion of solar cookers in Sudan faced many challenges, this research deliberated these challenges, and two objectives were considered; i) to measure to which extent of adoption of SBC by women who own for 12 years ii) to identify the factors that affect technology adoption. The methods used in this research were qualitative method using Participatory Rapid Appraisal (PRA) and quantitative method using questionnaire and women in Khartoum state who own the solar cookers for 12 years were been surveyed. The factors that influence the technology adoption are mainly accessibility, compatibility and perception. Accessabilty in this research has no noticable effect as most of the Solar Cookers were afforded by Sudanese Environment Conservation Society and UNIDO, some SBC were given for free others were given in installements. Compatability is very important factor in SBC adoption as it discussed whether

the women can use the SBC easily in terms of opening and closing, as well as tracking. Awareness, capacity building and education were also suggested as indicators to assess perception.

RELATED STUDIES

Halacy and Halacy (1992) stated the first scientist that had experiment with solar cooking is a German physicist named Tschirnhausen (1651-1708), then solar cooking had been promoted as a cooking device with specific potential benefits and offering more choice and flexibility to consumers. Normally, consumer forced to use specific fuels or appliance combinations because of affordability and accessibility issues (Wentzel, 2007). Generally, solar cookers are classified into three main types of solar cookers; solar box cooker (SBC) or solar oven, solar collectors and solar concentrators cooker (Kimambo, 2007).

There are different experiences of solar cooking in each country for example; a baseline study conducted by DME/GTZ targeting the dry North Western region of South Africa, where 100 families made up as a test sample. The results showed that there is acceptance of solar stoves used relatively more than other cooking options in the hottest hours of the day, between 10 am and 3 pm for two meals dinner and supper (GTZ, 2001). On the other hand, there were various constraints in the use of solar cooker, the technical constraints mainly compatibility that solar cooker is not able to cook all type of cooking i.e., different recipes, beside high initial cost and repairing and these considered as economic constraints (Sandhaya and Singal, 2009).

Generally, solar cooker not presented as substitute for other cooking problems it is introduced as alternative that mean with existence with other cooking devices. In one of the communities in South Africa, solar cookers were offered as part of an integrate cooking package, including fuel efficient stove and a heat conservation device so the consumers could buy the complete package or just the device that they feel may have the most benefit to them (Wentel, 2007). In some other studies in solar cooker utilization in India, it was reported that only 28 out of 54 respondents were able to report for monetary saving (Palmer Development Group, 1997a and Palmer Development Group, 1997b), (Palmer Development Consulting, 2002a and Palmer Development Consulting, 2002b). Also (Rodgers, 1994) showed some adoption results of SBC use in Zimbabwe, the users were asked some questions in a workshop this showed in Table (1).

Questions	**Workshop Participants response**
Adoption If you have tried to cook in a solar cooker yourself? What was your experience?	Tried once or twice/used for a while, didn't like it:3% Liked it, but don't use anymore:15% Still using sometimes: 82%
Frequency of use How often do you cook using solar cooker?	Most sunny days:71% Several days/month:22% Several days/year: 5%
Frequency of use compared to last year How often do you cook using solar cooker?	More:27% Less : 52% Same : 20%

Table 1: *Solar Box Cooker Adoption. (***Source:** Rodgers, 1994)

A report on "Research and Development for the Promotion, Local Manufacture and Dissemination of Solar Box Cookers in Sudan" (UNIDO, 2008) emphasized that solar cooking

has a certain probability of acceptance by the local population in several regions of Sudan, and has the potential to reduce pressure on the fuel wood to conserve the environment. Nevertheless, there are many barriers mainly socioeconomic barriers that related to type of Sudanese food cooked in solar cooker and the initial cost of the technology and these are considered the biggest challenges to promote the use of solar cookers. These challenges clearly exposed in some solar cooking projects implemented by some national organizations, NGOs (Sudanese Environment Conservation Society) and research institutions (Energy Research Institute). Those projects apparently have not produced the desired results because of a number of key barriers related to the economic and socio-cultural aspects.

METHODOLOGY

A Survey conducted with 42 women from different localities in Khartoum state, who owned the solar box cooker for 12years ago. All these women were been trained for 3 days in how to use the SBC cooker and how to cook Sudanese food in it. The survey covered all users of Solar Box Cooker (SBC) type. Also, participatory rapid appraisal (PRA) tools were used (Babbie E, 2001), mainly interviews as qualitative method. All solar cookers afforded for women from institutions; Sudanese Environment Conservation Society, Energy Research Institute and UNIDO. Few were given from UNIDO and ERI free for research purposes, but the majority were given with cost (80$) this is in the year 2000. The data analyze using SPSS program, the results grouped in three categories related technology adoption, which is accessibility, compatibility and perception.

RESULTS AND DISCUSSION

The dissemination of solar cookers must begin with an analysis of the local situation, mainly focus on traditional cooking habits and local needs, not with the selection of solar cooker type (GTZ, 1999). Users like women will adopt technologies, if these technologies were been introduced to suit their needs and appropriate for their traditional habits and culture. On the other hand, the technology should be affordable, save time, conserve energy, and compatible with local environment of the users (Odebode, 1997). Reviewing (Roger, 1995) adoption theories, and other studies three technology adoption factors for solar box cooker were analyzed these were: i) accessibility ii) compatibility and iii) perception.

Solar cooker accessibility:

For this research, accessibility was one of main components in solar cooker adoption, so SBC price, family income and affordability considered. About 71% of women pay 80$ (equivalent) with installments, while 29% of them given the SBC free. All SBCs distributed afforded by organizations SECS, UNIDO, and ERI, in other words was not purchase from the market. Majority of beneficial families 85.7% were medium income. These issues discussed by (Biermann *et al*., 1999) who found that the main factor affects solar cooker dissemination the price and local availability of services in terms of manufacturing and maintenance and availability of small loans for purchasing.

	Family Income		
Frequency of use	**Low Income**	**Medium Income**	**High Income**
Daily use	7.1%	21.4%	0%
Day and day after	0%	2.4%	0%
When they need to use (occasionally)	4.8%	59.6%	4.8%
Total	11.9%	83.3%	4.8%

Table 2: *Relation between Women Frequency of use and their income.*

From Table (2) it was clear there is relation between frequency and family income, 59.6% of medium income families use the SBC occasionally. While 21.4% of them use the SBC daily, only 2.4% use it day after day. For low-income family 7.1% daily use and 4.8% occasionally use. For high income family, only 4.8% use solar cooker occasionally. Generally, the rate of use for medium income was found as total to be 83.3%,and low income was 11.9% and high income was 4.8%. Low rate of frequentely of use for low income families may be attributed to that families had not enough food to cook daily. On the other hand, low rate of use of solar cooker for high income families may be due to that families had other cooking options like LPG stove or electrical cooker. These results the same with an Indian study findings that showed 61% of families use the solar cooker had an income of Rs.10.000 to 15.000 per month, these families are classified as medium income families (Sandhaya and Singal , 2009).

Solar Cooker Compatibility

Compatibility was one of the important factors in adoption; solar cooker utilization in terms of opening and closing or tracking, ability to cook some food and food acceptability considered as parameters that reviewing compatibility.

	Utilization problem	
Frequency of use	**Yes**	**No**
Daily use	7.1%	21.4%
Day and day after	0%	2.4%
When they need to use(occasionally)	21.4%	47.6%
Total	28.6%	71.4%

Table 3: *Women Frequency of use with SBC utilization.*

Type of food	**Percentage of Women that able to cook food (%)**
Boiled food	19%
Tea and coffee	8.6%
Sudanese Food	11.9%
All Type of Food	57%

Table 4: *Women capability to cook food.*

From table (3) it is clear that 71.4% face no problem during utilization, while only 28.6% face some problems in tracking and from interviews findings women comment only on solar cooker small size. Table (4) showed that women could cook boiled food, tea and coffee with different percentages and57% of them can cook all types of food. Results from interviews show that family members found solar cooked food well cooked with good taste. This in line with many research findings like (Goyal and Kakkar,1987) and (Oberoi *et al*.,1991) reported that food cooked in solar cooker did not get cold very soon and the device acted as a hot case, also respondents perceived that food cooked in solar cooker was tasty and preserving nutritive value. This in contradictory with (Sandhaya and Singal, 2009) who found that there were some limitations, solar cooker not able to cook all types of cooking.

Perception:
The surveyed women; 35.7% are housewives, 40.5% are employees and 23.8% practice small business. Perception was one of the most important parameters in adoption, awareness; capacity building and education were been suggested as indicators to assess perception. 69%of women notice that solar cooking help in time management while 31% did not notice that. In addition, 54.8% starting cooking at midday as they aware that there is high radiation intensity. Generally, from interviews it was found that all women users aware about the benefits of solar cooking and there were no complains about insufficient training. There are many factors affect the perception some of it related to culture and food habits. However, education is one of the important factors affect perception positively. This were shown in research results, as women that use solar cooker most of them were educated; 28.6% primary education, 23.8% secondary education and 42.9% graduated from universities, only 4.8% are illiteracy. From Table (5) it was clear that the graduated women use the solar cooker occasionally with 33.4% and secondary educated women use it occasionally with19.1% and 14.3% of women primary educated use it daily. On the other hand, the findings of interviews with women about their general opinions and beliefs of solar cooking, the voice of graduated women was high compared with other education level, they confirm that solar cooker is good as energy alternative for household, as it is easy to use and save the used conventional energy.

				Education
Frequency of use	**Illitrate**	**primary**	**secondary**	**graduated**
Daily use	0%	14.3%	4.8%	9.5%
Day after day after	0%	2.4%	0%	0%
When they need to use (occasionally)	4.8%	11.9%	19.1%	33.4%

Table 5: *Women education level and its effect on SBC Frequency of use.*

(Palmer Development Consulting, 2002a and 2002b) reported saving time by using a solar cooker was reported by 44% of the respondents and it was found to be between 18 and 26hr per month. (Wentzel and Pouris, 2007) found that the use of solar cookers resulted in a noticeable fuel and time saving and increased energy security for households. This also agreed by (Biermann Eberhard *et al*, 1999) who found that all families were able to achieve considerable saving on household energy on average38%, and spent significantly less time on collecting firewood. (GTZ and DME, 2002a) reported that during solar cooker field test the overall fuel saving were 38%, 60 tons wood, 2tons gas and over 2000L of paraffin. Generally, to determine solar cooker use rate and resulting saving is a difficult task, as user behavior towards solar cooker utilization was fluctuate over time.

CONCULUSION

In this research, accessibility was not one of main component in solar cooker adoption, as SBCs were distributed by organizations SECS, UNIDO, and ERI, in other words was not purchased from the market. The majority of beneficiary families were medium income and face no problem in SBC utilization, this mainly because women were trained in how to use SBC. Also the solar cooked food accepted by the family so the SBC is compatable for women use. Education positively affected perceptions, most of women that use the solar cooker were educated. Solar cookers are considered as one of energy alternative at household level, it should be sold or promoted as part of an intergrated package to address household cooking problems, the package can be consist of improved stove, LPG stove and solar cooker.

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ECOVILLAGE MODELS AS SOLUTIONS TO COMMUNITY VULNERABILITY TO HUNGER, DISASTERS AND DEVELOPMENT CHALLENGES IN AFRICA

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Abstract
The root causes of and solutions to hunger, conflicts, disasters, and development-related problems transcend local, regional and international activities. Efforts to find answers to these problems continue to face numerous barriers, including institutional capacities, financing, droughts, access to natural resources, and climate change. Development of models that advocate for sustained, inclusive, and economic growth where wealth is shared, and income inequality is addressed to promote people-centric economies that facilitate empowering communities is critical now more than ever before. This study examines ways to achieve sustained, inclusive, and people-centric economies using ecovillage models. Ecovillages are settlements where human activities are harmlessly integrated into the natural world in a way that is supportive of healthy human development, and which can be successfully continued into the indefinite future. Developing countries have relied on agriculture for economic development, but the current depletion of environmental resources, climate change, and reduced water quality and quantity have affected the agricultural potential for many of them. This study sought answers to the following questions: How can ecovillages be designed to prevent hunger and remove barriers to local community empowerment and development? How can ecovillages be designed to avoid emerging vulnerabilities and build resilient communities? This study answers these questions by reviewing the literature on existing ecovillages to generate lessons learned that can help with the universal design and development of ecovillages as solutions to hunger and other various human vulnerabilities and sustainable development problems. Specific recommendations about investing in resilience at the local level, developing empowerment strategies, building institutional capacity, and innovating technologically to mitigate severe environmental impacts are discussed.

Keywords: Climate Change, Resources, Hunger, Community Vulnerability, Sustainability.

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USING GEOSPATIAL TECHNIQUES TO ASSESS LANDUSE CHANGE DUE TO FLOOD HAZARD IN KOSTI LOCALITY, SUDAN

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Abstract
In recent years human activities (land use change) in many circumstances are changing the floods from their natural behaviour. This study was conducted in Kosti locality with aim to analyze the flooding damages according to different land use and land cover (LULC) classes such as urban land and vegetation to determine the percentages of loss in different LULC in various corresponding year. In this study Geospatial Techniques were used with Remote Sensing through Satellite images from Landsat 7 for the year 2010, and Landsat 8 Operational Land Imager (OLI) for year 2019 as long with Geographic Information System (GIS), which have become a key tool for flood monitoring in recent years. Images of study time periods (2010 to 2019) have been analyzed with Geographical Information System (GIS) software. The analysis demonstrates the variation of land use changes before and after flood occurrence months from 2010 to 2019 depends on this change. The result showed that due to the flooding. the percentage of water body converted from 10% to 31% which impacts on all other LULC, urban land was also shifted from 62% to 27.8%, the vegetation cover was increased from 22% to 33.9% of total lands and the bare land also increased from 5.9% to 7%. Furthermore, the flooding of 2019 covers most of the land area of Kosti (34% of the locality) and washed out a huge amount of bare land and urban areas. The study recommended the utilization of this information to help the decision makers to identify the flood risk zones. It also helps the decision makers for planning residential, urban and land use system of a catchment area. It also provides the useful information to the town planners to use mitigation, modernization, flood protection and flood management system to reduce the properties and live losses.

Keywords: Remote Sensing, Kosti, Floods, Geographical Information System (GIS), Maps.

INTRODUCTION

All over the world people have been influenced by natural hazard, such as floods and drought. Floods is the most environmental hazard affected human life, beside their impact on changing land use, it's also destroyed the community life (Lingadevaru, 2015). Flash flood is most popular type of floods, it generally defined as a rapid onset of flood with a short duration and a relatively high peak discharge. It occurs rapidly, within one hour of rainfall, and sometimes accompanied by landslides, mud flows, bridge collapse, damage to buildings, and fatalities (H. A. P. Hapuarachchi, 2011).

In recent years remote sensing and GIS have been used in the evaluation of geo- environmental hazards (Pradhan, 2010). So To effectively mitigation and management of natural resources and hazard, the information on land use land cover change (LULCC) is essential. The relationship between floods and the change in land use is strong, and as the result any change in land use within the catchment area may be result in frequencies in floods event occurrences and economic loss (Alexakis, 2004).

There have been several studies on flood susceptibility mapping using remote sensing data and GIS tools (Pradhan, 2010), (Rao, 2011), (H.G.Savenije, 2002), (Jain, 2005), and (Hatzopoulos, 2008). Hamid (2020), depend on geospatial techniques to study environmental sensitivity to flash flood hazard. LULCC and vulnerability to floods have been studied by (Kabanda, 2013). (IsmailElkhrachy, 2015), used satellite images and GIS tools to generate flash floods map for Najran city, Saudi Arabia. (Idowu, 2021), assess the LULCC in the context of flood hazard in Lagos state, Nigeria.

In regard to Sudan, it has been classified as the most flood prone country in Africa according to (Chan-juan Li, 2016).in this country, the Flash floods are flooded regularly from June to October every year, and causing great disasters. El-Hamid (2016), concluded that, the study of flash floods hazard has been become very important for sustainable development, with the fact that flash flood has been caused a certain degree of harm to the agriculture sector and resident especially those on the lower area of the Nile River. H.M.SuliemanaN.A.Elagib (2012), reported that flood is the most popular natural hazard in Sudan causing severs destruction. The governments Humanitarian Aid Commission reported that about 179,000 people have been affected by floods and heavy rains in Sudan, and the worst affected state is the White Nile State (about 66.500) people have been impacted by flooding. Flood water destroy or damaged at least 34,500 homes and impacted wash and health facilities. Additionally, thousands of livestock have been killed which is likely to affect livelihoods and food security, (OCHA 20\08\2019).

This study was aimed to study the effect of flooding on land uses, vegetation cover and urban land by using the satellite images and GIS to evaluate the damages and changes caused by floods in Kosti locality during the periods from 2010 to 2019.

MATERIAL AND METHODS

Study area

Kosti locality (figure 1) is one of the major cities in Sudan that lies south of Khartoum, the capital of Sudan, and stands on the western bank of the White Nile River. The city lies 300 km south of Khartoum, between 12◦00 and 14◦00N in latitude and 32◦00 and 32◦40E in longitude (FNC, 1993). And it is situated at elevation 387 meters above sea level.

The White Nile River is the major geographical feature in the city, which runs from the south to north. The rainy season in the area of study extend from July to September. The average annual rainfall is 250-350 mm, and the highest rainy month is the August.

The main vegetation type is woodland savannah which generally reflects the semiarid climate. The vegetation is characterized by several *Acacia species.* The area is inhibited both by settled and nomadic population, their economy is dominated by traditional rain fed agriculture and seasonal wages (Kobbail, 2012).

Data used and its pre-processing

Landsat 7 and Landsat-8 OLI image with 30 m spatial resolution were used in this study. The cloud-free image was acquired in 3thFebruary, and 14 August for the year 2010, in regard to year 2019 the images were acquired on 31th august and 5th December, with a combination of path–row 173–51 respectively. The image collection considers two different times (1) In the flooding period (July to September) and (2) During the dry period (December to May).

The following pre-processing steps to both Landsat 7 and Landsat-8 OLI were included: Projecting the images into Universal Traverse Mercator (UTM) Zone 36 N with World Geodetic System 1984 (WGS84) datum, (ii) extracting the images to represent the study area (iii) unsupervised classification before and after flood occurrence months. The rainfall data were downloaded from the OCHA website (OCHA, 2019).

Methodology

To monitoring and assessing the damage caused by flood two maps' types were generated:

1- Land use land cover maps of the Study area before floods.
2- Land use land cover maps of the Study area after floods.

To generate the map before and after floods unsupervised classification has been used to classify the Landsat images used in this study. The classes were included four major land cover land use types namely: vegetation, urban area, bare land, and water body.

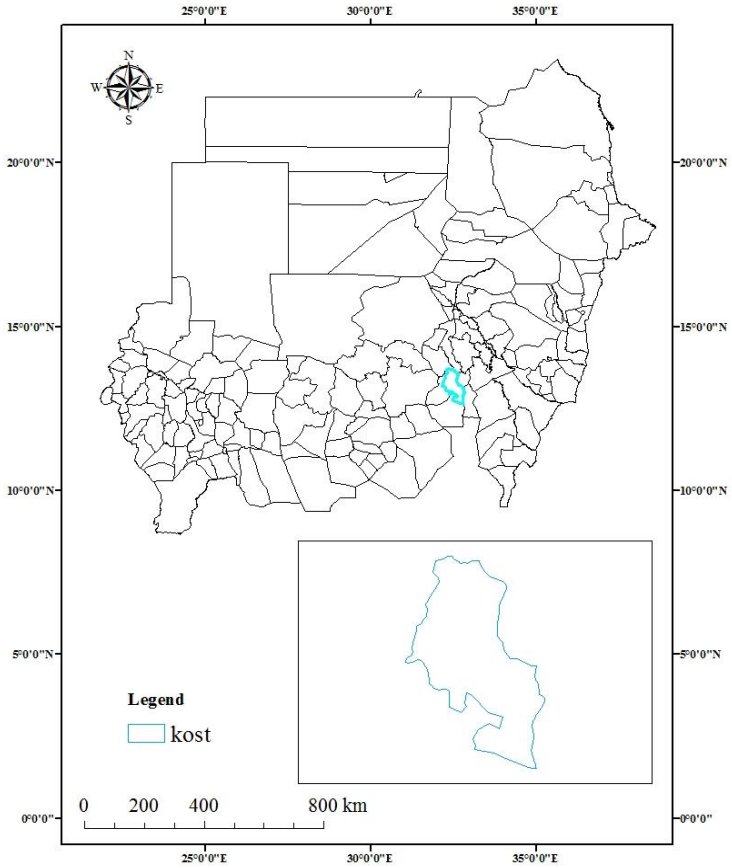

Figure 1: *Location of the study area.*

RESULTS AND DISCUSSION

Rainfall analysis

Table 1 represent Kosti locality main average annual rainfall for the month of August 2010-2019. The main average rainfall for the month of august for the year 2010 is 153.51 mm and 161.02 mm for the year 2019.The average annual rainfall through the study time period (2010-2019) is 152.24 mm.

The analysis results of the main average annual rainfall for the study time period (2010-2019) showed an increasing trend by 0.4889mm. and when comparing the average main for the years 2010 and 2019 with the long-term average main for the study time period the result showed that there are increasing by 1.27mm and 8.77mm for the years 2010-2019 respectively. Rainfall is the driving force for floods and as the situation in kosti, for the both years (2010, 2019) the main average annual rainfall is more than the average of the study time period and as the result the locality faced more floods during this year's.

years	Rainfall (mm)
2010	**153.5139**
2011	169.4149
2012	150.1024
2013	164.6146
2014	181.566
2015	135.8559
2016	121.4913
2017	141.4271
2018	143.4271
2019	**161.0174**

Table 1: *Average rainfall for the month of August 2010-2019.*

Flood mapping assessment in Kosti locality

The study area has faced a huge amount of changes due to flooding years 2010 and 2019. For the year 2010, the results shows that the land use land cover changes (LULCC) for two months in year 2010, figure 2, the image of (a) February, 2010 which is taken for showing the land use conditions before occurring flood and the image of (b) August, 2010 is taken for showing the lands use conditions after flood.

The interpretation of Landsat image (a) shows that the study area was covered by10% of the water body, 62% of the urban area, and 22% of vegetation and 5.9% bare land of total area of study. The data shows only 10% of water body existed before an overflow of water. But after increasing the overflow of water in the month of August 2010, the percentage of water body represents a massive change. The Figure 2b shows the changes of water body after the flood which affected all other land uses. The figure represents that the percentage of water body converted from 10% to 31% which impacts on all other land uses. Due to an increase of water body, the percentage of urban land was reduced from 62% to 27.8%. Similarly, increasing of flooding also affects the vegetation cover which was shifted from 22% to 33.9% of total lands and the percentage of bare land was increased from 5.9% to 7%. From the point of view, the increasing of water body result in destroying the urban area, that appears in the reducing in the urban land percentage. And at that time changing in the water body area result in the increasing percentage of vegetation cover.

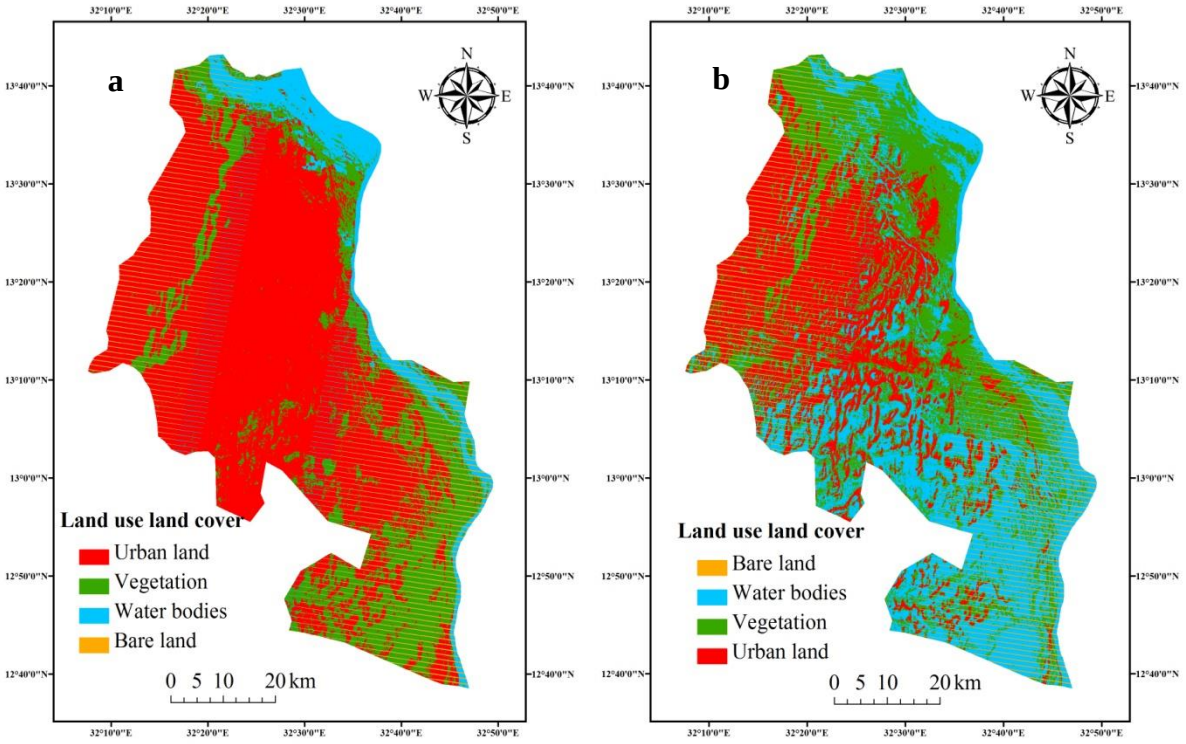

Figure 2: *a) Land use map before occurring flood (February 2010) and b) Land use map after flood (August, 2010).*

The results indicate that, 34.2% of the urban land was flooded because of occurring flood and people became homeless. The most importance finding of the analysis of the flood of 2010 is, the flood covers most of the land area of Kosti locality (34% of the locality) and washed out a huge amount of bare land and urban areas. According to (IPCC, 2014), increased frequency of extreme precipitation events has severe impacts on urban areas through flooding, causing destruction to livelihoods, properties, and infrastructure, contamination of water sources and spreading of water-related diseases, which happened in Kosti locality through this period.

In 2019, (Figure 3) represents the LULCC, where the image of (a) December 5th, 2019 which is taken for showing the land use conditions before the flooding and image (b) August 31th, 2019 is representing the lands use conditions after flooding. The results from Figure 3b shows that the percentage of water body was increased from 8.6% to 20%. The amount of land flooded was 38300 km^2 of 89325 km^2. Due to an increase of water body, the percentage of urban land was also shifted from 37.8% to 38%. Similarly, increasing of the flooded area also affects vegetation cover which was changed from 26.9% to 22.3% and bare land was moved from 26.7% to 19.7% as the result of flood. The result indicates that, due to the overflow of water most vegetation land was flooded an as the result it washed out. In addition, 0.2% of the urban area was also flooded and as the result people became homeless after they lose their hoses, in the fact most of those houses were built using traditional local materials (dried mud and bricks), making them structurally weak to withstand heavy rains and floods. This finding is with the line with the (Hamid, 2020), which concluded that, poor infrastructure and lack of preparedness were the main causes of disasters from floods in Sudan.

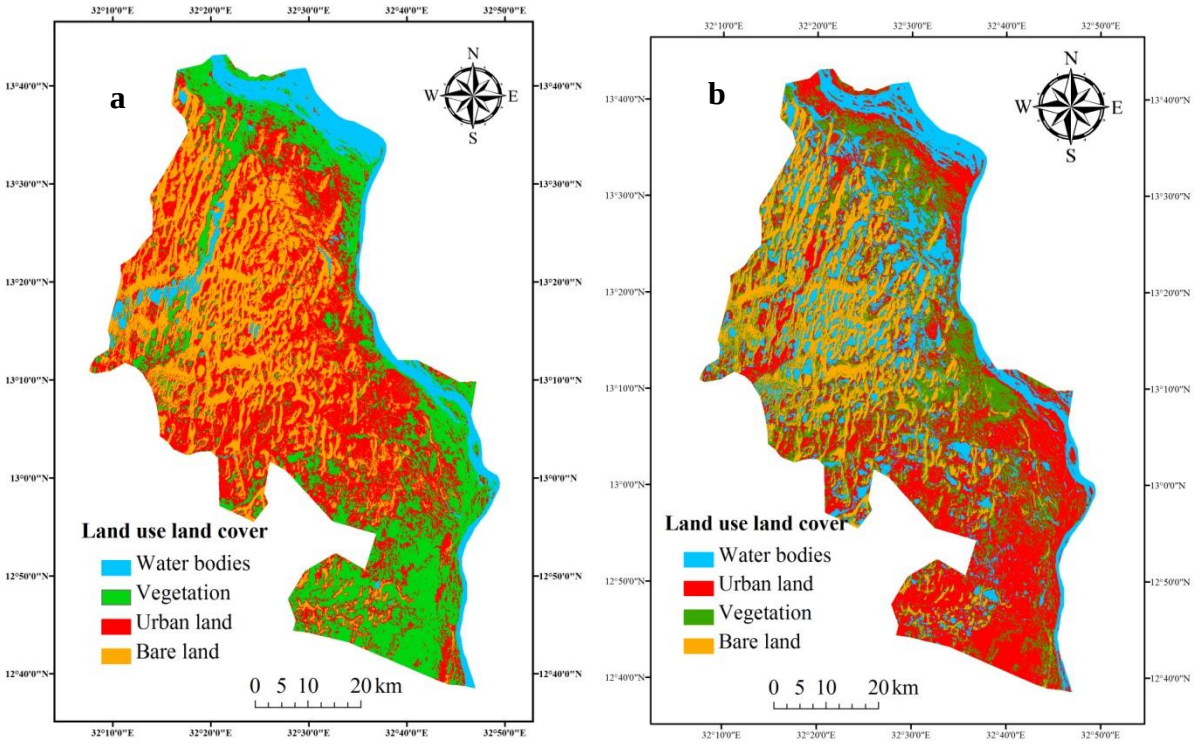

Figure 3: *a) Land use map before occurring flood (December 2019) and b) Land use map during flood (August, 2019).*

The decreasing in the bare land (from 26.7% to 19.7), explain by the fact that most of this bare land was cover by water; similarly, the vegetation land was flooded.

Flood level change assessment

Figure 4 represent the most flooded area with respect to their corresponding year. In 2010 about 1386 km^2 land was flooded and in 2019 this flooded land was increased to become 8932 km^2. The figure also reveals that the percentage of damage in urban area was increasing year after year, that means due to increasing of urbanization, urban area damages was increased by 34.2% during the period 2010 to 2019. Population in Kosti have been increased rapidly after the year 2010 because the south Sudanese refugees fled to the locality after the local ware in south Sudan, those refugees clear a lot amount of trees and vegetation cover, so the land become bare, which accelerating the floods and water erosion.

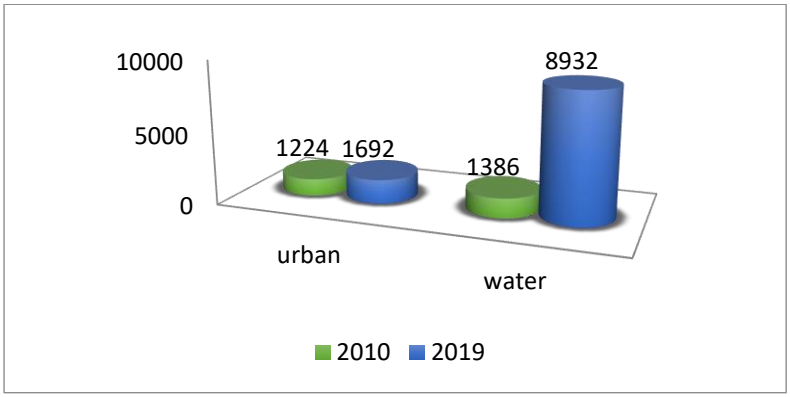

Figure 4*: Area (km^2) most under Water land during Flood for the year 2010 and 2019.*

Damage assessment of land use land cover classes during flood

Figures 5 represent the total percentage of loss during flood with their corresponding year. The figure represents that percentage of damage to urban area was increasing through the study time period. It is known from the literature increasing in population means increasing in urbanization. However urban area damages were increasing from 27.8% in year 2010 to 38% In the year 2019, people of kosti city suffered most in this year, the figure also represents the total percentage of bare land damaged land with its corresponding year. The percentage fluctuated in a different year. In 2010, the percentage of vegetation land was 33.9% but in 2019 the percentage decreased to 22.3%. After 2010, the damage of water body was 31% and it decreased to 20% in 2019. The key point is that, day by- day due to flood, property as well as vegetation lands are destroyed most and therefore the economic loss is increasing constantly which adversely affect the locality's economic condition.

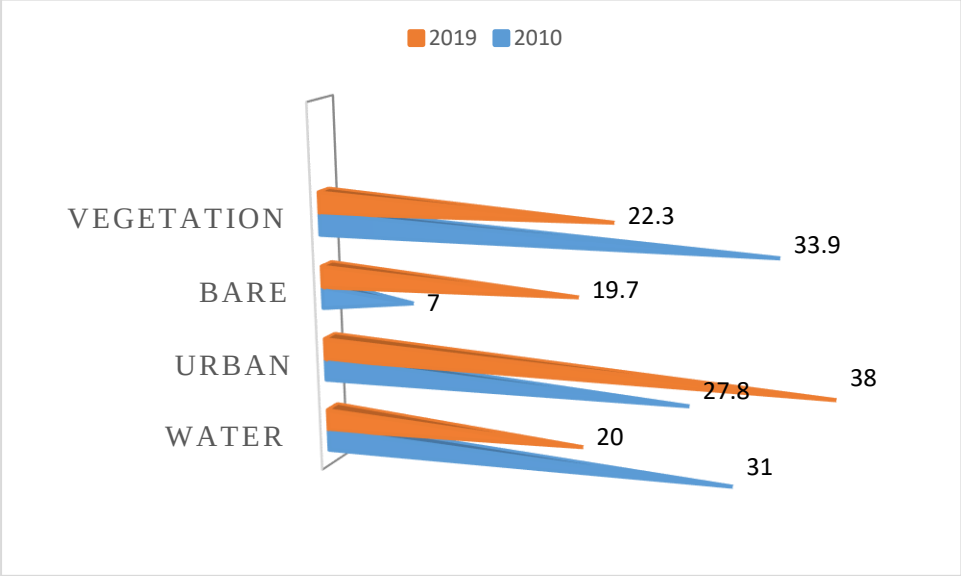

Figure 5*: Percentage of land use land cover damages during floods 2010 - 2019.*

Much research work has documented the effectiveness of remote sensing and GIS in assessing the floods damages in urban area. For example (Mohammed, 2020), study the Vulnerability assessment for flash floods using GIS spatial modelling and remotely sensed data in El-Arish City, North Sinai, Egypt, and he reported that using the composite flash floods vulnerability index can help in identifying the area vulnerable to flood. However, these studies have either been short-term studies or have not focused on estimating the percentage of damages of the areas affected by floods. In our present investigation we tested the use of remote sensing and GIS in assessing floods damages according to the changes in land use land cover areas percentage and amount. We found that in both years (2010, 2019), the flooding lead to increase in water body's which affected all the other types of LULC including urban area and vegetation cover. These results are in line with the finding of (H.M.SuliemanaN.A.Elagib, 2012) who reported that flood is the most popular natural hazard in Sudan causing severs destruction. Similarly, OCHA reported that about 179,000 people have been affected by heavy rains and flooding across 15 States. Worst affected is White Nile State with nearly 66,500 people who are impacted by flooding. 34,500 homes were destroyed. Additionally, thousands of livestock have been killed which is likely to affect livelihoods and food security, (OCHA, United Nations Office for the Coordination of Humanitarian Affairs OCHA, 2019).

CONCLUSION AND RECOMMENDATION

This study indicates that the benefits gained from using remote sensing and GIS may address needs across wide range of developing countries, which under the economic pressure. Most notably, this is the first study to our knowledge to investigate the effectiveness of remote sensing and GIS in floods assessment in kosti city. Our results provide compelling evidence for long-term assessment of land use land cover change and suggest utilization of the GIS and mapping as an effective method in assess and evaluate floods control and hazard, The study represents an efficient methodology to accurately evaluate and assessment damage of the flooded areas with the help of remote sensing data and GIS tools in Kosti locality, Sudan. The study concluded that most damages happen in the urban lands due to the massive increase in water body area. The study recommended the using of mapping and recent tools such as GIS in flooding assessment to help the decision makers to identify the flood risk zones. It also helps the decision makers for planning residential, urban and land use system of a catchment area. It also provides the useful information to the town planners to use mitigation, modernization, flood protection and flood management system to reduce the properties and live losses.

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BUILDING THE ELECTRICITY SECTOR IN SUDAN: ADDRESSING FAULT SCENARIOS IN SMART GRID

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Abstract
Despite challenges in Sudan's transition to democratic rule, the overthrow of a thirty-years dictatorship in 2019 opened opportunities for rebuilding different sectors. Interrupted with a military coup that occurred in October 2021, one of the most important tasks in Sudan's transition would have been developing the electricity sector's infrastructure. The lack of investment in this sector translates into excessive power cuts, and thus affects people's daily lives. One way to do so would have been through advancing electricity automation and the deployment of Smart Grid technology using wireless infrastructure instead of the wired technology currently used for electricity automation. Using Smart Grid enables networks to exchange energy efficiently and sustainably. The use of wireless technology ensures affordability and ease of deployment and upgrading of electricity infrastructure. These technologies are more likely to attract entrepreneurs and small businesses as investors in electricity generation. Research in this area has focused on the applicability of standard wireless technologies to Smart Grid. The use of affordable wireless technologies like Wi-Fi in electricity automation, however, involves stringent time requirements for interaction between producers and consumers in faulty situations. It is thus important to ensure low latency in such scenarios. This paper, which is based on the author's doctoral research, discusses factors that affect the deployment of Concurrent Transmission (CXMSN) using user-grade IEEE802.11 devices in realistic scenarios. The paper offers insights regarding future research that can enhance efforts for building the electricity sector in Sudan and elsewhere in Africa, provided there is political will, and provided there is a conducive environment.

Keywords: Concurrent Transmission, Smart Grid, Wifi, Low-Latency, Electricity Sector, Sudan.

INTRODUCTION

Located in Northeast Africa, Sudan has one of the highest levels of solar radiations worldwide, which means the country has great potential for producing renewable and clean energy. Paradoxically, the country holds one of the lowest electrification rates in the world (45%) which is much less than the average rate (84%) (Arab Future Energy Index (AFEX) 2019). The current electricity public sector power grid in the country does not cover some rural areas which constitute about 65% of the country (World Bank 2020), due to technical and structural factors. Where there is electricity coverage in urban areas, the sector is unable to meet the high demand. Urban areas in Sudan suffer from long hours of power-cuts. Lack of access to electricity impacts not only major sectors, including industry and the economy in Sudan, it also affects people's quality of lives, including the quality of healthcare services, education, and people's overall welfare.

Challenges abound. Technical challenges include the high cost of cable deployment and maintenance. In addition, engineers encounter difficulties in inspecting power lines given the large area of the country. Structural factors include bad governance, and a lack of political will regarding the development of electricity infrastructure, corruption, and the diversion of

resources from developing critical sectors to sustaining the army and security establishment. Political instability continues to impact this sector. Importantly, the country still relies on gasoil, diesel and heavy fuel as primary movers for thermal generation which constitutes more than 40% of the total electricity generation in Sudan (Ali A. Rabah et al. 2016). This is not to suggest that Sudan does not generate energy using renewable resources. To the contrary, the country's percentage of renewable energy generation is comparably high (54%) due to the country's hydro capacity. This percentage drops to 5%, however, if we excluded hydro generation (Arab Future Energy Index (AFEX) 2019). The country has joined global efforts to reduce gas emissions and ratified the *Paris Agreement* which aims to reduce "global greenhouse gas emissions to limit the global temperature increase in this century to 2 degrees Celsius while pursuing efforts to limit the increase even further to 1.5 degrees" (Paris agreement 2015). Sudan has also endorsed the Sustainable Develop Goals (SDGs). Goal 7 mandates that governments and the private sector "ensure access to affordable, reliable, sustainable and modern energy for all" (17 Goals to transform our world 2015). The advancement of scientific knowledge in Smart Grid technology is thus not only important to ensure access to electricity. It enables Sudan (under a democratic government) to contribute to meeting the SDGs through the production of clean and sustainable energy.

To address this challenge, the Ministry of Electricity and Water Resources in Sudan had developed a National Renewable Energy Action Plan which aims to increase the generation of renewable energy to 50% (excluding hydro energy) by 2031 (Arab Future Energy Index (AFEX) 2019). Achieving the targeted percentage requires combining political, regulatory and technological endeavours to expand the country's power grid and to establish new power generation plants. Equally important, is maximizing the efficiency, reliability, and sustainability of the overall power grid via smart management of power resources, to improve equitable access to electricity. Smart Grid can play a key role in this respect.

The merits of Smart Grid are numerous, especially in a context like Sudan. In addition to generating and managing the distribution of electricity, Smart Grid involves the use of intelligent controllers and state-of-the-art telecommunication technologies and automation features. These enable remote monitoring and control and thus minimize the cost of maintenance, leading to reduced electricity tariff. This is important in a country like Sudan, where poverty levels are high, and where inequality is prevalent.

Moreover, *The Declaration of Appropriate Technology* ((INAT) 2010) emphasizes the importance of prioritizing appropriate technologies to meet the basic needs and human rights of communities and populations, especially marginalized groups. This includes access to "clean air and water, safe food, affordable, accessible and available healthcare, adequate shelter, renewable energy, relevant education and access to information and communications". These interdependent needs and human rights are *all* relevant to this research and to the use of renewable energy and Smart Grid. Electricity enables access to all these rights. The use of wireless networks like Wi-Fi which do not require laying cables, for example, facilitates expanding the electricity network to reach historically marginalized areas and populations, depending on political will. Further, the two-way electricity generation feature in Smart Grid enables consumers and small businesses to participate in electricity generation, given the low cost and ease of deployment of wireless networks.

This is not to overlook local innovation and indigenous knowledge that communities, especially women, use to preserve food; to communicate, and to educate younger generations. This is also not to overlook important grassroots initiatives, such as the "Solar Mamas"

initiative in Sudan and in other countries in the global South. Through the Solar Mamas program, for example, women from Sudan's Nuba Mountains received trained and became community engineers who used solar power to generate electricity for their communities (Kadoda 2020).

The next section focuses on the technical part of Smart Grid. I define Smart Grid and present the findings of my research on ways to address challenges that might arise when using Smart Grid, through conforming Wi-Fi to the low-latency requirements for fault scenarios in Smart Grid.

Smart Grid

Although Smart Grid has emerged as a commercial term, there are several technical definitions from three main standardization bodies: NIST (NIST Smart Grid framework and roadmap for Smart Grid Interoperability Standards 2012), IEEE (Colak 2016), and IEC (Smaht). A Smart Grid is a network of actors such as electrical substations, energy storage systems and loads connected in a two-way, real-time communication. These actors cooperate to enhance energy generation and consumption. The applications served by Smart Grid include electric vehicles which do not release carbon dioxide, including Vehicle to Grid (V2G) (al. 2022), and Advanced Metering Infrastructure which measures, stores and analyses electricity usage data.

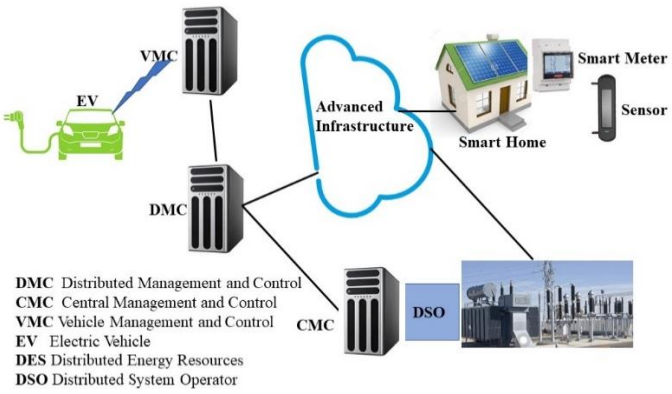


Figure 1: *Smart Grid key actors and applications.*

A typical Smart Grid is shown in **Figure 1**. It consists of functional building blocks; the Distributed Energy Resources (DERs) which include renewable energy and are often located outside the main energy generation or distribution network. Among the different renewable energy sources, solar energy is the safest, most reliable, and clean natural energy source (H. Kanchev et al 2011). One of the most common ways of generating solar energy is through Photovoltaic (PV) cells. PV cells are mounted on the roofs of buildings or in open areas that are exposed to sunlight. The generated energy is stored in a storage system called Distributed Energy Storage System (DESS) near the corresponding DERs. DERs and DESS are managed by Distributed Management and Control (DMC) which is then managed by the Central Management and Control (CMC) system. The Supervisory Control Data Acquisition (SCADA) is a software that is used to monitor and control the processes (Axel Daneels and Wayne Salter 1999).

Power utility automation (IEC61850)

Power Utility Automation is one of the core standards in Smart Grid developed by IEC (IEC TC57 2010). IEC61850 provides an abstract data model that simplifies modelling the electrical

devices and substations. Part 5 of the standard specifies the communications requirements of Smart Grid. Instead, Part 8 specifies the data frames used to exchange information among the Smart Grid actors. In this research, I use Generic Object-Oriented Substation Event (GOOSE) data frame which is exchanged among the Smart Grid actors in fault scenarios, as benchmark for the ability of the wireless infrastructure to fulfil the Smart Grid requirements. The transfer times of the data messages specified by the IEC61850 standard range from 3 ms to 1 second depending on urgency of the service provided by the Smart Grid. For example, monitoring events and non-critical alarms tolerate up to 1 second, while GOOSE message requires 3 ms to avoid consequences like cascaded faults or blackout. It is worth mentioning that synchronization plays a key role in the accuracy of the measurements taken by sensors, as well as the decisions taken by the SCADA. While GPS provides accurate timing (nanoseconds), due to high cost, only time is sampled in few stations and distributed using an efficient protocol such as Precision Time Protocol (PTP) which provides (µ seconds) accuracy (IEEE standard for a precision clock synchronization protocol for networked measurement and control systems 2008).

Communication network in Smart Grid

The communication network plays a key role in exchanging information among Smart Grid actors. Since the proliferation of Smart Grid, several communication technologies have been used such as Power Line Communication (PLC) *(Ghadi Sebaali and Brian L Evans 2015)* which uses power lines for remote monitoring and control. PLC does not require cable installation; however, it suffers from the wavering nature of power supply and radio interference. Ethernet requires laying cables; Fiber optics is an efficient technology with high data rates and expensive installation cost; Wireless public networks such as cellular networks and private wireless networks such as zigbee and Wi-Fi are also used in Smart Grid. Zigbee *(Chenghao 2020)* and LoRa *(J. L. Gallardo 2021)* are used for low data rates Smart Grid applications.

This research focuses on Wi-Fi, standardized as IEEE802.11 which is used in Smart Grid applications such as energy optimization, load balance, EVs, Power Saving, etc. IEEE 802.11 networks have many useful features, such as the low cost of installation and deployment and the contention-based nature which a does not require central control. Among several IEEE802.11 such as a/b/g/n/ac/ax/be, we focus on the state-of-the-art IEEE802.11b/g/ac. These provide 1, 54, 866 Mbps respectively. I further focus on two PHYs; Direct Sequence Spread Spectrum (DSSS) and Orthogonal Frequency Division Multiplexing (OFDM).

IEEE802.11 PHYs DSSS and OFDM

DSSS (Don Torrieri 2015) is one of the spread spectrum techniques used to widen the spectrum of a narrowband signal. To achieve this, a single bit is multiplied by 11 Barker chips and transmitted with a lower power spectral density while keeping the total power. Upon reception, the received signal is multiplied using the same chips to extract the original signal, given the *autocorrelation* property of the Barker chips. Due to the low power spectral density, a transmitted signal appears to a third party as noise. This embeds robustness attributed to the inability of the third party to sniff the signal. Further, the spreading technique used in DSSS minimizes interference by spreading the interfering signal at the receiver and by applying a match filter.

A typical reception process starts by receiving the preamble which contains *Sync* bits used by the receiver to train the *self-synchronizing descrambler* to avoid long sequences of 0's and 1's. The receiver then extracts the header which contains overhead information over the length of

the data part and the data rate. The receiver then decodes MAC Packet Data Unit (MPDU) which contains the data. Finally, the receiver checks the integrity of the frame using Cyclic Redundancy Check (CRC).

OFDM (IEEE LAN/MAN standard committe 2007) instead subdivides the channel (20MHz in 6 Mbps) into narrow, closely and uniformly spaced orthogonal subchannels. A stream of bits is then subdivided and modulated using orthogonal subcarriers. Each modulated sub stream is sent in the corresponding subchannel. Prior to subchannel assignment, each bit stream is first scrambled to avoid long sequences of 0's and 1's upon reception. Then the bits in each stream are coded using *Convolutional Encoder to* minimize the probability of random errors at the receiver. The coded bits are set into constellation points using the *Mapper*, then assigned to the corresponding channels using *Fast Fourier Transform (FFT)*. The transmitter then adds *Pilot* subcarriers used to carry the state of the channel used later for symbols *equalization*. Then the transmitter inserts *Guard* Subcarriers and DC subcarrier which are set to zero. The transmitter prepends a *Preamble* which consists of short and long training sequences (*STS* and *LTS*). The Preamble is used by the receiver to detect the received signal and to compensate for the phase shift by utilizing the *Phase Equalization Mask* generated from the *Preamble* and pilots. The advantages of OFDM include high data rates depending on the mapping and coding scheme; and immunity to selective fading by distorting only a subset of subcarriers carrying subset of data. A disadvantage is that OFDM is sensitive to differences in frequencies between the transmitter and receiver which is called *Frequency Offset*.

Concurrent Transmission (CXMSN)

CXMSN is a light-weight flooding protocol (F. Shi, X. Tuo, S. X. Yang, J. Lu and H. Li 2020) which relays frames from the transmitter to the receiver using a network of forwarders. Unlike PHY and MAC schemes that aim to mitigate interference as in the case of contention-based protocols (Indika SA Dhanapala et al 2016) (Yifan Gu et al 2016) (Martin G Guldberg, Jim Hunter, and Timothy Lee Roco Carter 2016), CXMSN exploits interference to enhance packet reception by increasing the amplitude of the received symbols. CXMSN was first introduced by Glossy for IEEE802.15.4 devices (Federico Ferrari et al 2011). The concept behind CXMSN, see **Figure 2**, is to send copies of the same frame using coarsely synchronized forwarders located at different spatial positions as in Macrodiversity. At the receiver end, symbols belonging to the transmitted frame accumulate naturally due to *Constructive Interference*, increasing the amplitude of the received signal. A closely related phenomena, *Capture Effect,* occurs when a stronger signal is received followed by a weak signal. The receiver synchronizes itself with the stronger signal and neglects the weak interfering one. *Constructive Interference* increases the probability of correctly decoding the frame denoted as *reception* in this paper.

CXMSN has several advantages. A Macrodiversity technique where a signal is transmitted over highly decorrelated channels compared to Microdiversity techniques such as MIMO and Beamforming, CXMSN does not overload the networks because frames are forwarded in cascades. CXMSN is also simple and does not require previous channel state information or signalling. CXMSN reduces the overall network delay because it does not require channel access, instead, frames are forwarded immediately. As a decentralised protocol, CXMSN does not require explicit coordination or signalling. If not deployed properly, however, CXMSN frames may cause broadcast storm (Hyojun Lim and Chongkwon Kim 2021). Further, CXMSN might suffer from Frequency, Time and Phase Offsets caused by differences in oscillators, scheduling times and non-coherences among the forwarding devices.

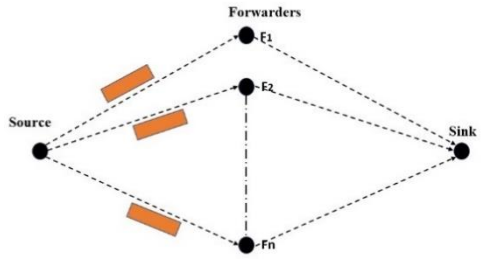


Figure 2: *C.XMSN illustration.*

METHODOLOGY

This research is based on experimental investigation of the conformance of the state-of-the-art Wi-Fi to Smart Grid in fault scenarios. Motivated by the inability of the current Wi-Fi to fulfil the Smart Grid requirements, the author explored and analysed the reasons, and modelled the factors mathematically. The author validated the model practically.

RESULTS & DISCUSSION

Investigating state-of-the-art Wi-Fi

The author investigated IEEE 802.11g link which works at the 2.4 GHz. The author activated a single forwarder F_1 in **Figure 2**. The link is composed of two 50 m hops, each uses a separate channel to avoid interference at F_1. The maximum latency obtained using ping tool is 15 ms, losses obtained by iperf tool is 22 % for 15 Mbps which does not conform to fault scenarios in Smart Grid (Rinaldi, S., Ferrari, P., Ali, N. M., & Gringoli, F. 2015).

Investigating IEEE802.11ac

We then chose IEEE 802.11ac, which operates at the 5 GHz band, in a real scenario, where fault occurrence at the solar plant, shown in **Figure** trigger the transmission of *GOOSE* message over the wireless link.

Figure 3: *Smart Grid testbed wireless topology.*

We fulfilled synchronization and measurement requirements by using GPS antennas and Agilent counter with high accuracy. For the estimated transfer time for the link with/without background, see Figure 4.

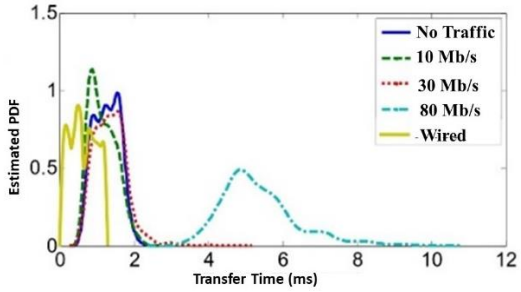


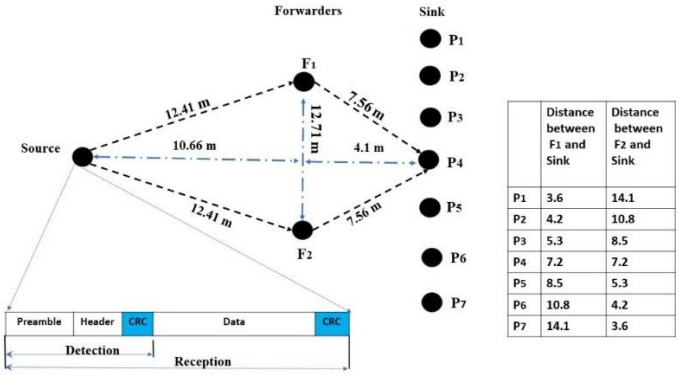
Figure 4: *The estimated power spectral density(pdf) of the GOOSE transfer time over IEEE802.11ac with different rates of background traffic (Mb/s).*

Figure 4 shows the transfer times of the wireless link in comparison with a wired-reference case. While the transfer time in the wired link is less than 2 ms, wireless link with 30 Mbps background traffic fails to meet the Smart Grid requirements (Rinaldi, S., Ferrari, P., Flammini, A., Gringoli, F., Loda, M., & Ali, N. 2016).

To conclude, the-state-of-the-art Wi-Fi does not conform to Smart Grid due to latency and reliability problems. So, we have to find low-latency technique.

Investigating CXMSN

The experimental setup is shown in **Figure 5** where we used user-grade LinkSys nodes. At the forwarders, we ensure rapid forwarding by deploying Open FWWF (F.Gringoli, L.Nava 2008) with customized code so that frames are forwarded within 10 µs. This in turns, created course synchronization between the forwarders. Since the technique is not data-specific, we transmitted 166 Bytes frames and we tested *detection* and *reception* as illustrated in **Figure 5**. *Detection* means decoding the first part of the frame including the header, and *reception* means decoding the whole frame correctly.



	Distance between F1 and Sink	Distance between F2 and Sink
P1	3.6	14.1
P2	4.2	10.8
P3	5.3	8.5
P4	7.2	7.2
P5	8.5	5.3
P6	10.8	4.2
P7	14.1	3.6

Figure 5: *Initial setup: the receiver is tested in seven positions, leading to different amplitudes of the received signal in each position.*

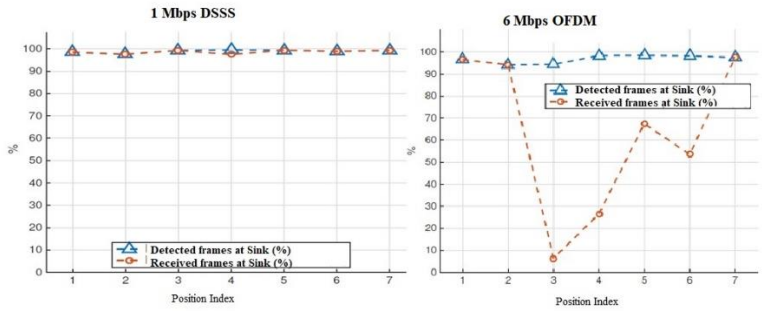


Figure 6: *Packet detection and reception for 1Mb/s (left) and 6Mb/s (right) for seven positions of the receiver.*

While the majority of DSSS frames (98 %) were *received* as shown in **Figure 6** / left, we notice a critical position in **Figure 6** / right where OFDM frames are *detected* but not *received* at the sink. Given the two forwarders, we attribute this observation to the invalidity of the *phase equalization mask* at the sink towards the middle of frame causing inability of the receiver to decode the whole frame correctly (Gringoli, F., Klose, R., Hollick, M., & Ali, N. 2018).

CXMSN model

We explain the findings by modelling reception in CXMSN, where we assume two signals s_1 and s_2, transmitted by two forwarders for simplicity. The two forwarders have identical transmitting power which yields the highest interference, representing the worst-case scenario. With this, the model could be easily generalized to a higher number of forwarders.

Taking the IEEE802.11 PHYs into consideration, we assume the basic and most robust data rates 1, 6 Mbps for DSSS and OFDM respectively. Each frame is composed of a train of non-overlapping Q symbols. Each symbol indexed q where $(0 \leq q \leq Q-1)$ has a *complex envelop* c_q and duration T_s. Where T_s depends on the PHY (DSSS or OFDM).

In IEEE802.11b, DSSS $T_s = 1\mu s$ and represents one bit. For IEEE802.11g, OFDM symbol duration $T_s = 4\mu s$ represents 24 bits.

We assume that s_1 and $s_2$arrive at the sink having offsets in time Δt, phase $\Delta\theta$, and frequency Δf as shown in Equations (1) and (2):

$$s_1(t) = 2\Re\left[\sum_{q=0}^{Q-1} c_q(t - qT_s)e^{j2\pi f_0 t}\right] \quad (1)$$

$$s_2(t) = 2\Re\left[\sum_{q=0}^{Q-1} c_q(t - qT_s - \Delta t)e^{j2\pi(f_0-\Delta f)t} + e^{j\Delta\theta}\right] \quad (2)$$

The received signal is the composition of the two forwarded signals as in Equation (3)

$$s^{rxvd}(t) = s_1(t) + s_2(t) \quad (3)$$

Considering only the *complex envelop*, we neglect the noise at this stage and we only focus on the impact of Δt, $\Delta\theta$ and Δf. So, the *complex envelope* c^{rxvd} at the receiver is shown in Equation (4):

$$c^{rxvd}(t) = \sum_{q=0}^{Q-1} \left[c_q(t - qT_s) + c_q(t - qT_s - \Delta t) e^{j2\pi\Delta f t} e^{j\Delta\theta} \right] \quad (4)$$

PHY-DSSS

In DSSS, the frame starts with the *Sync* sequence which is used for recovering the clock at the receiver. While the length of the whole sequence is 128 bits, only some of the q_s are used to train the *self-synchronizing descrambler*. Consequently, the crucial part in the analysis starts from q_s up to the end of frame Q.

DSSS with perfect time synchronization Δt = 0:

In this scenario, the two forwarded signals s_1 and s_2 arrive at the receiver at the same time. So, we substitute $\Delta t = 0$ in Equation (4), and we change the temporal reference to the q^{th} symbol as follows:

$$c_q^{rxvd}(t) = c_q\left(1 + exp(j2\pi\Delta f(t + qT_s) + j\Delta\theta)\right) \quad (5)$$

To avoid phase inversion, the total phase shift (composed of the Phase Offset Δθ and the phase distortion caused by the Frequency Offset) should satisfy the following conditions ∀k ∈ Z:

$$\begin{aligned} 2\pi\Delta f q_s T_s + \Delta\theta &> -\pi + 2k\pi \\ 2\pi\Delta f Q T_s + \Delta\theta &< +\pi + 2k\pi \end{aligned} \quad (6)$$

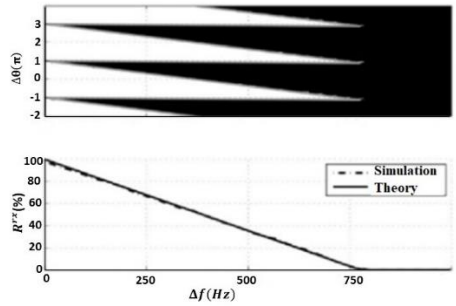


Figure 7**:** *The top subfigure shows regions of frame reception/errors in white/black colors respectively. The bottom subfigure shows the frame reception rate after averaging the Phase Offset. MPDU length is 147 Bytes.*

Figure 7 (top) shows the regions that satisfy the boundary conditions for $k = 0$. The areas of frame *reception* are shown in white color while the regions of *errors* are in black for a 147 Bytes MPDU frame.

The grey lines depict the boundaries specified by the conditions in Equation (6). The maximum Frequency Offset could be found at the intersection of the two boundaries and is given by the following equation:

$$\Delta f_{max} = \frac{1}{(Q - q_s)T_s} \quad (7)$$

At Δf_{max}, the receiver can *receive* only the frames having a single value of $\Delta\theta$. The rest of the values will lead to phase inversion which results in zero rate of frame *reception*. Contrarily, when Δf is zero, the value of Phase Offset has no impact on the frame *reception* rate.

To find the frame reception rate $R_{rxvd}(\Delta t)$, considering the uniform distribution of the phase offset, we average the region of Phase Offset delimited by the two boundaries over the whole range [−π, π]:

$$R_{rxvd}(\Delta f) = \begin{cases} 1 - \dfrac{|\Delta f|}{\Delta f_{max}}, & 0 \le \Delta f \le \Delta f_{max} \\ 0, & elsewhere \end{cases} \quad (8)$$

Figure 7 (bottom) reports the rate of frame reception. We notice that when $\Delta f = 0$, the frames are *received*. However, very few frames are *received* when the Frequency Offset reaches its maximum value Δf_{max}. that even if Time Offset was zero, the maximum Frequency Offset would cause high error rates.

PHY-OFDM

In OFDM, the STS and LTS occupy 16 µs = 4Ts. We assume that training sequences have to be received correctly to enable reception; Decoding an OFDM symbol requires sampling the entire symbol, then extracting only the data subcarriers.

We start from Equation (5), and we find the Fast Fourier Transform (FFT) of the q^{th} symbol:

$$C_q^{rxvd}(f) = C_q(f) + C_q\ (f - \Delta f) e^{j2\pi\Delta f(t+qT_s)} e^{j\Delta\theta} \quad (9)$$

We then approximate $C_q(f - \Delta f) \simeq C_q(f)$ because the Frequency Offset is much less than carrier spacing (312.5 kHz). We replace the frequency f with the frequency at subcarrier n: $f = {}^{n}/_{NT_c}$, where T_c is the sampling time (50 ns), N is the FFT length (N = 64).

The packet reception depends on the *complex envelope* $C_q^{rxvd}(n)$ of the received signal which could be approximated by:

$$C_q^{rxvd}(n) \simeq C_q(n)\left[1 + exp\left[j\left(2\pi\Delta f - 2\pi\frac{n\Delta t}{NT_c} + \Delta\theta\right)\right]\right] \quad (10)$$

Following the same reasoning in Equation (6), we find the maximum Frequency Offset:

$$\Delta f_{max} = max\begin{cases} 1 - \dfrac{\dfrac{n_1 - n_2}{NT_c}|\Delta t|}{QT_s}, & 0 \le |\Delta t| \le |\Delta t|_{max} \\ 0, & elsewhere \end{cases} \quad (11)$$

Where $n_1 = 26$ and $n_2 = -26$.

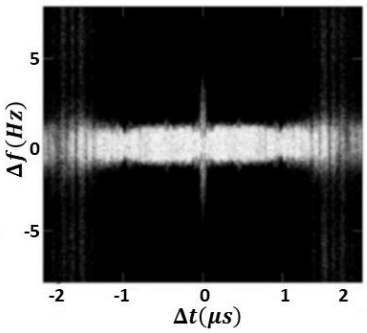


Figure 8: *Packet Reception for OFDM 6Mb/s on AR928 (black= 0 %, white = 100 %).*

The result of practical validation of the model using commercial AR928 receiver is shown in **Figure8** where we also configure offsets using WARP software defined radio. As shown, results match the analytical model qualitatively.

CXMSN RELATED WORK

Constructive Interference	**Capture Effect**	**Technology**
Glossy Model (Federico Ferrari et al 2011), (Prabal Dutta et al 2008), (Yanru Wang et al 2016), (Manjunath Doddavenkatappa, Mun Choon Chan, and Ben Leong 2013) and (Dingwen Yuan and Matthias Hollick 2015), (Manjunath Doddavenkatappa, Mun Choon Chan, and Ben Leong 2013)	(Michael Knig and Roger Wattenhofer 2016), (J. Jun, S. Yeon, T. Kundu, D. P. Agrawal and J. Jeong 2016) (Michael Knig and Roger Wattenhofer 2016) (Chun-Hao Liao et al 2016) (Dingwen Yuan and Matthias Hollick 2013)	**IEEE802.15.4 Zigbee**
(Hariharan Rahul, Haitham Hassanieh, and Dina Katabi 2010) and Qui (Hang Qiu et al 2016).		**WiFi IEEE802.11b/g**

Table 1: *CXMSN Related work.*

CONCLUSION

Despite its vast natural resources, Sudan has low electrification rate in both urban and rural areas due to structural, political and technological factors. Only 53.8% of the country's population has access to electricity. This impacts major economic sectors and industries. It also impacts people's quality of life as lack of electricity hinders access to quality healthcare, food safety, education, and access to technology and communications.

Not only is addressing the lack of access to electricity, especially for marginalized populations in Sudan important in its own right. This also enables the country to meet its commitments under the Sustainable Development Goals, and under the legally binding *Paris Agreement - UN Framework Convention on Climate Change.* An important strategy to build the electricity sector and infrastructure as a way of empowering all people of Sudan as stated in the *Declaration of Appropriate Technology*, is to introduce Smart Grid technology. Smart Grid ensures low-cost electricity generation and thus a low-cost electricity tariff, because it facilitates remote monitoring and control of the production of electricity. This technology also enables consumer investment in energy generation and contributes to halting *Climate Change*.

In short, using wireless technology (Wi-Fi) ensures affordability, and ease of deployment and upgrade. This paper is based on technical analysis to make the case for using Smart Grid in Sudan. The main contribution involves addressing challenges that might arise when using Smart Grid. Research has shown that state-of-the-art Wi-Fi does not conform to the low-latency requirements in faulty scenarios in Wi-Fi due to the high losses (22%) at a data rate of 15 Mbps, and the high latency (more than 3 ms) for data rates greater than 15 Mbps. Even when 5 GHz band is used, the latency increases at the presence of 30Mbps background traffic. Experiments that the author conducted has shown that low-latency techniques like Concurrent Transmission, enhance the reception of the received frames by utilizing coarsely synchronized forwarders. The superposition of the forwarded signals increases the amplitude of the received signal

leading to high reception rate. Concurrent Transmission enhances the reception in the case of DSSS (98%) while OFDM suffers from low reception rates due to Frequency Offset.

Through modelling, this research has identified the factors that limits Concurrent Transmission. This was followed by practical validation using Atheros AR928 commercial devices. The practical validation perfectly matches the analytical results. Implementing this research thus contributes to the development of electricity sector in Sudan and beyond, mainly through deploying efficient wireless technologies in Smart Grids. Challenges expected include the cost of renewable energy generation, transmission and distribution by exempting required equipment from customs and fees. This should include telecommunications and control equipment. Further, mobilization of the National Energy Strategy accompanied by policy reforms requires a democratic system. So is linking Sudan with sources of international funding dedicated to renewable energy in Africa and beyond. Since energy generation in Smart Grid is intermitted and decentralized, capacity building on several levels is required. This involves training of personnel, engineers and non-engineers on the political, technical and the financial aspects of Smart Grid, and a cost-benefit analysis that encourages investment in small businesses.

ACKNOWLEDGEMENT

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CONSTRUCTION AND INFRASTRUCTURE

|

CITIES AND SPACES

PAPERS

EXPERIMENTAL ASSESSMENT OF FABRIC-REINFORCED CEMENTITIOUS MORTAR (FRCM) MECHANICAL PERFORMANCES

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Abstract

This paper examines the main characteristics (i.e., tensile and bonding behavior) of Fabric-Reinforced Cementitious Matrix (FRCM) systems composed of glass fabric and cementitious mortar. Two types of glass fabric samples 250 and 550 and two cementitious mortars (lime-based ordinary and polymer-enriched mortars) were used to create four FRCM systems. Then the results of using the two kinds of cementitious mortar were compared with drawing the conclusions on the performance of the different tested systems. Bonding tests for each FRCM system were performed on two types of masonry panels, Red and clay (Tuff) bricks. The two masonry panel types are commonly used in northern and southern Italy, respectively. Uniaxial tensile tests were performed to investigate the mechanical characteristics and failure modes. The results of this study form a basis for tensile and bond characterization, such as ultimate stress, ultimate strain, conventional limit strength and strain, and the tensile modulus of elasticity, of FRCM systems and present background data for future studies on FRCM systems.

Keywords: Tensile Test, Bonding Test, Mechanical Characteristics, Failure Modes, Masonry Structures.

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UTILIZING OF PLASTIC WASTE INTO MANUFACTURING OF PAVER TILES

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Abstract

Using innovative technologies to transform environmental problems into creative solutions have been highly demanded in the construction sector. In this research an experimental test conducted to investigate compressive strength and water absorption characteristics for interlocking paver tiles, that manufactured by using plastic waste as a bonding agent instead of cement. The main objective of the study is to support infrastructure projects with a low-cost material beside of contributing in environmental aspects. The test conducted on six samples produced by using mix of (1:2) plastic waste (medium density) to Sand. Plastic waste prepared in small pieces and subjected to heating temperatures to be melted well then sand added gradually with mixing until consistent mortar formed, therefore casted on a standard mold. The Test showed that the average compressive strength was 19 Mega Pascal, which can be used in light weight areas. The study also investigated that the water absorption resistant less than 1% which was better than concrete conventional paver tiles.

Keywords: Plastic Waste, Interlocking, Paver Tiles.

INTRODUCTION

Plastic containers have been widely used to carry different materials, wherefore the percentage of plastic waste that have randomly thrown into the environment is very large, especially in poor countries that cannot concern with criteria of safe environment. Since the decomposition of plastic material naturally stays for long periods, and causes severe damage to animal's health, which in turn is reflected on humans, it has become necessary to treat or recycle this waste in various industrial product such as the manufacture of paver block tiles, which are used in squares, streets sidewalks, gardens, and other. Many researchers conducted huge efforts in this vital research field by mixing plastic wastes with other materials to produce interlocking tiles. The composite material which is the plastic waste as an essential component is subject to important tests to be an alternative building material for the cement products currently used. This research aims concerned with conducting a test of compressive resistance and water absorption, laboratory. Moreover, the sidewalks are subjected to more pressure there for thickness of the brick depends upon design load.

Research significance is transferring a randomly thrown plastic waste into the durable building materials to be used as interlocking pavers, especially in Khartoum, Sudan which was affected with popular protests that led to destroying impacted interlocks in the main streets, the study contributes to two areas, either environmental issues in term of plastic waste disposal, or providing new building materials for pavements.

PREVIOUS STUDIES

Researches in the field of recycling plastic waste are many nowadays. Mohan D. M. S. *et. al*, (2018), conducted experimental research in reuse of plastic waste to produce paver block tiles

by study some characteristics in order to obtain a lowest cost and most economical floors, where the compressive strength test result was close to conventional cement pavers, in addition to reduce weight around 15%. Arjun et. al (2019) also conducted a laboratory study in samples of pavement blocks manufactured by mixing plastic waste, lime sludge and sand, to reduce the cost when compared with concrete paving tiles. The study investigated that the resistance of water absorption was greater than recommended in most global standards, which was appropriate with road side walks. In addition to that the compressive strength test showed a less value than the alternative concrete block. In this context B., Shanmugavalli *et al*. (2017) used plastic waste with quarry dust, coarse aggregate and crushed ceramic waste in order to produce low-cost paver block. When four materials had mixed, the product presented good result, in addition to good fire resistance. The study concluded that the compressive strength was lower than concrete paving tiles, which can be suitable for streets sidewalks paths and light weight subjected areas such as gardens. In similar study, Apoorv T. et al. (2019) used, coarse aggregates, quarry dust, plastic chips, and plastic granules, the research showed when 20 percent of plastic waste was used in the mix, it would have presented an optimal value, however, the results under the required strength that must be compared with alternative. Owolabi W. and Amadi AN. (2020) conducted a laboratory test on the pavement mass produced by melting waste plastic (LDPE) at temperatures ranging from 180°C - 250°C in a closed system, then mixing it with granite dust in different proportions (50:50, 40:60, 30:70) in the first, then used sand instead of granite dust and clay lastly. The same mold was also used to produce cement paving blocks to comparing the properties. The compressive strength, water absorption, abrasion resistance and fire resistance tests on samples, where the results carried out that the paving blocks produced from plastic are more solid, durable, heat and abrasion resistant compared to the paving blocks produced from conventional cement. Pooja B. et al. (2019) studied on samples produced using a low-density plastic waste (LDPE)and fine sand with a mixing ratio of (1:3), where the test curried out that the compressive and tensile strength was (8.18), (1.26 - 3.15) Mega Pascal (Mpa), respectively. However, in a study by Aadity J. *et al*. (2018), used mixing ratios (1:1, 1:2, 1:3, and 1:4) for high-density plastic to find sand, where the compressive strength reached (11.5) MPa for a mixing ratio of (1:3) as an ideal value. Based on the foregoing in this research, we follow a simple experimental test to determine the cost and properties of an interlocking paver tiles to compare results as alternative cement-based product.

RESEARCH METHODOLOGY

The study based on an experimental laboratory test to investigate the properties of the interlocking paver product, where the components of the basic mixture from fine sand and high-density plastic waste weighed according to the proportions of (1: 2), the quantity of plastic waste is placed in a circular container which is a top vented. Moreover, that container attempt to the temperature for melting plastic around (100-180)℃, when the plastic material formed in a liquid mortar, sand gradually poured with genteelly mixing to obtains a consistency mortar, then mortar pour into the standard interlock mold, to obtain the studied sample which can be tested.

The study also based on the requirements of the British standard BS 1338-97, for sidewalks pavers, although it depends on cement tiles as a material, but it taken to account, so the studied model was built according to these standards in term of compressive strength and water absorption resistance only.

Research Place

All samples prepared at Al-Shajara Industrial Complex Khartoum Sudan. The tests conducted in Constructional and Environmental Laboratories Center, Khartoum, Sudan. The state of Khartoum has high population, wherefore the percentage of plastic wastes is very large, which are thrown directly on roads and squares. Wastes isolation exist but in a limited extent. The amount of plastic wastes in Sudan around (50,000) tons per year (2021). Therefore, the importance of this study is to achieve the environmental requirements that related to the disposal of these wastes.

Materials and Source

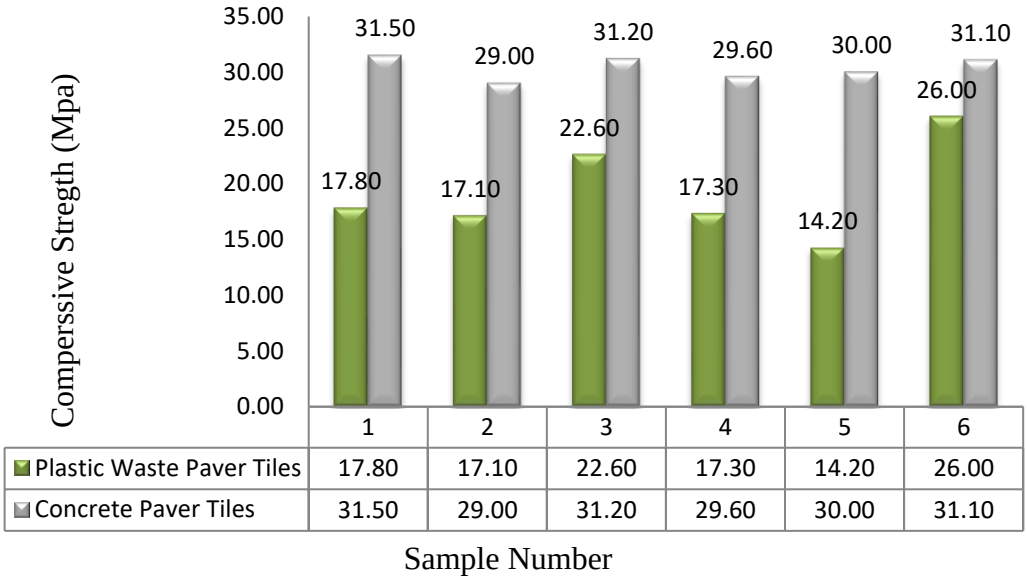
Firstly; Plastic waste materials (low, medium and high density) sourced by collecting from roads and open areas water bottles, bags, etc. Moreover, some factories waste, which must be well prepared, by crushing in small pieces. Whereas some types of plastic, such as PVC products must be excluded. Secondly; Sand existing in Sudan's valleys is in a wide scale, where the white sand called Al-Qetina sand (a valley located in the south of Khartoum city) which was used in this study. It is also widely used in the produce concrete interlocking block.

LABORATORY TESTS RESULTS AND DISCUSSION

Quality of paving tiles are measured according to the compressive strength test that by subjecting on the sample direct loading gradually until collapse (Figure 1 and Figure 2), according to the British Code (BS 6717) for concrete interlock tiles. The same test conducted for the considered samples, beside calculation of the Water absorption (Figure 3) by immersing the product for a week and measuring the weight difference, this method used based on paver standards recommendations. The test conducted for both concrete and plastic waste pavers with a thickness of 6 cm, for all.

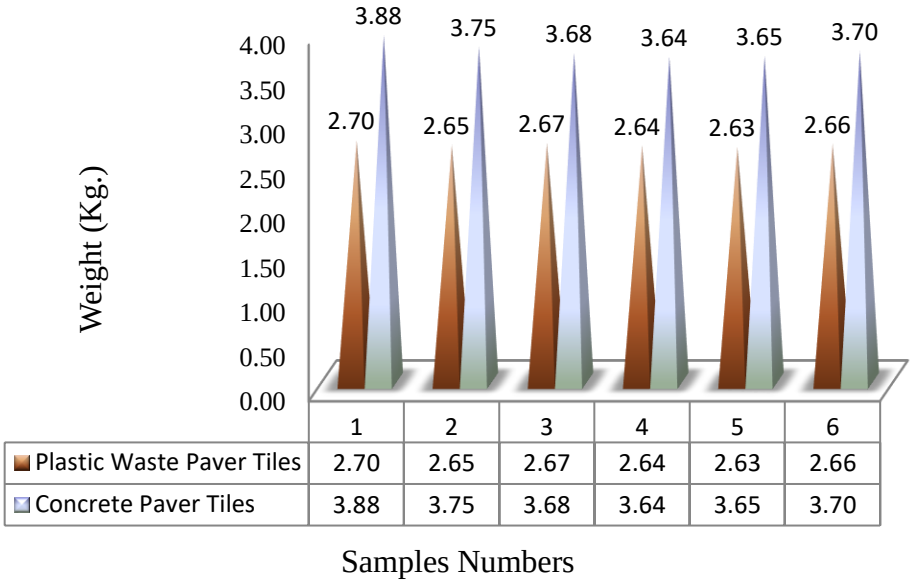
(a) Tested sample on Compressive machine. (b) Mode of failure.

Figure 1: *Test setup of Plastic samples.*



	1	2	3	4	5	6
Plastic Waste Paver Tiles	17.80	17.10	22.60	17.30	14.20	26.00
Concrete Paver Tiles	31.50	29.00	31.20	29.60	30.00	31.10

Figure 2: *Chart for plastic paver sample compressive strength with concrete interlocking tiles.*



	1	2	3	4	5	6
Plastic Waste Paver Tiles	2.70	2.65	2.67	2.64	2.63	2.66
Concrete Paver Tiles	3.88	3.75	3.68	3.64	3.65	3.70

Figure 3: *Chart for weight of plastic paver sample compared with concrete interlocking tiles.*

The compressive strength result of considered samples as illustrated on the Table (1) and Table (2), for plastic wastes indicate much more differences, when compared between the lowest value (14.2 MPa) and highest (26.0 N/mm2). Where the maximum recorded value in the concrete interlocking pavers test was (31.5 N/mm2), Figure (1). But concrete samples shown close values.

Water absorption test found that the plastic samples was a high resistant to absorb water, according to the BS 1388. Refereeing to the results, the average was 1%.

SAMPLE NUMBER	WEIGHT (kg)	DENSITY (kg/cm^3)	COMPERSSIVE STRENGTH (N/mm^2)
B01	2.70	1.85	17.80
B02	2.65	1.82	17.10
B03	2.67	1.83	22.60
B04	2.64	1.81	17.30
B05	2.63	1.81	14.20
B06	2.66	1.83	26.00
Average	**2.66**	**1.83**	**19**

Table 1: *Plastic waste paver sample Compressive strength test.*

SAMPLE NUMBER	WEIGHT (kg)	COMPERSSIVE STRENGTH (N/mm^2)
C01	3.88	31.50
C02	3.75	29.00
C03	3.68	31.20
C04	3.64	29.60
C05	3.65	30.00
C06	3.70	31.10
Average	**3.72**	**30**

Table 2: *Concrete paver sample Compressive strength test.*

CONCLUSION

Based on laboratory tests showed in the present study, it can be used plastic waste to manufacturing interlocking paver tiles, in term of the design compressive strength less than 19 MPa, whereas is recommended in corridors, road islands and gardens, however the water absorption was low and therefore, it appropriates in intensive rain fallen places. The study concludes that the product is low weight when compared with concrete paver, which was decreased around 50%. Eventually, the study recommends that using different ratios to increase strength, in addition to conducting more durability studies such as abrasion, tensile strength and elasticity limit.

ACKNOWLEDGEMENTS

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THE EFFECT OF USING CEMENT DUST ON THE PROPERTIES OF MORTAR AND CONCRETE

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ABSTRACT
This study was conducted to examine cement kiln dust (CKD), which comes as a by-product from the cement industry, as it is considered one of the most solid industrial wastes in the world. Industrial waste management is considered one of the most important axes of sustainable development goals (SDGs), and extensive studies are being carried out on the possibility of recycling it to reduce its quantities and the side effects resulting. The chemical and physical properties of cement dust were studied and presented. Thus, cement mortar and concrete cubes were prepared with 0%, 30% and 40% CKD, replacing the Ordinary Portland cement in the mixes. The compressive strength test was done according to the ASTM codes, and through the experimental results of the study, 30% was taken as an optimal percentage.

Keywords: Cement Kiln Dust, SDGs, Concrete, Mortar, Compressive Strength.

INTRODUCTION

The cement industry is one of the most important industries in the world and can be considered the basis of urban progress and development. Cement plays a major role in all areas of construction as a primary or secondary component alike. Cement is one of the most important components of reinforced concrete structures. Concrete is one of the most consumed materials in the world, estimated at about 31 Gton/year in 2006 and cement consumption was estimated by 4 Gton/year (Najim, Mahmod, and Atea 2014). Cement industry is arguably regarded as the second largest producer of the greenhouse gases that cause global warming phenomenon, which contributes by (5–8) % of the worldwide CO_2 emissions. These numbers are in a steady increase in proportion to the large increase in the number of population and the growth of civilization and development in the field of infrastructure (Najim, Mahmod, and Atea 2014).

Recently, there has been a huge increase in the number of cement factories all over the world, especially in the third world countries. This steady increase in the number of cement factories has led to the emergence of many wastes resulting from the cement industry in a large and noticeable way. These wastes must be disposed of in a scientific and correct manner in order to ensure societal, environmental and professional safety and be recycled as much as possible to benefit from them as secondary income besides the cement industry.

One of the most important of these residues is cement kiln dust (CKD) or cement bypass dust. It is considered one of the largest industrial wastes in the world, due to the large increase in the cement industry. CKD is produced and controlled using specific techniques in advanced factories, but most ordinary cement factories do not have these technologies that help reduce the emission of this dust. Therefore, it is used in many fields such as: Soil stabilization, paving layers, sewage treatment and its use in the manufacture of concrete products. CKD contains high percentages of alkalis, sulfates and chlorides. These materials must be studied with great accuracy and their effect and percentages of presence in order to ensure the safety of using

CKD in all industries, especially recycling it for use again in the cement industry, which in turn will save huge amounts of raw materials.

Research significance

Achieving sustainable development goals by eliminating huge amounts of cement dust emitted from factories, which in turn will help in the following aspects:

- Recycling and using industrial waste as organic fertilizer.
- Environmental health and safety of communities
- Occupational Health and Safety.
- Providing great job opportunities.
- One of the most economic inputs for countries due to the huge quantities of cement produced and the dust emitted from it.

Research problem

Cement production is very large, which has led to the emergence of many problems, including the emission of harmful gases and solid waste, which in turn have a negative and very harmful effect on the environment and the human race in the short and long term alike. Solving the problem of these emissions will achieve many sustainable development goals. Examples of these wastes are carbon dioxide and cement dust, and the latter is considered one of the most solid industrial wastes around the world. Cement dust contains many harmful substances, and the biggest problem lies in the huge quantities in its production due to the reasons mentioned above. The biggest challenge is controlling the extraction of dust, containing it, and then recycling it in a scientifically correct way and using advanced technologies. Because dust contains high levels of alkalis, chlorides and many other substances that can have a negative effect, as it limits the use of dust in many industries, there is a need to conduct extensive studies on dust to know its chemical and physical properties and the impact of its use in the cement industry and its use in cement paste, reinforce concrete and many other industries.

Research questions

There are many questions that can be answered during investigation of this study as follows:

- Is the cement dust being a waste material?
- Does the recycling of cement dust can be useful in different manner?
- What are the chemical and physical properties of the dust?
- What is the best replacement ratio of the cement dust that can give a good result in enhancing the compressive strength and other properties that govern of using the dust?

LITERATURE REVIEW

Cement

Cement, in general, adhesive substances of all kinds, but, in a narrower sense, the binding materials used in building and civil engineering construction. Cements of this kind are finely ground powders that, when mixed with water, set to a hard mass. Setting and hardening result from hydration, which is a chemical combination of the cement compounds with water that yields submicroscopic crystals or a gel-like material with a high surface area. Because of their hydrating properties, constructional cements, which will even set and harden under water, are often called hydraulic cements. Cements may be used alone (i.e., “neat,” as grouting materials), but the normal use is in mortar and concrete in which the cement is mixed with inert material known as aggregate (Mason, Thomas O. and Lea n.d.).

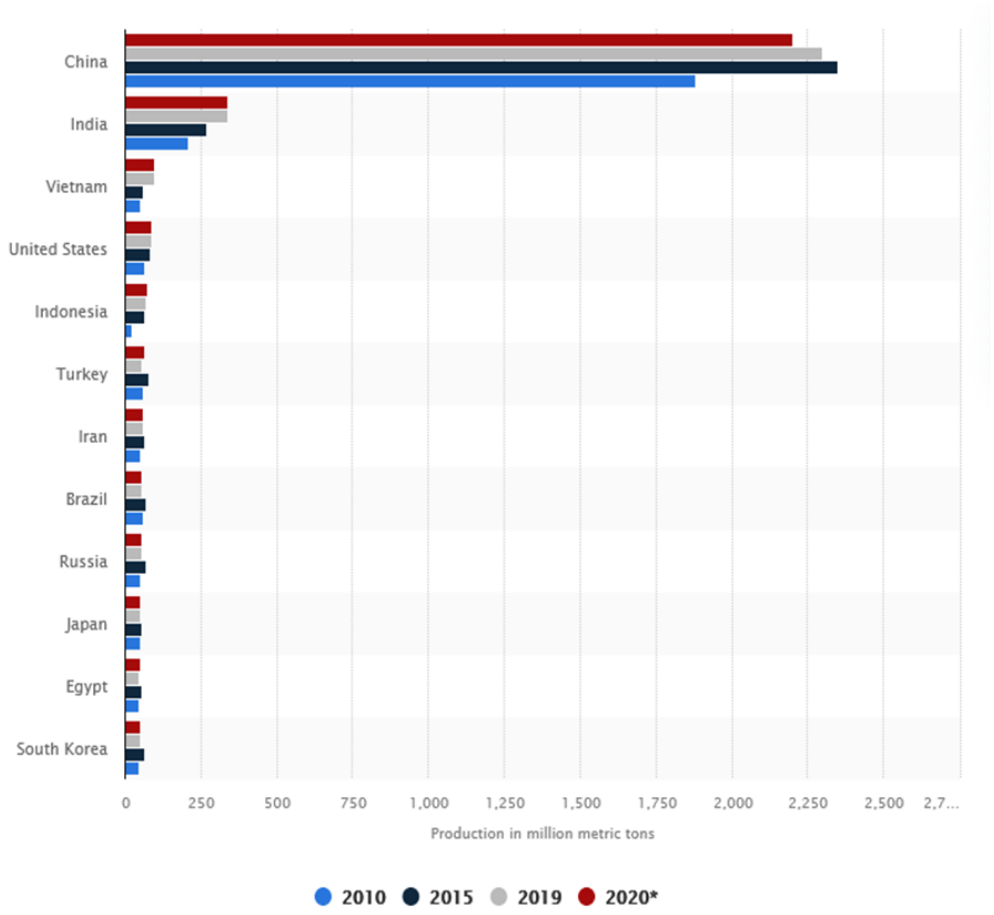

Figure 1: *Major countries in worldwide cement production from 2010 to 2020.*

Concrete

Concrete is one of the most versatile and widely-used construction material one earth, it's strong durable, low maintenance, fire resistance and it's cheap. Above all that and despite of the simple materials that concrete is made of born the basis of the entire world's infrastructure. From skyscraper to the canons and everything in between. It can be literally the foundation of our modern society.

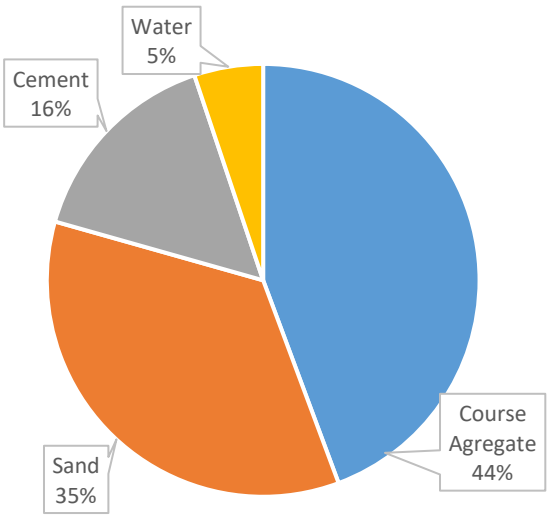

Figure 2: *Concrete Components*

The Environmental Impact of Cement and Concrete

Concrete material that creates the majority of the world's bridges, roads, dams, and construction, concrete releases an extreme amount of CO_2 each year. It's the highest consumed product on earth besides water. Until the overall emissions are cut worldwide, the environment will continue to be polluted with over 4 billion tons of carbon dioxide annually due to this industry. That process releases nearly no carbon emissions, the cement is the true problem when it comes to carbon footprint. The cement process is sole reason why the concrete industry makes up 8% of overall global emissions. Concrete is counted as one of the mostly consumed construction materials where it is estimated by 31 Gt/year in 2006 Cement consumption was estimated by 4 Gt/year (Najim, Mahmod, and Atea 2014). The cement sector is the third largest industrial source of pollution, emitting more than 500,000 tons per year of sulfur dioxide, nitrogen oxide, and carbon monoxide and cement kiln dust. Production of one ton of cement, which is the main component of the concrete, releases about one ton of CO_2 and uses natural resources such as lime stone and clay.

Industrial waste material in cement manufacturing

As mentioned previously, from the figures and facts about the cement industry, taking into account the huge quantities consumed, whether of cement or concrete, there was a need to conduct extensive studies on the wastes resulting from the cement industry, to determine their quantities, and to study their impact on humans, the environment, and even cement factories. There are still various wastes produced from its production that require more attention to get rid of it or try to reuse it in a safe way. The cement factories dispose of more than eleven million tons'/year solid waste and produce more than 1.3 million tons'/year wastewater (Hasaballah et al. 2021).These materials are not recycled or reused in industry as raw materials or synthetic fuels and most of them are disposed of in a landfill. Uncontrollable disposal of these pollutants increases environmental pollution problems. The most important material disposed of in these materials is Cement kiln dust (CKD) (Hasaballah et al. 2021).

Cement Kiln Dust (CKD)

It is defined as a fine-grained, solid, highly alkaline by-product waste material (K_2O and Na_2O). The particles diameter ranges between few µm and 50 µm removed from cement kiln exhaust gas by air pollution control devices, as shown in Figure 3. CKD forms in cement plants during the manufacturing process when the kiln's temperature is ranging between 800 and 1000C°(Najim, Mahmod, and Atea 2014). CKD is different from plant to another, based on the fed materials. (CKD) collected at the out let of cement kiln gases by fabric filters or electrostatic precipitator and it has pozzolanic properties (Bagheri et al. 2020).

Figure 3: *Sample of Kiln Dust.*

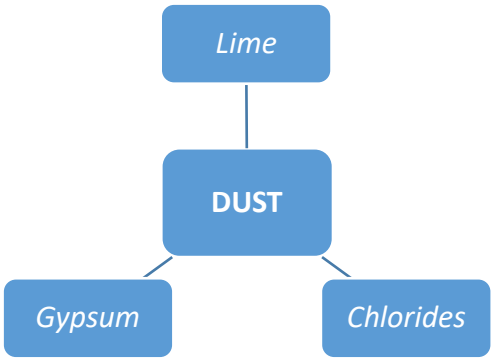

Figure 4: *Cement Dust Components.*

A significant amount of CKD is produced by factories per year. In the United States in 2000, with a survey of 92 factories, the production of this material from 68 million tons of raw clinker was about two million tons. In general, the amount of CKD resulting from the cement production process is about 15 – 20% of cement clinker, whose approximate production until 2012 was about 680 million tons. Approximately 15 million tons of CKD are produced annually by the American Cement Industry (Al-Harthy, Taha, and Al-Maamary 2003).

Sustainable development goals

Recycling cement dust

Waste material recycling into useful products has become a main solution to waste disposal problems. Major environmental problems arise from the disposal of kiln dust. This dust production is not only unpleasant for the worker, but also equipment failures, decrease efficiency and produce maintenance problems.

Very few research works have been published on the use of CKD in concrete and mortar mixtures. With the increasing need to recycle industrial by-products and to protect the environment, there is a growing need to provide technical data about the performance of concrete and mortars containing CKD. This study investigated the potential benefits of using CKD in concrete and mortar. This was achieved by studying its effects on the strength of concrete and on the permeability characteristics of mortars.

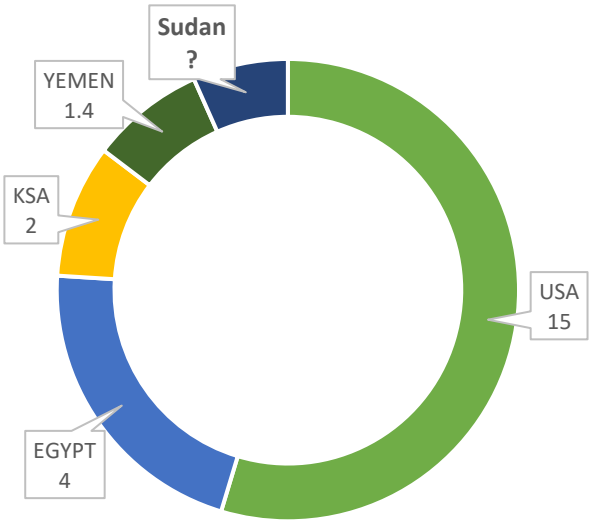

Figure 5: *Annually amount of Cement Dust [Million Tons].*

In a UK study, it was reported that over 200,000 tons of landfill space could be saved if CKD could be recycled or if alternative uses could be found (Hasaballah et al. 2021). Environmental issues are a major concern of all industries and ready mixed concrete is no exception. Emissions of cement dust are strictly controlled by the use of dust-extraction systems in loading areas, cement silo filter systems, restrictions on powder-blowing pressures and the provision of high-level silo alarm systems (Crompton 2003).

Green Concrete

Although concrete has advantages over other building materials, the negative effects of its use on the environment increased the respective concerns. Therefore, implementation of sustainable/green technologies in the concrete de sign and production can significantly solve these problems.

"***Green concrete***" issued for concrete produced and used with environmentally friendly methods**,** in fact, the use of alternative/ green materials in concrete to replace Portland cement and natural aggregates can reduce these negative impacts. In addition, the uses of industrial waste as a cement substitute would be followed by a dual environ- mental advantage. The contribution of concrete to sustainable development can be attributed to the optimization of its constituents such as cement, aggregate, and even water and their effect on the concrete proper ties over the structure life. In addition, decrease in the amount of the cement clinker has positive effects on the environmental life cycle of concrete (Bagheri et al. 2020). Most CKDs tend to generate relatively high pH levels when mixed with water. The higher alkalinity and finer particle size, in addition to their (sometimes) cementitious properties, make these materials usable for several applications:

- Waste solidification.
- Replacement of Portland cement in concrete block.
- Manufacturing and ready-mix concrete.
- Construction of hydraulic barriers in landfill liner/cover applications.
- Use as agricultural soil amendments.
- Flowable fills.
- Mineral fillers in asphalt paving.
- Mine reclamation operations.

Cement kiln dust as a replacement material to Portland cement

The use of industrial plant wastes such as cement kiln dust (CKD) is an optimal solution to improve some of the fresh and hardened properties of concrete and also from an economic perspective to reduce the construction costs and reduce cement consumption(Bagheri et al. 2020). CKD was introduced back into the clinker-making cycle as a raw material with modern manufacturing techniques. However, the restrictions on the alkali and chloride contents in the cement make it a difficult process (Hasaballah et al. 2021). The reason has been attributed to the presence of excess alkali contents in raw CKD. Because of its high total lime content, CKD can also be used in lieu of lime for soil stabilization. It can also be used for neutralization or pH control of agricultural soils (Al-Harthy, Taha, and Al-Maamary 2003).

The most significant and useful applications of CKD have been reported in soil consolidation, soil stabilization, cement replacement, and sidewalks(Bagheri et al. 2020).CKD is a rich source of calcium, which is mainly used to supplement silica and alumina compounds such as Class F fly ash (FA). In fact, in this system, aluminum gel replaces calcium aluminate silicate hydroxide, which can form a strong bond with high calcium/ alumina and low magnesium. The

presence of such a calcium – rich binder (CKD/ FA) in cementitious mixtures can result in improved strength and high bonding(Bagheri et al. 2020).

EXPERIMENTAL PROCEDURE

Materials

In this research, ordinary Portland cement, which is produced locally, was used due to the lack of cement dust in Sudan as mentioned previously. Cement dust was brought from the Republic of Egypt to conduct this study. Cement dust was used as a substitute material in the mixture for both mortar and concrete samples. Table 1; shows the chemical analysis of cement dust, sieves analysis and Atterberg limits test were done, which were presented in Table 2.

Material	**Oxide (%)**									
	SiO_2	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O	Al_2O_3	Cl^-	L.O.I (Loss on ignition)
CKD	11	2.25	46.5	1.4	4.7	2.85	2.1	3.6	4.2	14

Table 1: *Chemical composition of CKD.*

Sample Description	Sieve Analysis			Atterberg Limits		Remarks
	0.6	***0.3***	***0.075***			
Cement Dust	100	99.8	96.4	NP	NP	-
Specifications	100	95	70			-
	100	100	100		Max 4	-

Table 2: *Sieve Analysis & Atterberg Limits FOR CKD.*

Mixture proportions

(1) Mortar

Mix A (0% CKD); This mix is the control one. It contains Portland cement, sand and water.
Mix B (30% CKD); This mixture where prepared using 30% of CKD replacement by total volume of cement
Mix C (40% CKD); This mixture where prepared using 40% of CKD replacement by total volume of cement
The cube strength obtained for all mortar mixtures are shown in Table 3. Each mixture has three cubes (50 X50X50mm) were prepared for compressive strength test.

(2) Concrete

Mix A; This mix is the control one. It contains Portland cement, coarse aggregate, sand and water.
Mix B; This mixture where prepared using 30% of CKD replacement by total volume of cement
Mix C; This mixture where prepared using 40% of CKD replacement by total volume of cement.

The cube strength obtained for all mortar mixtures are shown in Table 3. Each mixture has three cubes (150 X150X150mm) were prepared for compressive strength test.

Series	Mix ID	Load (KN)	Compressive strength (MPa)	Cube weight (gm)	Cube density (gm/cm^3)
Mortar 50x50 mm	0% CKD	61.36	24.57	288.76	2.313
	30% CKD	63.48	25.4	288	2.304
	40% CKD	55.82	22.3	284	2.272
Concrete 150x150 mm	0% CKD	451.9	20.1	8204	2.430
	30% CKD	594.6	26.17	8287	2.455
	40% CKD	495.2	22	8088.67	2.397

Table 3: *Cube strength, average weight and density at age of 28 days.*

RESULTS AND DISCUSSION

Compressive strength development

It is noticeable from the results and tables that the addition of cement dust does not have a negative effect on the compressive strength values.

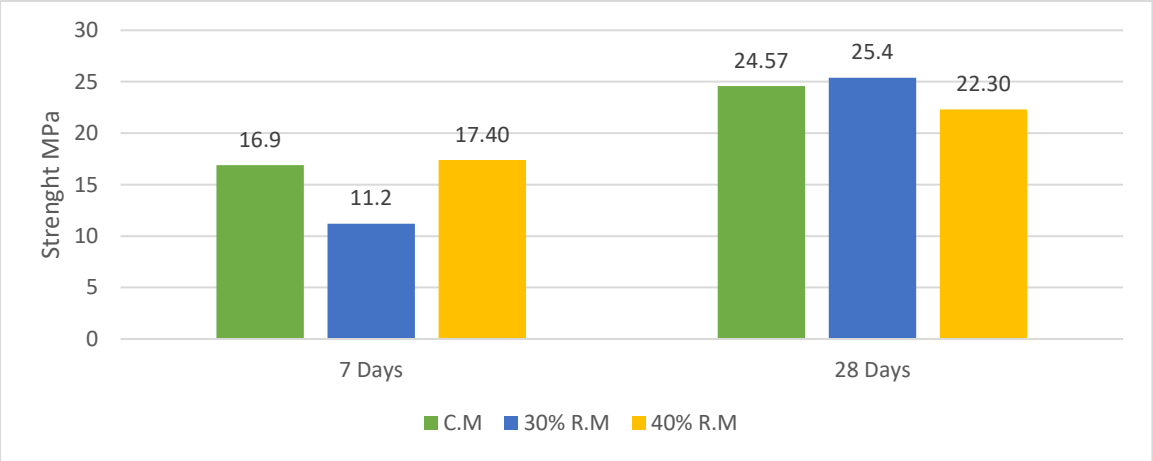

Figure 6: *Compressive strength development for Mortar.*

As for the mixture **B** (30% CKD), the change in the compressive strength values is observed after 28 days. This change is almost equal to the reference mixture, but the positive side here lies in reducing the amount of cement in the mixture (mortar and concrete), which in turn is a great economic benefit when looking at these numbers on huge projects. It is noticeable from the results and tables that the addition of cement dust does not have a negative effect on the compressive strength values.

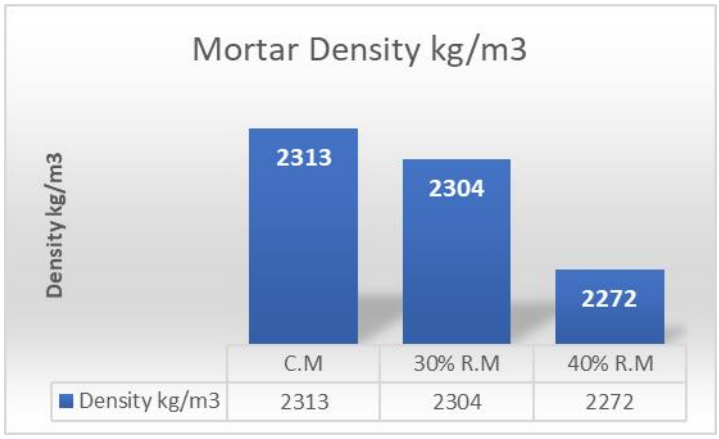

Figure 7: *Density development for Mortar.*

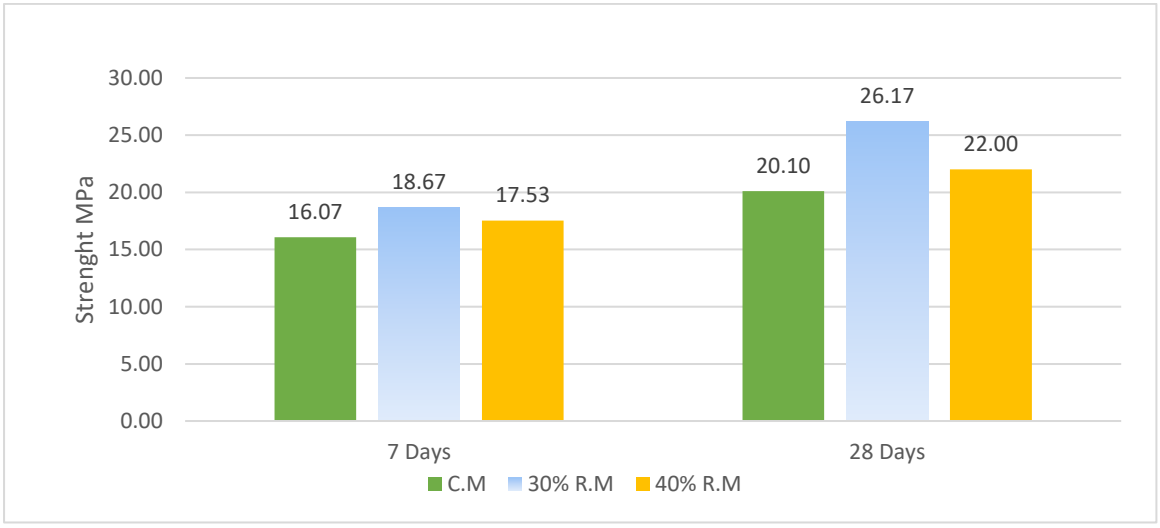

Figure 8: *Compressive strength development for concrete.*

Looking at the environmental aspect also, these figures are a clear indication of the reduction in the values of cement used in mortar and concrete mixtures, which in turn is also reflected in the rates of cement production globally and thus achieving one of the goals of sustainable development. It is also noted that the use of cement dust gives relatively higher compressive strength values for concrete, unlike mortar. Thus, after looking at the values, it was found that the use of 30% gives higher results, and the compressive strength values decrease automatically with an increase in the proportion of dust as it appears on mixture **C.**

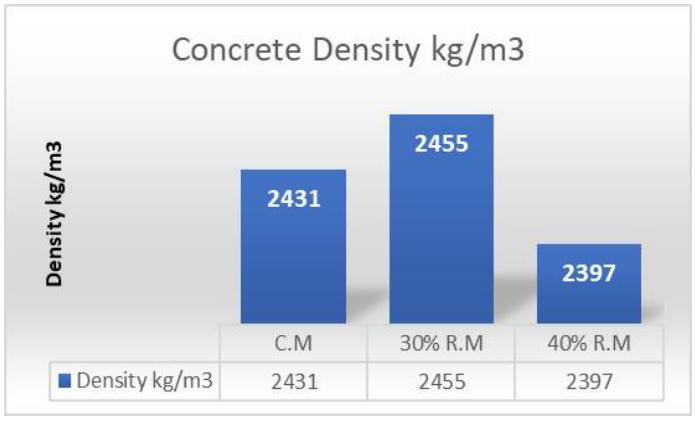

Figure 9: *Density development for concrete.*

CONCLUSIONS AND RECOMMENDATIONS

- There is a gap in the cement dust studies. Consequently, we recommend conducting intensive workshops based on intensive studies on how cement dust can be utilized in engineering in general and civil engineering in particular.
- During this study, cement dust in the concrete mix and mortar mix made a noticeable and effective difference in compressive strength development when 30% of the cement was replaced by cement dust.
- However, the use of cement dust could be one of the future solutions. This lies in reducing the cost of constructing concrete buildings as a whole and also in the cost of all concrete products
- Generally, the goal is to reduce harmful emissions from the cement industry. In addition, it is imperative to limit the spread of cement dust in the air without benefiting from it.

ACKNOWLEDGEMENTS

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DESIGN OF PASSENGER CARS ASSEMBLY FACTORY IN NORTH OF KHARTOUM USING BUILDING INFORMATION MODELLING (BIM)

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Abstract
Building Information Modelling (BIM) is widely accepted as an efficient tool for construction projects. However, its use in Sudan is still pre-mature and considered at level 1 on the scale of BIM maturity. Thus, this research aims at studying associated aspects of implementing BIM principles in a typical design case in the North of Khartoum. The case study is an existing cars-assembly factory. Using BIM in this project included the planning and design phases, covering 3D, 4D, and 5D BIM dimensions. The third dimension (3D BIM) is the modelling of the architectural and structural elements. Autodesk Revit for architectural and structural modelling, Autodesk Robot Structural Analysis for structural design, and Autodesk Advance Steel for connection design and detailing were used to enable this part. The fourth dimension (4D BIM) represents construction sequencing, for which Autodesk Navisworks was used for time simulation in conjunction with Oracle Primavera P6 to incorporate the project schedule into the simulation. Navisworks was also used for the federation of architectural, structural and MEP (mechanical, electrical, and plumbing) local models into one integrated model, which allowed for detecting clashes between these disciplines and upgraded the process into BIM Level 2. While quantity take-off and cost are the fifth dimension (5D BIM) in which Autodesk Navisworks was also used. Then, a comparison was carried out between the typical industry practice, seen as BIM Level 1, and the implemented approach, considered as BIM Level 2 in terms of time, effort, and cost. The study found that BIM has significantly reduced the spent time and effort on coordinating design between various disciplines, and proved the possibility of implementing BIM Level 2 successfully. It also provided deeper insights into aspects related mainly to the Sudan construction industry.

Keywords: Building Information Modelling, Structural Analysis, Clash Detection, Time Simulation, Quantity Take-Off.

INTRODUCTION

Building Information Modelling or BIM is digitally transforming the construction industry all over the world. BIM adoption is getting well underway worldwide and its use is quickly becoming the norm. Even though BIM adoption varies by country, many stakeholders in the field of construction in many countries are either using BIM or considering its use. BIM delivers numerous benefits and increases the profitability of construction projects (especially large projects) by improving productivity and avoiding errors, time delays, and extra costs.

Sudan's construction industry is improving slowly; it is hindered by a lack of technologies, as conventional methods prevail, while projects suffer from poor productivity and a low level of coordination between relevant engineering disciplines. Furthermore, many external factors, such as market instability, economic status, and the state of the government, have an impact on

the construction industry. These factors have an impact on the deliverables of a construction project in terms of time, cost, and quality.

Even though BIM is becoming more recognized and used in the field of construction in Sudan, its level of maturity in most construction companies is Level 1 (Ibrahim and Abdelatif 2020). Most small firms in Sudan are unaware of BIM and continue to use CAD only, and some do not use technology at all. Furthermore, there are some misconceptions about BIM such as 'BIM is merely using 3D models' and 'BIM is solely for designers' and not for other disciplines in construction.

As a result, the purpose of this research is to encourage and promote proper BIM adoption in Sudan, as well as to correct the misconceptions concerning BIM through a BIM implementation approach to a case study of an industrial building in North Khartoum, Sudan. Furthermore, the study emphasizes the structural design.

RELATED STUDIES

Definition of BIM

There are many definitions of BIM, but they all agree that BIM is a digital process of creating a model of a building with its associated information. PAS 1192-2:20131 defines BIM as the "process of designing, constructing or operating a building or infrastructure asset using electronic object-oriented information".

BIM is not a piece of software, nor a 3D model in isolation; BIM is a process. "It is a process, not a single technology solution or software. In fact, it is a collaborative process enabled by technology". (The Institution of Structural Engineers BIM Panel 2021).

BIM covers the entire lifecycle of a project; it covers all project phases; "BIM supports feasibility, planning, design, construction, and operation stages of the project lifecycle" (The New Zealand BIM handbook 2019).

Dimensions of BIM

BIM is classified into dimensions depending on the information attributes added to the BIM model. Every dimension adds a layer of information to the model. BIM dimensions are primarily 3D, 4D, 5D, and 6D, corresponding to model, time, cost, and facility management. However, there is some uncertainty about them and there is no actual agreement beyond 5D.

The fourth dimension or 4D BIM is the addition of time or scheduling information to the model. This allows for the visualization of time schedules by creating animations of construction sequence. It provides a better understanding and planning of the project. It requires scheduling software as well as software that utilizes time simulation.

Linking cost information to the BIM model is 5D BIM. A BIM software can generate accurate quantity take-offs from a BIM model in a faster and more accurate process than a traditional bill of quantities, and if changes are made to the model, the generated quantities automatically adjust, making this a more effective approach.

Facility management or building lifecycle information is 6D. After completion of construction, the BIM model can be upgraded to an as-built model, and then operation and maintenance

information can be added to it to help in the facility management phase. In addition, 6D also utilizes space management, energy analysis, and lifecycle management. 6D BIM has some ongoing discussion about it and is sometimes known as sustainability. There is some confusion about the dimensions beyond 6D; they can be defined depending on what attributes are desired in a BIM model. Some consider safety as a BIM dimension; safety information can be added to help in safety planning and risk assessment.

BIM maturity levels

BIM implementation is categorized into four stages or levels, known as maturity levels (level 0 to level 3). Level 0 employs 2D CAD with paper or electronic exchange of information (no BIM). Level 1 is managed CAD, which can be a 2D or 3D model with information exchanged using a common data environment (CDE) but the models are not shared between designers (non-federated data). Level 1 is called 'Lonely BIM'.

Level 2 BIM is defined as "structured federated information models" which are distinguished by collaborative working; each party works on their data first, then exchanges their work using a common data environment to combine the data to create a federated BIM model. Level 2 BIM allows for the use of 4D and 5D, as well as clash detection, which is the detection of system conflicts between multiple disciplines in the federated model before construction or installation. BIM Level 2 enables collaboration and coordination of information through the use of a federated BIM model, which satisfies BIM. Some governments and private sectors are mandating the use of BIM Level 2 in construction projects. In 2016, the UK Government mandated Level 2 BIM on all public projects (The Institution of Structural Engineers BIM Panel 2021).

BIM level 3 is defined as "full collaboration between all disciplines by means of using a single, shared project model that is held in a centralized repository" (Sacks, Eastman, Lee, & Teicholz, 2018). This level is known as 'Open BIM' or 'Building Lifecycle Management' or 'Integrated Building Information Model' (also referred to as iBIM) as the models are server-based. Level 3 can utilize 6D, alongside 4D and 5D.

BIM maturity levels are represented in figure 1 sourced from the BIM Handbook (Sacks, et al. 2018). It shows the BIM maturity model by Mark Bew and Mervyn Richards, reproduced based on PAS 1192-2:2013 (BSI, 2013) and BS 1192-4:2014 (BSI, 2014a).

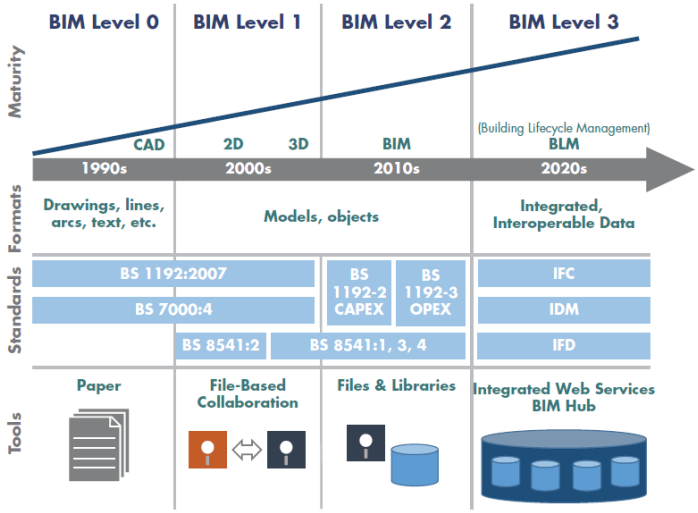


Figure 1: *The BIM maturity model by Mark Bew and Mervyn Richards.*

Level of development

The BIM model can progress from a preliminary design to an as-built model depending on the BIM Level of Development (LOD), which is a scale used to show the level of detail of the model elements; and it depends on BIM maturity level and level of information in the model. LODs aid in specifying what to author in the models at each stage of the project. Two plans defined stages for BIM LOD: American Institute of Architects (AIA) Schema (mostly used in the USA) offers six LODs ranging from LOD 100 (preliminary design) to LOD 500 (as built). The other plan is the Royal Institute of British Architects (RIBA) Digital Plan of Work (mostly used in the UK), which offers seven levels of LOD ranging from 1 (Preparation and brief) to 7 (In use). Figure 2 shows a comparison between the two plans (The Institution of Structural Engineers BIM Panel 2021).

RIBA (2013) | AIA (2007)

Stage		Default LOD	Stage	Default LOD
1	Preparation and brief	1		
2	Concept design	2	Schematic design	100
3	Developed design	3	Design development	200
4	Technical design (Only in UK for complex or critical elements)	4	Construction documents	300 350
5	Construction	5	Construction phase	400
6	Handover close out	6	Project completion	500
7	In use	6		

Figure 2: *RIBA Plan of Work compared to AIA Schema LOD stages.*

Uses and benefits of BIM

BIM covers a wide range of tasks and processes known as BIM Uses. “A BIM Use is defined as a method of applying Building Information Modelling during a facility’s lifecycle to achieve one or more specific objectives” (Kreider and Messner 2013). With BIM Uses, we can define how we will use a BIM model, and they need to be defined before applying BIM for any project. There are numerous BIM Uses; the New Zealand BIM handbook identifies twenty-one BIM Uses sourced from the Penn State BIM Execution Planning Guide. Existing conditions modelling, cost estimating, 4D modelling, design authoring, design review, facility energy analysis, and 3D coordination (The New Zealand BIM handbook 2019). Through these uses, BIM can provide significant benefits to all project stakeholders, including owners, contractors, architects, and engineers before, during, and after construction.

The benefits of BIM revolve around the idea of allowing stakeholders to visualize and interact with the project in the digital environment before construction begins, thereby eliminating potential risks and problems. Visualizing the project with a 3D information model, along with coordination and collaboration among the various disciplines involved in the project, leads to better understanding, allowing everyone to work more efficiently, making faster and more informed decisions, and improving productivity and quality during the design phase. As well as early detection of design changes, detecting and resolving issues, can all result in significant savings in construction time and costs. Also, by using BIM, we can avoid manually entering data; for example, quantity takeoffs and drawings can be generated automatically from the BIM model, avoiding human error and time-consuming manual work, resulting in improved accuracy in less time.

METHODOLOGY

In this project, BIM is to be implemented in the design phase using software. Level 2 BIM is used in the implementation, which includes 3D, 4D, and 5D BIM. The modelling LOD is set to 350. The Methodology comprises structural modelling, structural design (both manually and by software), models federation, clash detection, scheduling, time simulation, and quantification. Figure 3 illustrates the project methodology. First, information was gathered from the project owner and consultant; the project plan view was obtained in CAD format, while the architectural and MEP models of the project were obtained in Revit format. In addition to receiving the project schedule in MS Project format.

The following step was selecting appropriate BIM tools. The mainly selected BIM tools were Autodesk Revit, Autodesk Robot Structural Analysis Professional (RSA), Autodesk Advance Steel, Oracle Primavera P6 Professional, and Autodesk Navisworks Manage. 2019 versions of Autodesk programs and version 17 of Primavera P6 were chosen. Table 1 shows the BIM use and the selected software for it. The reasons for choosing these tools are that they implement the necessary BIM functions for this project, as well as their compatibility with their each other, which allows for easy importing and exporting of models and data between them. Autodesk programs are fully compatible with one another, and Primavera P6 data can be exported for use in Navisworks for 4D modelling (time simulation).

BIM Use	Selected Software
Design authoring	Revit 2019
Structural analysis and design	Robot Structural Analysis Professional 2019
Detailed modelling	Advance Steel 2019
3D coordination	Navisworks Manage 2019
4D modelling	Primavera P6 Professional 17, Navisworks Manage 2019
5D cost estimation	Navisworks Manage 2019

Table 1: *Software selected for this research and its BIM use.*

RESULTS & DISCUSSION

Introduction

The case study project is an industrial facility that is a cars assembly factory in the Garri Free Zone in North Khartoum. Autobash Co. Ltd. is the owner, Newtech Consulting Group is the consultant, and Concrete Engineering is the contractor. Autobash cars factory consists of many facilities, which are the assembly line and warehouse (steel gable frame), accommodation buildings, administration and showroom building, powerhouse, firefighting office and service facilities. The construction of these buildings was either in progress or had not yet begun at the time of this research, except for the ‘assembly line and warehouse’, which was the only facility to be completed and operational, and it is the one considered as the case study for this research.

The assembly line and warehouse are housed in a 172.5*120 square meter steel gable frame. The gable frames have a 7.5 m spacing and span in the long direction. The structure faces east-west and has an east entrance. The gable frame is symmetric, with side columns 11.5 meters high, internal columns 13.5 meters high, and middle columns 15.5 meters high. The frame is divided into two equal parts an assembly line and a warehouse. The assembly line includes a separate inner frame that carries the crane used in car assembly. The architectural and MEP models of the steel frame were obtained from the consultant for federation and clash detection.

The structural model was redesigned with minor changes to sections of structural elements in the gable frame. As for the internal frame, only the plan view was obtained, thus, its redesign was an entirely new one that is different from the original.

Structural modelling, analysis, and design

Using Robot Structural Analysis Professional (RSA)

The first step was to model the main structural steel elements in RSA 2019, which included columns, rafters, purlins, side rails, struts, and bracing, as well as cladding. Afterwards, to define and assign loads and load combinations to the structure and then perform analysis calculations. The selected codes of practice were British standards mainly (BS 5950-1:2000). Figure 3 shows a screenshot of the modelling and analysis done in RSA 2019.

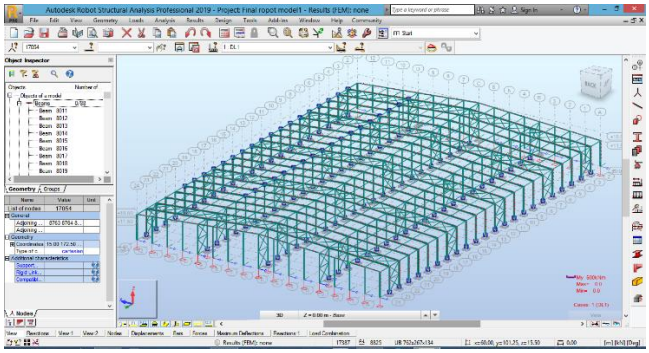


Figure 3: *Screenshot of the modelling in RSA 2019.*

The steel design was the next step, which included selecting appropriate and cost-effective sections and running them through RSA 2019 Steel Members Design to obtain acceptable and reasonable steel sections. Table 2 shows the final steel sections chosen for each steel element in the structure.

Structural Element	Section
Bracing	2 EQA 50x6
Struts (roof and wall)	RHSH 150x100x8
Gable Rafter	UB 254x146x43
Gable Post	UB 457x152x74
Rafter	UB 533x210x122
Side Column	UB 610x305x179EP
Internal Column	UC 254x254x89EP
Purlin	PCF 150x90x24
Side Rail	PCF 200x90x30

Table 2: *Selected sections of structural steel elements in the model.*

The structural design of foundations and connections came next. The foundation design was carried out using RSA 2019 providing reinforcement details and footing required dimensions. As for connection design, most connections were designed in RSA 2019 except for bracing connections and connections of the gable post, which required connection types that were not available in RSA 2019. Although it is possible to design foundations and connections with RSA 2019, their level of detail in the model is only conceptual and they cannot be fully detailed in the model, RSA 2019 only displays their full details separately, rather than in the model. This is where Autodesk Advance Steel comes in handy.

Manual Analysis and design

To ensure that the software results were correct, manual analysis and design were performed. Furthermore, the separate inner crane frame, bracing connections, and gable post connections were designed by hand, then added to the model and detailed with Advance Steel 2019.

Using Autodesk Advance Steel

Using Advance Steel 2019, we were able to model details that were not visible in RSA 2019 and add connections that were not available before. We also used it to model and detail the internal crane carrying frame. The new details modelled using Advance Steel 2019 were isolated footings, ground beams, pedestals, and connections' details such as bolts, plates, and stiffeners. While the added connections were gable post connections and bracing connections. Figure 4 shows screenshots of the model with the new modelled details in Advance Steel 2019.

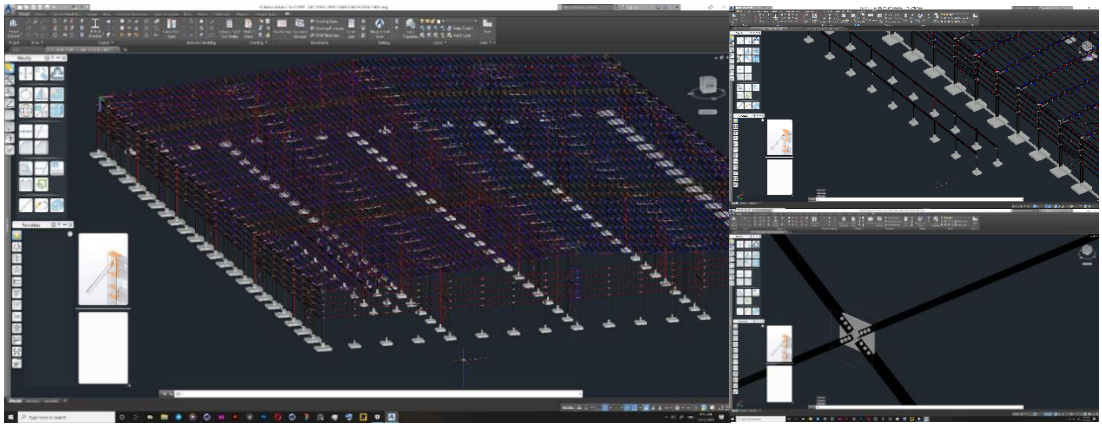


Figure 4: *Screenshots of the model with the new details in Advance Steel 2019.*

Models' federation and clash detection

A federated model of the 'assembly line and warehouse' was created in Navisworks Manage 2019 by combining the architectural, structural, and MEP models in the software. Following that, to detect clashes, three clash tests were performed: architectural vs structural, architectural vs MEP, and structural vs MEP. The clash tests were performed considering geometry, hence, detecting hard clashes (two objects intersecting each other), while initially setting tolerance to zero to show every detected clash. At first, the results of zero tolerance tests resulted in a total of 12889 clashes in the architectural vs structural test, 129 clashes in the architectural vs MEP test, and 5 clashes in the structural vs MEP test. The clash tests were repeated with a 0.5 cm tolerance (after observation, it was determined that any clashes in that zone could be ignored), resulting in 12,034 clashes in the architectural vs structural test, and 30 clashes in the architectural. Vs MEP test, while the number of clashes in the structural vs MEP test remained constant at five.

There are a lot of clashes in the architectural vs structural test. The majority of the clashes in this test were caused by a large component in one of the two models colliding with numerous smaller elements in the other model (e.g., architectural floor clashing with the structural columns). These clashes are not far apart, and they can be easily resolved by shifting the large element away from the other elements that are clashing with it. To improve the results, these clashes were organized into groups consisting of the large element and each smaller element clashing with it, thus reducing the number of detected clashes in the architectural vs structural test to 448 clashes, and to 12 in the architectural vs MEP test. The structural vs MEP test did not require any grouping of clashes. A sample clash report that is structural vs MEP clash report can be found in Table 3.

Structural vs. MEP	Tolerance	Clashes	New	Type	Status
	0.005m	5	5	Hard	OK

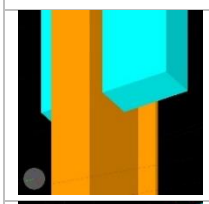
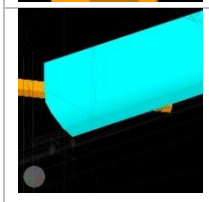
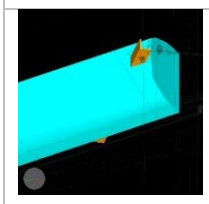
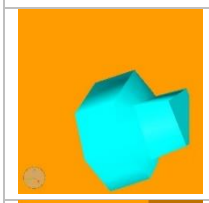
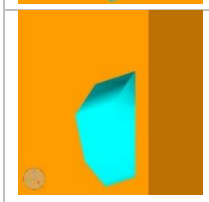
				Item 1	Item 2
Image	**Clash Name**	**Distance**	**Grid Location**	**Path**	**Path**
	Clash1	-0.209	A-24: GROUND FLOOR	ASTBEAM [78B2E]	Electrical Equipment > Distribution Board TP&N (AUB) > 63 A
	Clash2	-0.115	B-24: GROUND FLOOR	ASTBEAM [BD2D8]	Mechanical Equipment > SPLIT AC INDOOR UNIT WALL MOUNTED 30000 BTU (AUB)
	Clash3	-0.082	B-24: GROUND FLOOR	ASTBEAM [BD11C]	Mechanical Equipment > SPLIT AC INDOOR UNIT WALL MOUNTED 18000 BTU (AUB)
	Clash4	-0.033	E-8: GROUND FLOOR	ASTBEAM [C6]	Fire Alarm Devices > Fire Alarm Sounder (AUB) (SCALE 100) > Standard
	Clash5	-0.032	C-18: GROUND FLOOR	ASTBEAM [2A2]	Fire Alarm Devices > Fire Alarm Sounder (AUB) (SCALE 100) > Standard

Table 3: *Structural vs MEP clash report.*

These clashes can be resolved by changing the position of intersecting elements or by changing sections. The clash tests can then be re-run until the clashes are resolved. Some clashes, such as the majority of those involving MEP elements, could be easily resolved on-site and thus ignored.

Scheduling and time simulation

The factory construction officially began on September 1, 2018. The steel frame was the first facility to be built, and it was scheduled to be finished by July 2019, with a 312-day construction period. The original timeline was influenced by unexpected factors; the project was stopped and delayed numerous times due to the country's economic and political state before and during the 2019 Sudanese revolution. Oracle Primavera P6 version 17 was used for the redesign to create a new optimized schedule for the steel frame with no delays. The new schedule has a duration of 274 days. The created schedule is illustrated in figure 5.

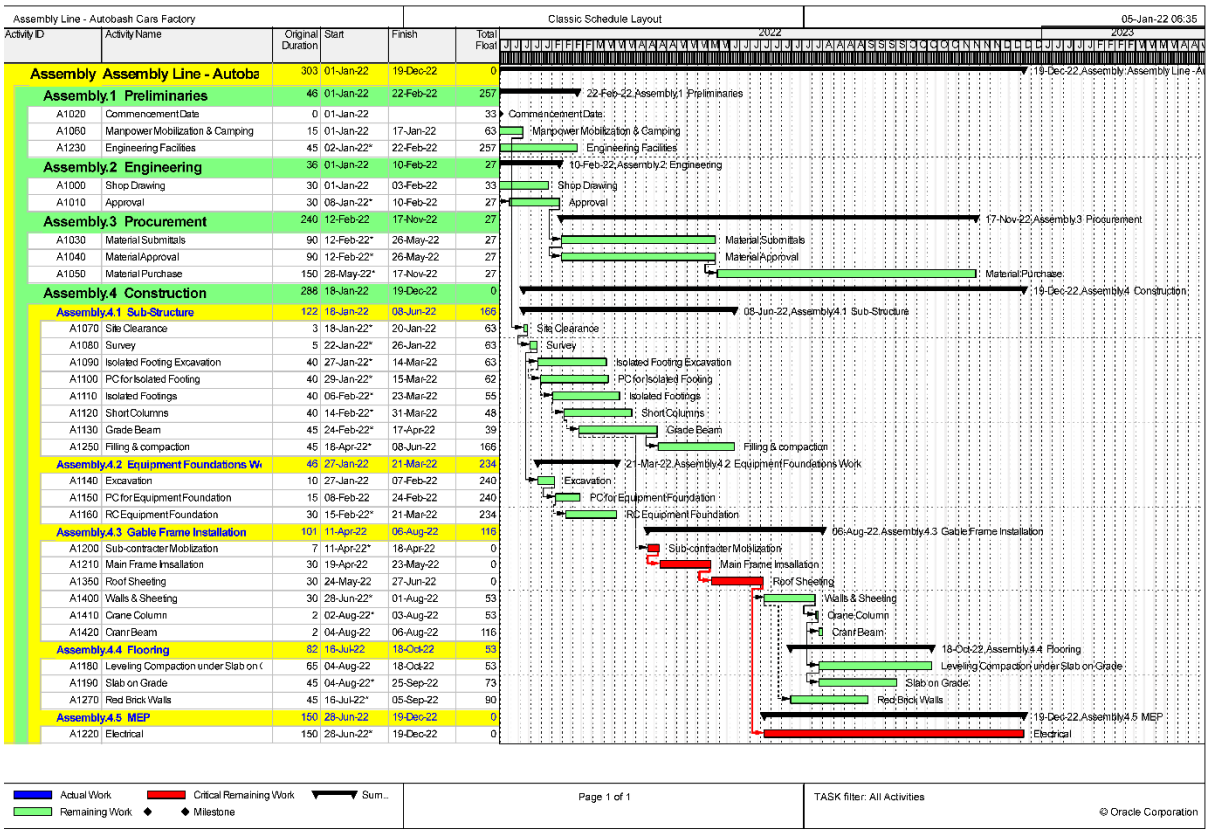


Figure 5: *Screenshot of project schedule in Primavera P6 17.*

The scheduling data from Primavera P6 17 was imported into Navisworks 2019 TimeLiner for the time simulation process; activities were assigned to their corresponding elements in the model, and a time simulation was successfully run. Figure 6 shows snapshots of the resulting time simulation.

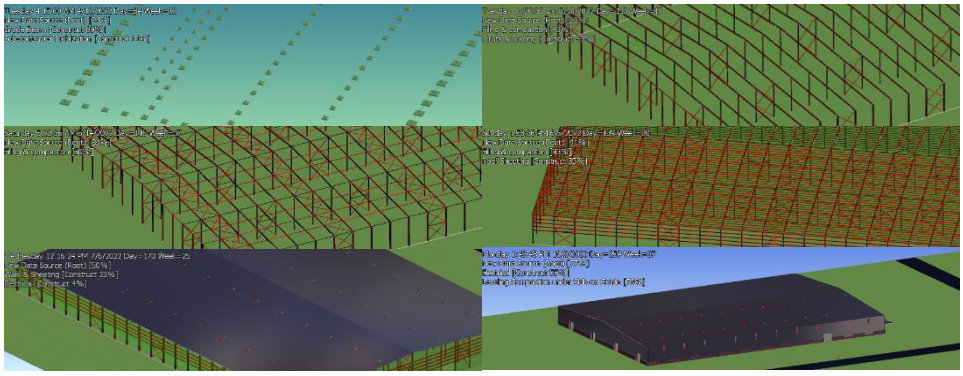


Figure 6: *Snapshots of the time simulation process executed using Navisworks 2019 TimeLiner.*

Quantification

The bills of quantities for the structural model were successfully generated using the Quantification tool in Navisworks Manage 2019. A total of 26 quantity reports for structural elements (e.g., foundations, columns, rafters, purlins, side rails, etc.) were generated. A sample quantification that shows a count of the structural elements can be found in table 4 below.

WBS/RBS	Group1	Group2	Item	Count
1	Sub structure			
1.1	Substructure	Foundations		
1.1.1	Substructure	Foundations	Side column foundations	48
1.1.2	Substructure	Foundations	Gable footings	30
1.1.3	Substructure	Foundations	Internal column foundations	66
1.1.4	Substructure	Foundations	Crane foundations	18
1.2	Substructure	Pedestals		
1.2.1	Substructure	Pedestals	Side pedestals	48
1.2.2	Substructure	Pedestals	Gable pedestals	30
1.2.3	Substructure	Pedestals	Internal pedestals	66
1.2.4	Substructure	Pedestals	Crane pedestals	18
1.3	Substructure	Ground beams		
1.3.1	Substructure	Ground beams	Ground beams	46
2	Superstructure			
2.1	Superstructure	side rails		
2.1.1	Superstructure	side rails	Side rails	390
2.2	Superstructure	Purlins		
2.2.1	Superstructure	Purlins	purlins	1840
2.3	Superstructure	Struts		
2.3.1	Superstructure	Struts	Wall struts	143
2.3.2	Superstructure	Struts	Roof struts	292
2.4	Superstructure	Bracing		
2.4.1	Superstructure	Bracing	Bracing	544
2.5	Superstructure	Rafters		
2.5.1	Superstructure	Rafters	Gable rafters	32
2.5.2	Superstructure	Rafters	Main rafters	263
2.6	Superstructure	Columns		
2.6.1	Superstructure	Columns	Side columns	48
2.6.2	Superstructure	Columns	Gable columns	30
2.6.3	Superstructure	Columns	Internal columns	66
2.7	Superstructure	Crane elements		
2.7.1	Superstructure	Crane elements	Crane beams	16
2.7.2	Superstructure	Crane elements	Crane columns	18
2.7.3	Superstructure	Crane elements	Columns brackets	18
2.8	Superstructure	Connections		
2.8.1	Superstructure	Connections	Bolts Dia 12	9147
2.8.2	Superstructure	Connections	Bolts Dia 20	8706
2.8.3	Superstructure	Connections	Bolts Dia16	100
2.8.7	Superstructure	Connections	Cleats	2330
2.8.8	Superstructure	Connections	stays	4441
2.8.9	Superstructure	Connections	stiffeners	744
2.8.10	Superstructure	Connections	welds	15519
2.8.12	Superstructure	Connections	Gusset plate	141
2.8.13	Superstructure	Connections	Gable cleats	126
2.8.14	Superstructure	Connections	Washer plates	684
2.8.15	Superstructure	Connections	Plate anchorage	684
2.8.16	Superstructure	Connections	Baseplate	162
2.8.17	Superstructure	Connections	Additional plates	4820
2.8.19	Superstructure	Connections	Crane brackets	36

Table 4: *Count of structural elements (a sample quantification).*

CONCLUSION

The study concluded that Level 2 BIM when combined with the appropriate tools and methods, can be successfully and effectively implemented on this project and other construction projects in Sudan, whether they are residential, infrastructure or industrial buildings. The study also demonstrates that using Level 2 BIM in the design phase can yield significant benefits. Early detection of clashes and the use of generated quantities through the quantity take-off process instead of manual, more error-prone and time-consuming methods save a significant amount of time and effort. Using 4D simulation, the project and scheduling process are better visualized. A final BIM model containing all of the information related to architecture, structure, and MEP, as well as quantity, schedule, and all other parameters, can be provided and accessed at any time by any of the project stakeholders. BIM was found to be a viable option for this project, as well as other construction projects in Sudan. With some effort, Sudan Level 1 BIM use could be upgraded to Level 2 BIM, yielding better results in terms of time, cost, and effort before, during, and after construction.

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ARTIFICIAL INTELLIGENCE APPROACH FOR PREDICTING THE COMPRESSIVE STRENGTH OF CONCRETE MIXTURE

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Abstract
In this study, an artificial intelligence approach is utilized to determine the compressive strength of concrete and the slump, aiming to minimize the time and cost which are consumed using conventional methods. An artificial neural network (ANN) model is programmed using the Keras framework (python) to predict concrete mix compressive strength and slump based on the input of proportions and properties of its ingredients. The data of 1557 samples are collected and converted manually from hard copy to soft copy. The (ANN) model gives results of a good accuracy for the compressive strength after 7 days, 28 days and the slump. In conclusion, using AI in the prediction of concrete strength is convenient and practical to a significant extent.

Keywords*:* Artificial Intelligence, Artificial Neural Networks, Compressive Strength, Concrete, Keras Framework (Python).

INTRODUCTION

It's known all over the world that concrete is the most utilized material in civil engineering. This is justifiable due to its effectiveness in the process of construction, this effectiveness is represented in its characteristics including strength against compression, workability, durability, fire resistance, and impact resistance.

Mechanical strength (Compressive strength) is the most important property of concrete due to it being descriptive of the quality of concrete. It's the result of concrete mixture design to be used in construction. In general, it is obtained by measuring the specimen of concrete after standard curing of 28 days. It's important to predict the 28-day compressive strength to get an idea about the development of that strength, and so it is necessary to measure the strength of the concrete specimen at its early stages. Conventional methods to predict the 28-day compressive strength of concrete are based on statistical analysis by which many linear and non-linear regression equations have been formed to model such a problem. The compressive strength is affected by multiple factors and components of concrete. The goal of most research in material modelling is to generate mathematical models to describe the relationship between components and material behaviour. These models consist of mathematical rules and expressions that capture these varied and complex behaviours, and concrete, it is a highly non-linear material, so modelling its behaviour is a difficult task.

Concrete as a material is created by the proper mixing of its four major components which are cement, coarse aggregates which includes gravel, fine aggregates which include sand and an adequate and controlled amount of water, studies have shown that the long-term properties of concrete can be improved by controlling some parameters of concrete such as the grade of cement, the water-cement ratio and slump (Ni and Wang, 2000).

MATERIALS

It is justifiable to say that concrete is a complex material, and that is due to the multiple parameters involved in its composition which can significantly change the properties and behaviour of concrete. These components also have different effects depending on the current state of concrete whether it is in the fresh state or the hardened state.

Cement: It is a very crucial material in the formation of concrete, and this is because the cohesion and solidarity of concrete are generated from the interaction between the chemical compounds of cement and water. In the fresh state of concrete, increasing the amount of cement will result in the reduction of consistency due to the increase of the resistance to flow. In the hardened state, cement should fit the appropriate standard required for concrete to acquire the best possible strength. In general, the increase in cement content increases in concrete strength. However, it must be taken into account that it should not result in the reduction of consistency due to the reduction of water since it will cause the concrete to become difficult to compact and strength will become less. ***(*CALcrete*, no date)***

Water: As said before, the stiffness of concrete results from the formation of hydration products between cement and water. Although water makes concrete more consistent, the higher the amount of it the less strong concrete will be. Therefore, to have better strength less water-cement ratio is preferable, which means less water.

Coarse aggregates (gravel): It aids in the workability of concrete, the coarser aggregates in the formation of concrete the more consistency it will have. If any increase in the amount of gravel occurs it will result in the increase of compressive strength due to the reduction of thesurface area of solid particles which in return will lower the water demand, which means less water-cement ratio.

Fine aggregates (sand): It causes the water demand to rise, which aids in the concrete being more consistent and workable in the fresh state. On the other hand, it has the opposite impact on the compressive strength of concrete, this strength increases as the number of sands decreases due to the increase of thesurface area of solid particles.

Admixtures: "An admixture is defined as a material other than water, aggregate, and hydraulic cement which might be added to concrete before or during its mixing".

ARTIFICIAL NEURAL NETWORKS

Artificial intelligence was born in the 1950s when some great computer scientists were wondering if computers could be made to think, a question that humans are still trying to solve. A simple definition of this field would be the effort to automate human intellectual tasks. Artificial intelligence is a general field, it includes deep learning and machine learning, but also includes many methods that don't involve any learning.

Machine learning is about the question of can a computer -We know how to order it to perform- and on its own learn how to do a specific task? Can a computer surprise us? Instead of programmers handcrafting data-processing rules, can a computer learn the rules automatically by looking at data? (Chollet, 2017) A machine-learning system is not explicitly programmed but rather trained. It's provided with a lot of examples related to a task, and using these

examples it finds a statical structure that allows the system to generate rules for automating the task. For example, if you want to automate the process of tagging your vacation images, you could try a machine learning system with a lot of images already tagged by humans, and this system would learn to associate specific images to specific tasks using statistical rules.

RELATED STUDIES

Since the start of the previous decade, researchers have been trying to use artificial intelligence for non-destructive compressive strength prediction. Most of the authors in the literature used the Artificial neural network method (ANN).

(Badawi and Ahmed, 2020) used data from the lab of materials of the University of Khartoum collected in the past 10 years. They used MATLAB to produce an artificial neural network (ANN) model to predict the compressive strength after 7 days and the workability of concrete. Their model got acceptable results. We used the same data and added more recent concrete mixtures data that were done in the years (2017 – 2021). We developed a new model using KERAS to predict the compressive strength after 7 days, after 28 days and the workability of concrete.

(Tayfur, Erdem and Kırca, 2014) tried 2 different models to predict the compressive strength of high strength concrete and compared them against each other. He used the Silica fume ratio and age of the mixture as input and the compressive strength as an output. The first was a fuzzy logic (FL) model. And the second was an artificial neural network model (ANN) with 3 layers and a sigmoid as activation function. From the results, he concluded that FL and ANN models have good capability in predicting the strength of high strength concrete.

(Chopra, Sharma and Kumar, 2016) proposed an artificial intelligence model to predict the compressive strength of concrete. The dataset used in this research is of 2 types; in one of them, 15% of cement was replaced with fly ash and the other without replacement. He tried several training algorithms along with various network architectures. It was found out that Levenberg-Marquardt with tan-sigmoid is best for the prediction of compressive strength.

(Gupta, 2013) proposed a method to predict the 28-days compressive strength of high strength concrete. The data he used in this research consisted of cement, water, silica fume, aggregate (coarse and fine), fly ash, superplasticizer and granulated grated blast furnace slag. The results showed a relative error of 7.02% in training and 12.64% which showed that ANN can work effectively in predicting the compressive strength of high strength concrete.

(Naderpour, Rafiean and Fakharian, 2018) aimed to predict the compressive strength of recycled aggregate concrete (RCA) using an artificial neural network. The model used six input features: water-cement ratio, water absorption, fine aggregate, natural coarse aggregate, RCA and water-total material ratio. The network type was backpropagation ANN with a sigmoid activation function and linear output layer. The results concluded that the ANN method can accurately predict RCA compressive strength.

(Ghazanfari *et al.*, 2017)used in his study MLP and GMDH artificial neural networks to discover relationships, predict mechanical properties and identify non-linear patterns in concrete mixtures. The results imply acceptable accuracy of the GMDH algorithm in predicting the compressive strength and workability.

METHODOLOGY

Neural network structure

As (Basheer and Hajmeer, 2000) stated, a neural network revolves around the following objects: (1) Data; (2) Layers; (3) Optimizer; and (4) Loss function.

Data

Data preparation:

The dataset used in this study was collected separately: 545 mixed designs samples were gathered from the lab of materials of the University of Khartoum, and 1012 mixed designs samples were collected in the previous 9 years (2009-2017) in Sudan and published by (Abdelatif *et al.*, 2018) to end up with 1557 samples.

Data used in the model has been tabulated, organized, analysed by plots and graphs to more observing odd data and structured into a spreadsheet. The data includes the main mix designs proportions in terms of cement content, water, and fine and coarse aggregate with added admixtures dosage. Moreover, the data provide the result of the slump test, concrete strength in 7 and 28 days for those mix designs. The data also includes properties of aggregates such as aggregate type, maximum size, percentage passing sieve 0.6 mm and hardened concrete density. The data is explained in Table 1.

Parameter	Designation	Minimum value	Maximum value	Average value (Most common)	Type
Type of coarse aggregates	X_1	Natural	Crushed	N/A	Input
Type of fine aggregates	X_2	Natural	Crushed	N/A	Input
Maximum size of coarse aggregates	X_3	10	40	20	Input
%age of aggregates passing sieve 0.6 mm	X_4	17	96.9	45	Input
Cement content (Kg/m^3)	X_5	250	450	350	Input
Water cement ratio (w/c)	X_6	0.4	0.72	0.5	Input
Water content (Kg/m^3)	X_7	100	290	180	Input
Additive type	X_8	N/A	N/A	Type G	Input
Dosage of additive (lit)	X_9	0	9	1.15	Input
Amount of fine aggregates (Kg/m^3)	X_{10}	477	865	1875	Input
Amount of coarse aggregates (Kg/m^3)	X_{11}	990	1365	1162	Input
Workability slump (mm)	Y_1	90	230	150	Output
Strength in 7 days (N/mm^2)	Y_2	19	45.9	29.6	Output
Strength in 28 days (N/mm^2)	Y_3	16.1	57	38	Output

Table 1: *Data used in the research and its properties.*

Data completion: After collecting the data, we found that recent year's data has missing values like the percentage of passing sieve 0.6mm. To solve this a regression model was used to predict the missing value.

Data division: To get optimized results and better performance of the model the data was divided into 70% as the training set, 15% as the validation set and 15% as the test set.

Data normalization: In this research's data, the water to cement ratio ranges between 0.33 -

0.72 and the cement content ranges between (220– 450). If features ranges are different, it would be problematic, the network might be able to automatically adapt to such heterogeneous data, but it would make learning more difficult. So, the normalization process was applied to the data.

The method that was used for normalization is called the Z-Score method. This method uses the mean and standard deviation to scale the data similar to (Singh and Singh, 2020). The normalized input is calculated using Equation (1).

$$x' = \frac{x - \mu}{\sigma} \tag{12}$$

Where:
x: the input
x': The new normalized data
μ: the mean of data
σ: the standard derivation

Layers
Every network consists of layers of neurons connected, starting with the input layer passing data to the hidden layers and generating output in the output layer. Each layer consists of a specific number of neurons.

After a lot of trial and error the chosen model was as follows:

- Input layer with normalization operation.
- First hidden layer with 160 neurons.
- 2nd hidden layer with 80 neurons with Relu as an activation function.
- Dropout layer that has a 0.2 dropout ratio.
- 3rd hidden layer with 40 neurons with Sigmoid as an activation function.
- 4th hidden layer with 20 neurons with Relu as an activation function.
- 5th hidden layer with 10 neurons with Sigmoid as an activation function.
- First hidden layer with 5 neurons with Relu as an activation function.
- Output layer with one neuron.

Optimizer
After trying two optimizers Stochastic gradient descent and Adam optimizers, we found out we should use the Adam optimizer. It implements a specific variant of stochastic gradient descent (SGD).

Loss function
The loss function that was used in this study is the mean squared error (MSE), it's calculated using Equation (2).

$$MSE = \sum \frac{(y' - y)^2}{n} \tag{13}$$

Where:
y': represents the predicted value of the model
y: represents the real output data
n: number of samples

Neural network parameters

Learning rate:
To get better efficiency of this model a learning rate that's not so big to not get bad efficiency and not too small to slow the learning. So, it was selected to be 0.01.

Number of epochs:
The model was set up to train for 20000 epochs with an early stopping mechanism that stops the training if more than 2000 epochs passed and no improvements happened to avoid overfitting.

RESULTS

To tell if any model is working well or not, we test it against the test set to see if the output of the prediction is close to the real output of the test set or not. This is done by calculating the difference. In this study the following error measure methods were used:

1- Root mean squared error (RMSE) calculated using Equation (3).

$$RMSE = \sqrt{\frac{\sum(y' - y)^2}{n}} \tag{14}$$

2- Mean absolute percentage error (MAPE) calculated using Equation (4).

$$MAE = \frac{\sum \frac{y' - y}{y} * 100\%}{n} \tag{15}$$

Where:
y': predicted output
y : real output
n : number of samples

Result of the strength after 7 days

The 1068 samples of predicted strength after 7 days are randomly divided into training (748 samples), validation (160 samples) and test sets (160). The results are shown in Table 2. And the trend line graphs are shown in Figure 1 (training, test, and validation respectively).

Data type	Average error	RMSE	MAPE	R^2
Training data	3.00	3.85	10.4%	0.623
Validation data	4.28	5.27	14.9%	0.38
Testing data	3.84	4.65	13.4%	0.44

Table 2: *Results of prediction of concrete compressive strength after 7 days.*

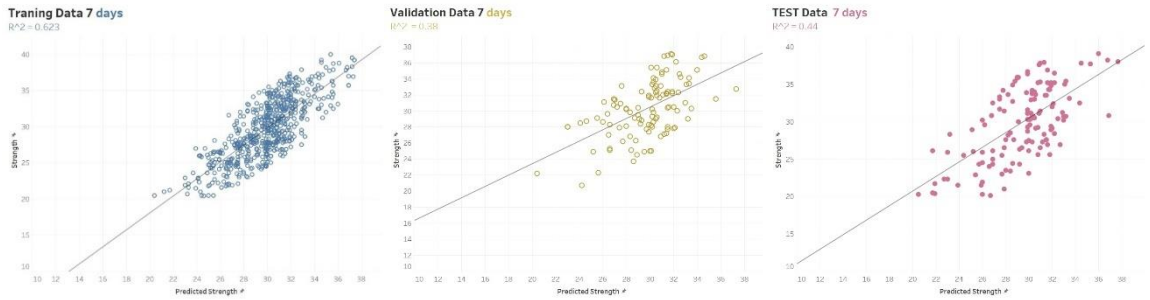

Figure 1: *Comparison of prediction and actual results of compressive strength after 7 days.*

Results of the strength after 28 days

The 470 samples of predicted strength after 28 days are randomly divided into training (329 samples), validation (71 samples) and test sets (70). The results are shown in Table 3. And the trend line graphs are shown in Figure 2 (training, test, and validation respectively).

Data type	Average error	RMSE	MAPE	R^2
Training data	2.77	3.60	7.44%	0.65
Validation data	3.51	4.24	9.6%	0.42
Testing data	2.84	3.66	7.16%	0.62

Table 3: *Results of prediction of concrete compressive strength after 28 days.*

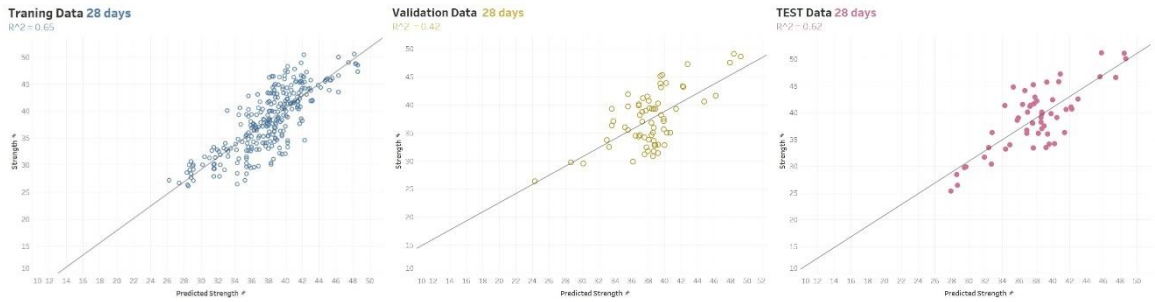

Figure 2*: Comparison of prediction and actual results of compressive strength after 28 days*

Results of the slump

The 1066 samples of the predicted slump are divided randomly into training (747 samples), validation (159 samples) and test sets (160). The results are shown in Table 4. Moreover, the trend line graphs are shown in Figure 3 (training, test, and validation respectively).

Data type	Average error	RMSE	MAPE	R^2
Training data	20.4	25.7	14.8%	0.6
Validation data	29.9	34.5	19.2%	0.284
Testing data	28.4	35.6	22.6%	0.39

Table 4: *Results of prediction of a slump.*

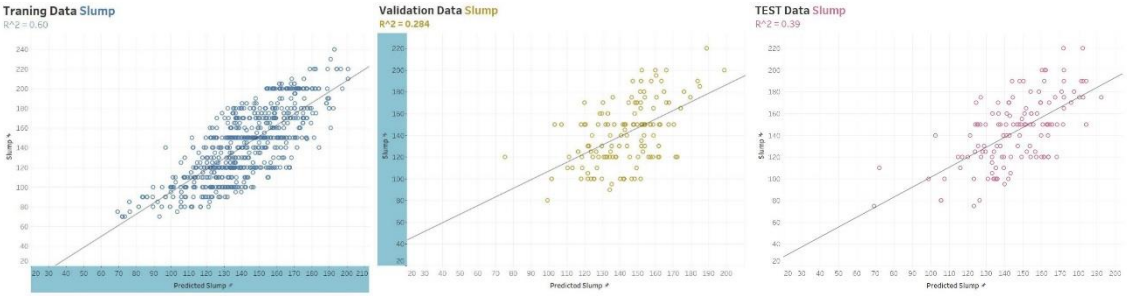

Figure 3: *Comparison of prediction and actual results of the slump.*

CONCLUSION

The results show an average error of less than 5 for the strength after 7 days which is accepted at some level. This research used a small number of samples of 1557 samples from these samples only 1086 samples contained the compressive strength after 7 days, yet an RMSE error of 4.65 was found. Of 470 samples contained the compressive strength after 28 days and got an RMSE error of 3.66 was found. Of 1166 samples containing the slump an RMSE error of 35.6 was found. The results are acceptable to some extent. And to improve these results collecting more data is recommended (especially these containing compressive strength after 28 days).

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PREDICTION OF SOIL'S COMPACTION CHARACTERISTICS USING ARTIFICIAL NEURAL NETWORKS (ANNs)

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Abstract
In all geotechnical projects, the determination of the compaction properties of soil plays an important role. Soil is compacted to improve its engineering properties like increasing its density, reducing its permeability, and increasing its shear strength. The compaction test is a relatively tedious test that consumes a lot of time and resources. Classically modelling this phenomenon will require a multi-variable regression analysis for all the factors that influence it. Artificial neural networks (ANNs) provide a powerful tool to model such complex systems. This paper discusses the development and use of two artificial neural network models as tools to predict the optimum moisture content (OMC) and the maximum dry density (MDD) of soil compacted at a standard proctor test. The first one is developed with Matlab neural network tool (nntool) using Levenberg-Marquardt's algorithm. The second one is developed using stochastic gradient descent's algorithm. Both models use atterberg's limits and particle sizes as inputs. The research shows that the two models are capable of predicting the maximum dry density and the optimum moisture content for various types of soils. This is indicated by the high coefficient of determination (R^2) value and the low Mean Absolute Percentage Error (MAPE), Mean Square Error (MSE), and Root Mean Square Error (RMSE) of the two models.

Keywords: Artificial Neural Network, Compaction Characteristics, Atterberg's Limits, Sieve Analysis.

INTRODUCTION

Compaction is the process in which soil particles are pushed closer to each other by reducing the volume of air in the soil. It improves its engineering properties. The compaction test consists of multiple points with calculated dry densities and moisture contents. From those points, a curve describing the relationship between moisture content and dry density is established. From this curve, the maximum dry density and its corresponding moisture content (known as the optimum moisture content) are found. The maximum dry density is the highest dry density achievable at a given compaction effort (energy). This takes several trials and it is both time and resources consuming. In a developing country like Sudan, engineers don't have the laboratory equipment to do this test in every city. These models will serve as a piece of technology that can overcome this shortage. This will significantly reduce the cost of engineering projects especially roads, and earth-fill dam construction which helps in the development of the country.

Developing a classic mathematical model to predict the outcome of a compaction test is not an easy problem. The compaction characteristics depend on many parameters. The degree of influence of those parameters varies with the soil type. For example: in clean coarse-grained soils the soil particle distribution will dominate the result of compaction. However, in fine-

grained soils, the plasticity of clays presented by liquid limit (LL) and plastic limit (PL) will control the expected compaction results. This variation makes it difficult to come up with a single mathematical model that yields accurate results for all types of soils (clean coarse-grained soils, fine-grained soils, and in between). Artificial neural networks can overcome these difficulties.

Artificial Neural Network

Artificial Neural Network (ANN) is a new machine learning concept that processes the data in a stacked-layer structure starting from an input layer that contains input until reaching the last layer that generates the output. Every layer contains neurons (processing units). It's called a neural network because it mimics the human brain neurons in the way it processes data.
Neural networks are one of the supervised learning methods which mean it needs initial data to learn from.

Neural Network Components

Neural networks have necessary components:

Input and Output

Every artificial neural network must have input(s) and output(s). In this study, the inputs are soil's index properties and classification. The outputs are the maximum dry density and optimum moisture content.

Weights

Every neuron in the layers of the neural network has a value that's called weight. It represents the importance of its corresponding input. During the training procedure, the model keeps updating and synchronizing these weights till the model's prediction accuracy becomes as good as it can be. These weights are usually randomly initialized.

Bias

In addition to the weights, there's also the bias. This is a single neuron added to every layer in the network to take into account any bias in the data. It's added to the weights when predicting the output of the layer.

Layers and neurons

It's very important to choose the number of layers in a network, and the number of neurons in every layer. It plays an important role in the accuracy of the model and the speed of training. It's chosen usually after a trial-and-error procedure.

Activation Function

It's a function that's used to convert a list of inputs to an output. This function takes into account the weights of the neurons of the model.

RELATED STUDIES

A lot of research has been done to predict compaction characteristics. Their efforts revolved around using simpler inputs to give reasonably accurate outputs. This part of the paper focuses on some of those studies and discusses their methodology and results.

A model was developed by (Tenpe and Kaur 2015) for predicting compaction parameters based on the liquid limit, plasticity index, soil particles less than 75 microns size, and soil particles greater than 75 microns size. The used dataset was divided into training, validation, and testing set. Other independent samples were used to evaluate the developed model. Another model was reported by (Jayan and N.Sankar 2015) in the special issue for ICETTAS'15. They studied the use of an artificial neural network to predict compaction parameters. They used liquid limit, plastic limit, plasticity index, percentages of fines, sand, and gravel, and specific gravity as inputs. The dataset was divided into training, validation, and testing set. The validation was based on the mean square error, and mean absolute error.

Another model was developed by (Atalar, et al. 2019) to predict the compaction properties of soil. They compared multiple regression models and an artificial neural network model. They used liquid limit, plasticity index, and percentage of fines to estimate the maximum dry density, and the optimum moisture content. An attempt was done by (Sivrikaya and Soycan 2009) to predict compaction parameters of fine-grained soil. They investigated the use of plastic limit to predict optimum moister content and maximum dry density. They also investigated the use of optimum moisture content to estimate the maximum dry density.

In their published work by the Multidisciplinary Digital Publishing Institute (MDPI), (Jeremiah, et al. 2021) provided a literature review for a vast collection of research related to geo-mechanical properties of stabilized clay. In these researches, artificial neural networks were used to predict several characteristics. Two models were reported in this research predicting optimum moisture content and maximum dry density. The first one used LL, PI, LS, clay-silt ratio, sand content, lime content, cement content, and asphalt content in percentage (Alavi, et al. 2010). The second one used Gs, Ls, free swell, D10, D30, D60, Cu, Cc, LL, and PL as inputs (Salahudeen, et al. 2018).

METHODOLOGY

Data

Data used in this research is taken from Building and Road Research Institute (BRRI). It consists of 232 data points from different parts of Sudan. The data covers various types of soil from expansive clays to clean coarse-grained soil. Some statistical parameters for the data are shown in table 1:

	Max	Min	Mean	Standard deviation
LL	80	18	34.6	12.25
PL	47	6	19.08	5.36
PI	48	3	15.47	7.88
Fines (%)	95	0.5	23.56	21.94
Sand (%)	84	2	18.74	12.59
Gravel (%)	97	0.1	57.77	25.34

Table 1: *Statistical parameters of soil characteristics.*

Data Types

The data usually gets divided into three important sets:
Training Set: This is given to the model to learn from and adapt its weights to according to it. It's usually the biggest part of the data so the model can learn about all kinds of data.
Validation Set: This is used to test the model's ability to predict against new data while training

to make sure training is going in the right direction, or stop training and fix the model if it's not learning. It indicates overfitting.
Testing Set: This is used to get the real accuracy of the model by trying the model against new data that it hasn't seen yet.

How Does the Network Learn?
When the input goes from the input layer to the first hidden layer, first the input is multiplied by the weights of the layer. The bias is added to the outcome and then it's transferred to the next layer after activating it using the activation function. This process continues from one layer to another till it reaches the output layer. The error is calculated using one of the error metrics. This error is used to update these weights to improve the accuracy of the network. The part of the network responsible for updating the weights is called the optimizer.

Important Parameters to Choose
Learning Rate
It's a rate used to decide the speed at which the model update its weights. Its value is very important in training. If it's very large the model may not reach its best accuracy, and if it's too small it may be very slow to train.

The Train/Test/Validation Data Percentage
It's important to decide which percentage of the data is set to the test data and the validation data. It affects the data distribution. If test data was so small, it might not give you a good idea of the model's accuracy. Both models in this paper use 80/10/10 percentages for training, validation, and testing respectively.

Accuracy Metrics
To know how our model is doing, we need to have some metrics to calculate the accuracy. We do this by calculating the error (the difference between the model output and the real data). Four common methods were used in this paper:

1- ***Mean Square Error (MSE):*** it's calculated using:

$$MSE = \sum \frac{(y' - y)^2}{n} \quad \textbf{(1)}$$

2- ***Root Mean Square Error (RMSE):*** it's calculated using:

$$RMSE = \sqrt{\sum \frac{(y' - y)^2}{n}} \quad \textbf{(2)}$$

3- ***Mean Absolute Percentage Error (MAPE):*** it's calculated using:

$$MAPE = \sum \frac{\left|\frac{y' - y}{y}\right| * 100\%}{n} \quad \textbf{(3)}$$

4- ***Coefficient of Determination (R^2):*** it's calculated using:

$$R^2 = 1 - \frac{\sum(y - y')^2}{\sum(y - \bar{y})^2} \quad \textbf{(4)}$$

Where:

y' ≡ Predicted value of a given output.
y ≡ Observed value of the same output.
$\bar{y}$ ≡ Mean of the observed values.
n ≡ Number of samples.

Levenberg-Marquardt's Model

Normalization of Data

In artificial neural networks, normalization means putting the data to the same scale. This process can be done with a lot of equations most commonly used being the linear ones. In this model, both the inputs and the outputs are normalized. The normalization can increase the learning speed. It can also improve the accuracy of the model. The following equation is used for the normalization of inputs and outputs after trying various approaches:

$$Xnorm = 0.1 + 0.8 * (\frac{Xi - Xmin}{Xmax - Xmin}) \quad \textbf{(5)}$$

Where:

Xnorm ≡ Normalized value of the parameter.
Xi ≡ Value of the parameter.
Xmin ≡ Minimum value of the parameter.
Xmax ≡ Maximum value of the parameter.

Construction of the Artificial Neural Network

A feed-forward backpropagation network is developed to predict the compaction properties. It consists of an input layer, hidden layer, and output layer. The inputs used in this model are liquid limit (LL), plasticity index (PI), and percentages of fines, sand, and gravel. The outputs are the optimum moisture content (O.M.C.) and the maximum dry density (M.D.D.). The number of neurons in the hidden layer plays an important role in the accuracy of the model. To determine the optimum number of neurons, a trial-and-error procedure was used. In this procedure, the architecture of the model was determined by using a varying number of neurons in the hidden layer. The numbers ranged from 1 to 10, and the (MSE) was used as a performance metric. The results of this procedure are shown in Figure 1, and the final network's architecture is shown in Figure 2:

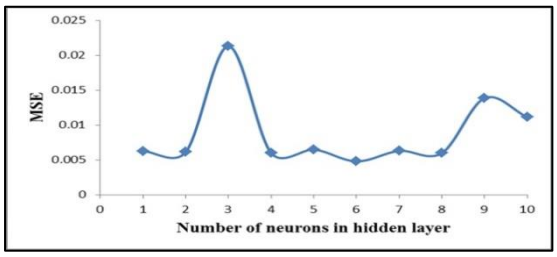


Figure 1: *Optimization of the hidden layer.*

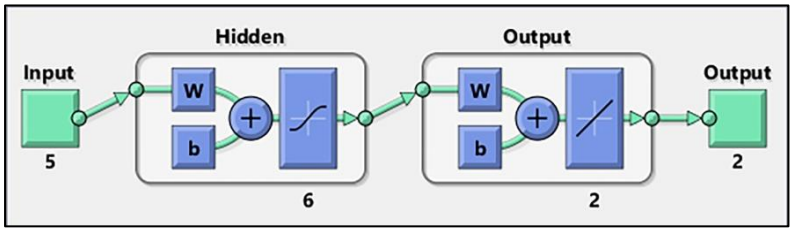


Figure 2: *Network's architecture from MATLAB.*

The hidden layer uses (TANSIG) transfer function. The output layer uses (PURELIN) transfer function. The network uses Levenberg-Marquardt's algorithm as a training function and gradient descent with momentum as a learning function.

Training of the network

The training is a crucial part of developing a functional model. Excessive training may lead to overfitting of the date. Overfitting is when the model gets too familiar with the dataset rather than developing a general repeatable relationship between the inputs and the outputs. An overfit model will have a nearly perfect result in training and very poor accuracy in testing rendering it useless in predicting future points. To overcome this problem, the weights and biases of the network corresponding to the most generalized network are used. To find this point, the accuracy of the validation is reported after every complete cycle of learning. The point with the minimum (MSE) is considered the optimum point. This procedure is shown in Figure 3:

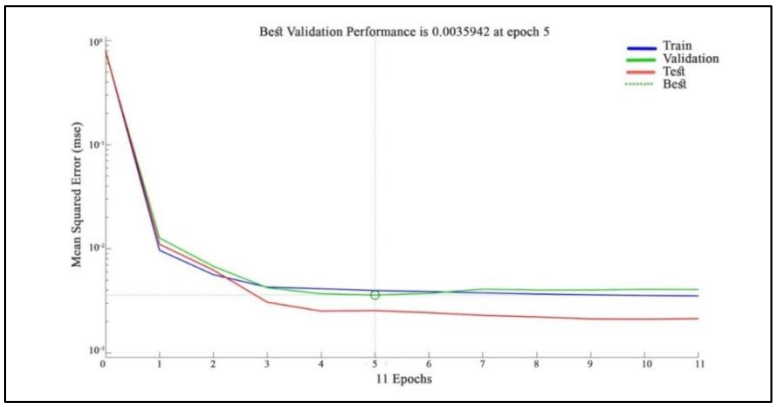


Figure 3: *Training performance of the model.*

Stochastic Gradient Descent's Model

Normalization of Data

In this model, the inputs are normalized in a linear scale between 0 and 1 using the following equation:

$$Xnorm = (\frac{Xi - Xmin}{Xmax - Xmin}) \quad \textbf{(6)}$$

Where:

Xnorm ≡ Normalized value of the parameter.
Xi ≡ Value of the parameter.
Xmin ≡ Minimum value of the parameter.
Xmax ≡ Maximum value of the parameter.

Construction of the Model

This model uses the normalized liquid limit, plastic limit and plasticity index, classification, and a new parameter (Ψ) as inputs. The classification is partially based on the Unified Soil Classification System (USCC). In this method, the classification starts with determining the mass percentage of fines, sand, and gravel within the soil. If the fines percentage is more than 50% the soil is classified as fine and it is designated by its type based on the A-line (silt (M) or clay (C)) followed by a letter describing its plasticity. The plasticity's description is explained as follows (Knappett and Craig 2012):

L: Low plasticity (liquid limit < 35).
I: Intermediate plasticity (35 < liquid limit < 50).
H: High plasticity (50 < liquid limit < 70).
V: Very high plasticity (70 < liquid limit < 90).
E: Extreme plasticity (liquid limit >90).

When the percentage of fines is less than 50%, the soil is classified according to the coarse part of it, and the percentage of fines. This procedure is explained in Table 2:

Fines' percentage	Classification method
Less than 5%	The soil is classified by its coarse-grained part (gravel (G) and sand (S)) by using two letters. The first one represents the dominant coarse-grain part. For example (GS) is sandy gravel.
Between 5% and 15%	The classification is a mix of 1 and 3. For example (GS-CH) is sandy gravel with some high plasticity clay.
More than 15%	The coarse part is ignored, and the classification is based on the fine part.

Table 2: *Classification method for soils with a significant quantity of fines.*

The parameter (Ψ) takes into account the water required to reach (OMC). For example, soil with 80% fines will have significantly higher (OMC) than soil with 5% fines. This parameter has a high correlation with (OMC) and (MDD) and it is given by the following equation:

$$\Psi = \sqrt{\left|\ln\left(\frac{fine\ \%}{\sqrt{sand\ \% * gravel\ \%}}\right)\right|} + \ln\left(\frac{fine\ \%}{\sqrt{sand\ \% * gravel\ \%}}\right) \qquad \textbf{(7)}$$

Where:

Fine % ≡ Percentage of fines.
Sand % ≡ Percentage of sand.
Gravel % ≡ Percentage of gravel.

In this model, we used stochastic gradient descent (SGD) as an optimizer and mean squared error as a loss function. We tried a large network to get better accuracy. The optimum network architecture was found by trial and error. The network has 6 hidden layers with the following number of neurons respectively: 160, 80, 40, 20, 10, and 5. The activation functions used are Rectified linear activation unit (Relu) and Sigmoid. The learning rate was selected to be 0.01. Two dropout layers were used in this model since it was overfitting. One was added after the 80 neurons ANN layer, and the second was added after the 20 neurons ANN layer. The dropout layer concept is shown in Figure 4:

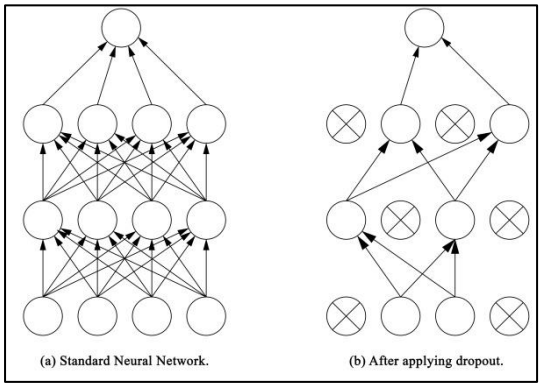


Figure 4: *Dropout layer in a typical neural network.*

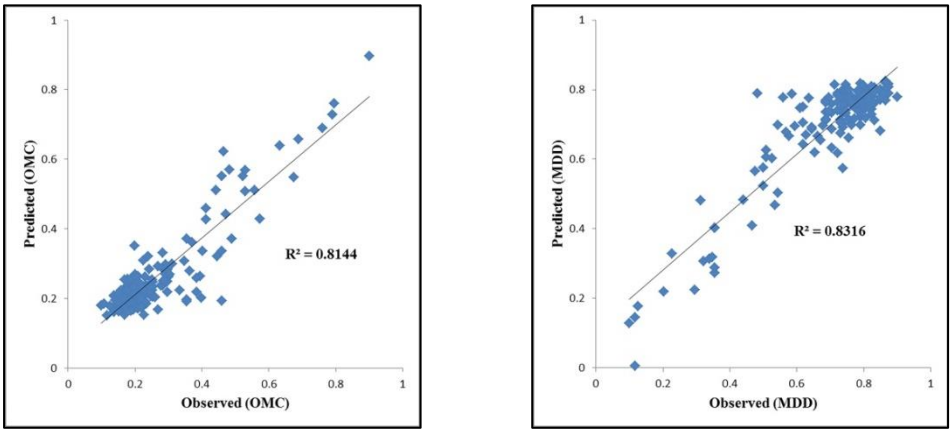
RESULTS AND DISCUSSION

Levenberg-Marquardt's Model

This part of the paper discusses the results of the model developed using Levenberg-Marquardt's algorithm. The results during training, validation, and testing are shown in Table 3 and Figures 5 to 7.

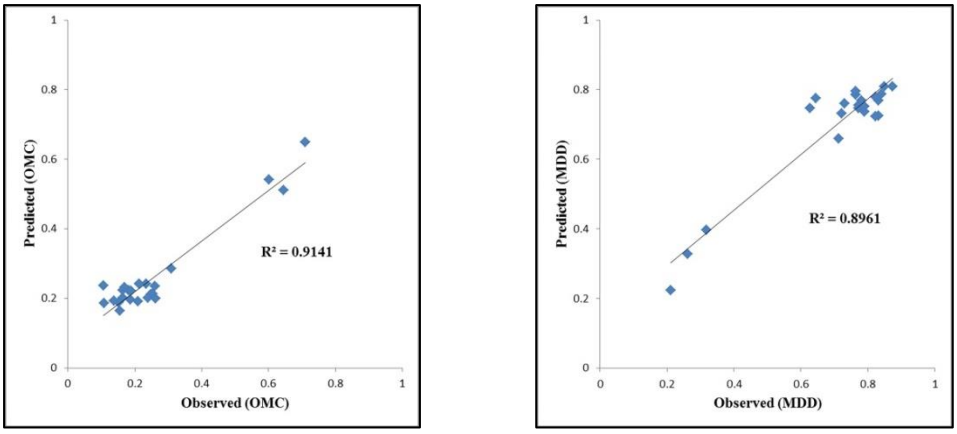
Performance metric	training		validation		testing	
	OMC	MDD	OMC	MDD	OMC	MDD
MAPE (%)	18.77	2.96	25.56	2.98	19.25	2.11
MSE	0.0035	0.0045	0.0033	0.0039	0.0029	0.0021
RMSE	0.0589	0.0668	0.0572	0.0626	0.0544	0.0463
R^2	0.8144	0.8316	0.9141	0.8961	0.9472	0.9511

Table 3: *The results of Levenberg-Marquardt's model.*



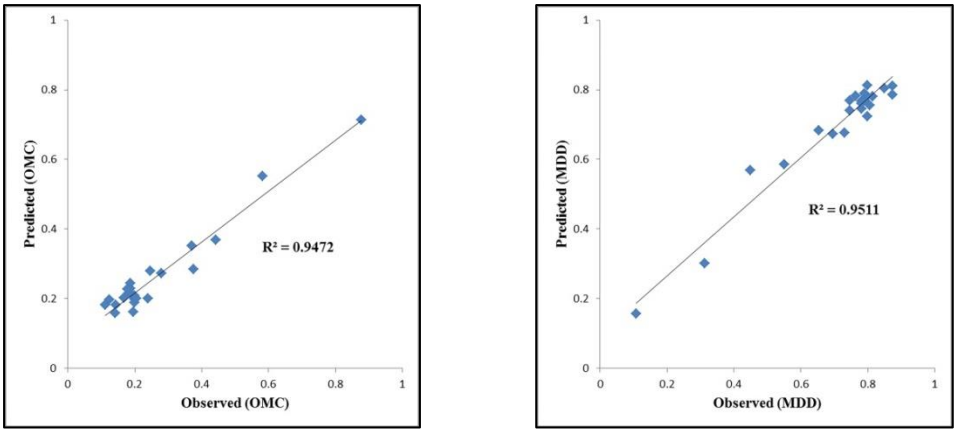
(a) *(b)*

Figure 5: *Training results: (a) predicted vs. observed (OMC), (b) predicted vs. observed (MDD) for Levenberg-Marquardt's model.*



(a) *(b)*

Figure 6: *Validation results: (a) predicted vs. observed (OMC), (b) predicted vs. observed (MDD) for Levenberg-Marquardt's model.*



(a) *(b)*

Figure 7: *Testing results: (a) predicted vs. observed (OMC), (b) predicted vs. observed (MDD) for Levenberg-Marquardt's model.*

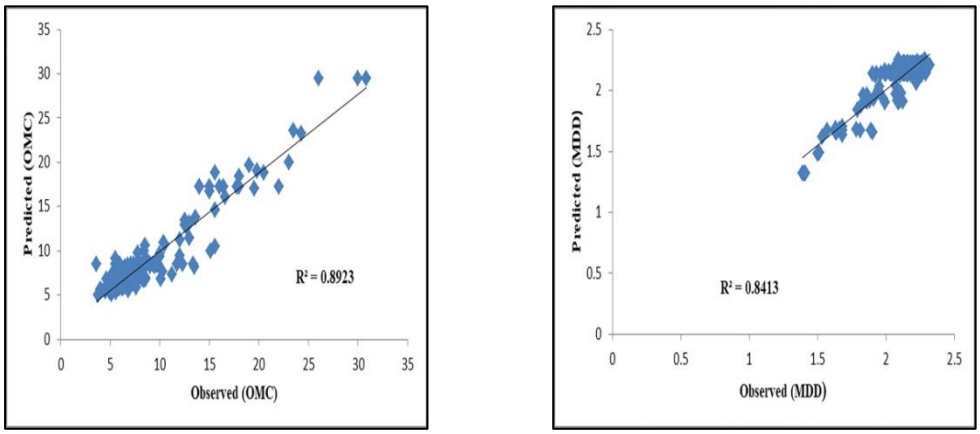
Stochastic Gradient Descent's model

This part of the paper discusses the results of the (ANN) model developed using stochastic gradient descent. The results of training, validation, and testing are shown in Table 4 and Figures 8 to 10.

The two models achieved high (R^2), and low error indicated by the three metrics (MAPE, MSE, and RMSE) during training, validation, and testing.

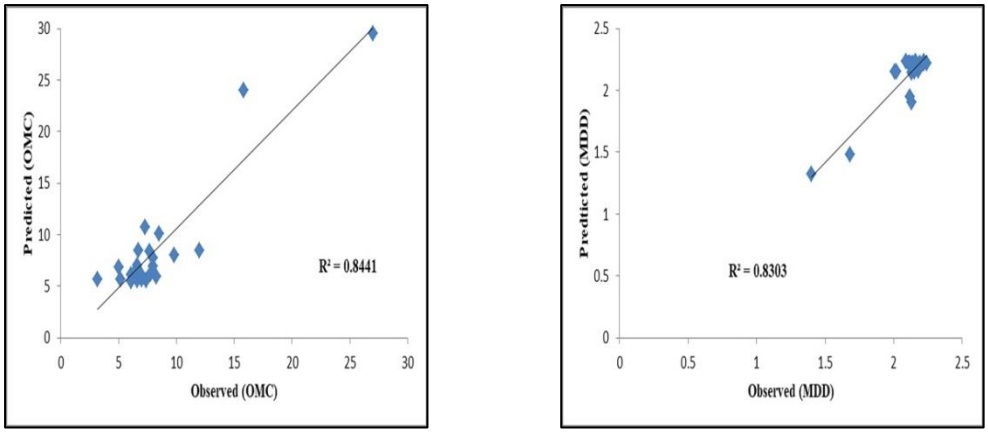
Performance metric	Training		Validation		Testing	
	OMC	MDD	OMC	MDD	OMC	MDD
MAPE (%)	13.97	3.05	19.96	3.99	20.98	2.55
MSE	2.5655	0.0064	5.8192	0.0105	5.824	0.0047
RMSE	1.6017	0.0799	2.4123	0.1022	2.4133	0.0688
R^2	0.8923	0.8413	0.8441	0.8303	0.8331	0.9055

Table 4: *The results of the stochastic gradient descent model.*



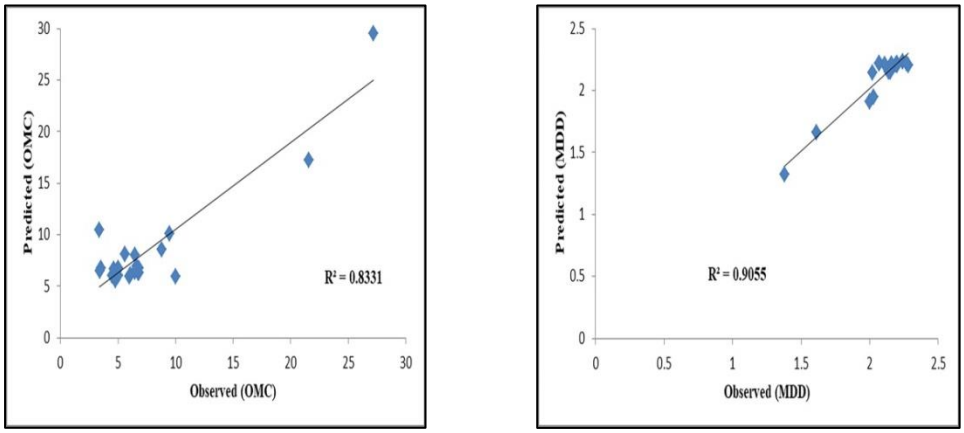
(a) *(b)*

Figure 8: *Training results: (a) predicted vs. observed (OMC), (b) predicted vs. observed (MDD) for Stochastic Gradient Descent's model.*



(a) *(b)*

Figure 9: *Validation results: (a) predicted vs. observed (OMC), (b) predicted vs. observed (MDD) for Stochastic Gradient Descent's model.*



(a) *(b)*

Figure 10: *Testing results: (a) predicted vs. observed (OMC), (b) predicted vs. observed (MDD) for Stochastic Gradient Descent's model.*

CONCLUSION

This research showed that the developed models can predict the optimum moisture content and the maximum dry density at a standard proctor compaction effort for different types of soils. This is indicated by their small error and a high coefficient of determination. The ability to predict the soil's compaction characteristics without the need for the compaction test has a lot of benefits. It can save time and resources during the geotechnical investigation stage. Such models can allow engineers around the country to decide in an instant without needing to transport soil samples several kilometres to be tested in another state. They can bring development to less developed areas in the form of large-scale projects like road construction, embankments for irrigation canals, earth-fill dams, etc. The models are hence deemed to be satisfactory in predicting the compaction characteristics of soils at a standard proctor compaction effort.

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REMARKS ON IDENTIFICATION AND APPROACHES OF PROTOTYPE BUILDINGS IN SUDAN_THE CASE OF PUBLIC SERVICES BUILDINGS

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Abstract

Contemporary architecture in Sudan has been influenced by modernization which has appeared in colonial architecture during the British era. The colonial architecture led to an architecture that paid little consideration to the prevailing local and regional context. Accordingly, the approach of prototype architecture has become a phenomenon for several types of buildings such as public services buildings. However, there is a lack of research considering this phenomenon in Sudan. This study aims to investigate of prototype design approach in governmental services buildings in Sudan. through analyzing the prototype building design and the response to the local context. A detailed analysis of building form, layout, and construction system has been carried out for six case studies. Structured interviews were conducted with architects, some of them had been involved in the design of some of the adopted case studies. The study has concluded that most of the prototype architecture application in Sudan has neglected some aspects including local environment and architecture for the sake of preserving similar building form and layout. Moreover, Prototype application has been classified into; identical, hybrid, thematical, and modular applications according to the method of replication. Prototype design can be more successful if the application adapts to site context, environment, and local architecture. The modular prototype can be considered as one of the successful practices in governmental services buildings such as school buildings where an identical unit; the classroom; is assembled or fragmented to create the school building layout.

Keywords: Prototype Building, Public Services Buildings, Sudan.

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SOLVING THE URBAN PROBLEMS FROM WITHIN: THE CASE OF MAYOUP

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University of Khartoum, Sudan

Abstract
Mayo Mandella, an IDP on the outskirts of Khartoum city, encapsulates 600,000 refugees and suffers from a vulnerable habitation environment of feeble infrastructure and the merest hint of sustainability. The Italian Agency for Development Cooperation (AICS), the Faculty of Architecture (FoA), University of Khartoum (UofK) and ARCò - Architettura e cooperazione (Italy) joined forces on a project that aims to improve the lives of Mayo's population by equipping the community of Mayo with the basic skills needed to build sustainable houses, while presenting the Ghaar Hiraa School as a live token. This paper encapsulates the endeavors towards enhancing the resilience of Mayo's community by improving its physical built environment. The prevailing problems were extracted from the outcomes of a survey conducted to collect data about the community and to study the status quo of the built environment in the neighborhood. The data collection employed observation and structured surveys to report and list the main issues in design and construction. A selection of 30 houses, with varying levels of damage and various conditions, were included. According to the survey, a recognized repeated pattern in the chronology of damages was recorded and found to be affected basically by weathering; typically, by rains. Building a school for the community – along with its direct impact on providing educational services – was efficient in raising the potential of the self-built construction techniques of the community to decrease the vulnerability of the houses to climate conditions. The construction of the school employs appropriate and environmentally friendly materials for the main envelope and the foundations. Practicing these construction techniques adopted a participatory approach to ensure achieving the ultimate goal of the project.

Keywords: Sustainable Construction, Appropriate Technology, Environmentally Friendly, Community Participation.

INTRODUCTION

Proper successful sheltering, is a crucial factor to the existence and wellbeing of humans (A. O. Windapo 2004), and ensuring evidence for their peace, as it contributes in the conveyance of safety settling and the feeling of belonging. However though in our vulnerable communities of developing countries, this factor of safety is always threatened through fragile and feeble construction. Amateur labouring, economic shortages, absence of infrastructures, less durable materials and the inconsistency of maintenance (Wells 1999) all fall within the domain of the leading causes behind vulnerable construction. To underpin the vernacular architecture of Mayo and change it from a collapsing to a well standing one, the major focus was dedicated to the training of the architects themselves, the original users, and the residents of Mayo. The aim was to pass on the techniques of a durable and suitable construction through involving them in one.

Aim of this Paper:

This paper aims to discuss the usefulness of appropriate technology that has been part of the project's aim, in regard to the community and culture of a specific context. It also demonstrates how this benefits them in the long term, through which methods and the usefulness of the techniques followed through. The objective of the paper is to demonstrate how appropriate technologies that are community sensitive could be adopted and shared. In an approach to acquire peace and settling, displaced residents may accommodate one's self to new changes, as a form of adaptation. The approach used to strengthen the self-taught knowledge and skills of building, is what this paper will handle explaining, discussing along the case of MayoUp.

MayoUp Project in a Brief:

The MayoUp project therefore-initiated by *The Italian Agency for Development Cooperation (AICS)*-is an attempt to equip the people with very simple and healthy techniques that are able to achieve a sustainable architecture. This type of architecture is described by Norton (1999) as environmentally friendly and relates to the climate of the place-Mayo in this case-economically and culturally fitting while using durable materials that are easily and successfully maintained over the time. Along applying a sustainable architecture, the approach also considered a community participation method. To be able to accommodate the solutions to the genius loci of the place, the context of Mayo was studied and regarded in the design and construction, with the help of the residents, all the while using the rehabilitated *Ghaar Hiraa School*, as a live token embracing within itself the approaches encouraged by the project. Designed by *ARCò - Architettura e cooperazionez (Italy)*, the concept depended largely on modularity and scalability, sustainable materials and matching praxis to the one already adopted there.

Method of Implementation to Achieve Aim:

A. Participatory approach: involving and engaging the community in the formulation of the problems and in developing the appropriate solutions
B. Collaborative approach and Partnership
C. Capacity building rather than ending up with technical solutions solely; on job training – demo project.

Mayo in a Brief:

Mayo was first initiated informally as a camp, in 1991, 15Km South of Khartoum (Figure 1). Today it became an official IDP that hosts about 600,000 multi-cultural refugees, settling in the different neighbourhoods that developed there. Both planned and unplanned settlements grew shelters in four blocks around all of Mayo, each given a specific name (Figure 2). The project takes place in Mayo Mandella, one of the four areas of main Mayo, which in time, has been divided into two parts itself, known as 'old' and 'new', with the new being urbanely planned and the old unplanned. As a result, the features of an original plot and its borders became unclear with absence in major services (Figure 3).

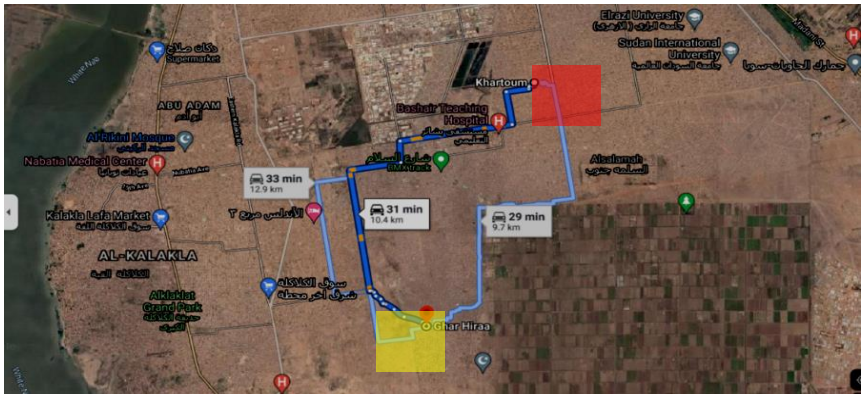


Figure 1: *Shows the direction from Khartoum city (red square) to Ghaar Hiraa school (yellow square) in Mayo Mandella, field of work. Source: Google map, edited by author.*

Figure 2: *Shows Map of Mayo divided into its 4 sections. Source:* (AICS 2021)

Mayo Mandella:

Services in Mandella extends to include a clinic and a mosque containing a Khalwa (a religious summer school/class for kids) within. Later when Ghaar Hiraa School was built it became a major service too and a landmark to the place, not only for being located in the central square of the neighbourhood, but for the significance a school can add, augmenting education. The urban setting is complemented by the vernacular houses radiating from around the square and extending toward the outskirts of the town. Intersecting properties between the houses' plots and the services of the area; like the mosque (Figure 3) and the clinic for instance, is a result of random urban settings.

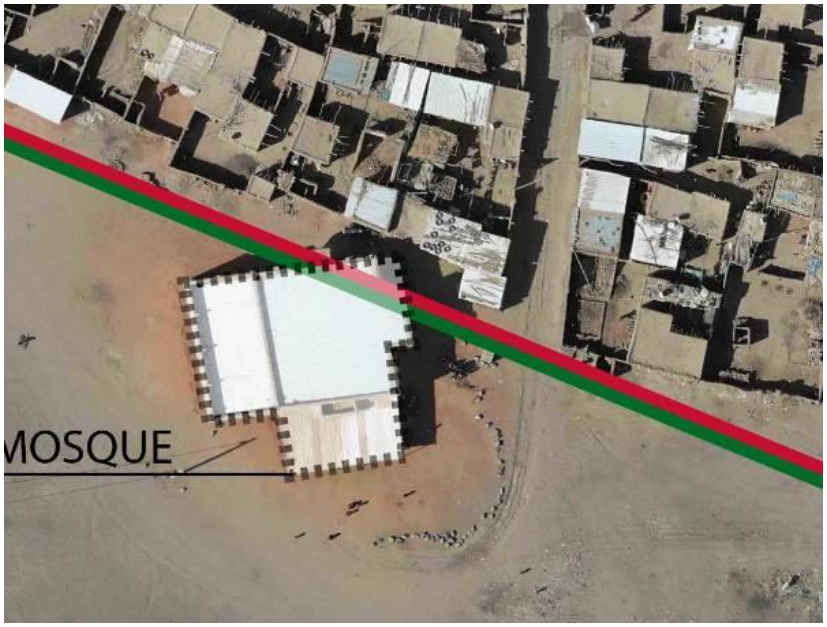


Figure 3: *Mosque's plot and other residential plots intersecting roads. Source: Google Map, edited by author.*

Mayo Mandella's Vernacular Architecture:

Most of those houses are made and designed by the residents themselves, in a process known as the vernacular architecture, which is by the people and to them, described also by (Bustillos 2007) referring to this process as the "engineering without engineers". As those houses reflect smart construction techniques, they unfortunately fail to fulfil sustainable construction. Sustainability in construction is described by (Singh 2007) as a construction that follows suitable methods and techniques, relatable to and do not harm the environment but improves it; a construction which is affordable and involves durable materials assembled together through a design concept that respects the culture after having studied it. Hence, in an area where child labour is involved in brick manufacturing, and the materials used are expensive when compared to the average income of the people, the whole process does not support sustainability but contradicts it, (Moon 2007) . Commonly, the materials used in the construction are sourced from either the available materials in the surrounding (category A), recycled from previous demolishes (Category B) or ones dominating the market (Category C, but this is an expensive alternative and thermally uncomfortable). As mentioned previously, the problem is the short-sighted construction and the unorganized pattern of maintenance. They are more of a temporary solution, with low tolerance, hence houses fail to resist weathering marking the failure in protection provision and leading to homelessness again.

Typical Mayo House Depiction:

The image below shows the elements and typology of a typical house in Mayo, in order to develop a clear understanding about the vernacular spatial design (Figure 4).

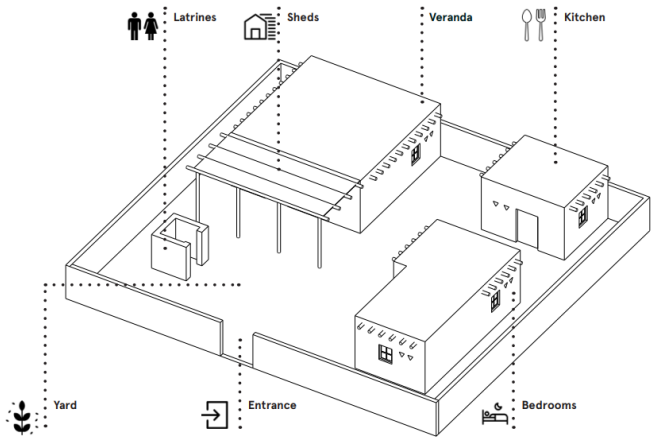


Figure 4: *Isonometric showing the combination of spaces and designing elements in the Mayo vernacular architecture. Source: (*AICS 2021).

THE PROJECT APPROACH (METHODOLOGY):

As previously explained in the aims of MayoUp , the approaches that were adopted to help reach the aim of the project depended on: a) Understanding the context of the area (the genius loci); b) Presenting to the people a collaborative approach that solidifies the necessity in their presence in building their own community and serves the third point of; c) Capacity building for strengthening the skills and the abilities of the individuals, in such a way that enables them to be ready to handle all the upcoming shortcomings after having learned new methods.

The Field Visits:

In order to present a context deemed design, one should fully understand the factors that shaped Mayo into its current architecture, and to learn about Mayo's praxis, through a deeper study of the everyday life's details and the challenges facing them and their background which is definitely manifested somehow in some way in the designs. Here comes the other complementary role of the field visits, in which a field survey was performed by the university's members. The visits were not only about getting introduced to the problems, but also introducing the solution (the school) to the people and receiving their remarks and thoughts. Methods followed were targeting quantitative data collection and observation.

The Survey Structure:

30 houses (check figure 6), randomly picked from both plots of Mayo Mandella (old and new) underwent the investigation of the survey. This included 16 open ended questions and multiple-choice questions with predefined answers offering respondents the chance to choose and rank among several options (AICS 2021). The content of the survey was categorized as social, medical and health, and architectural related questions. Below is an illustration.

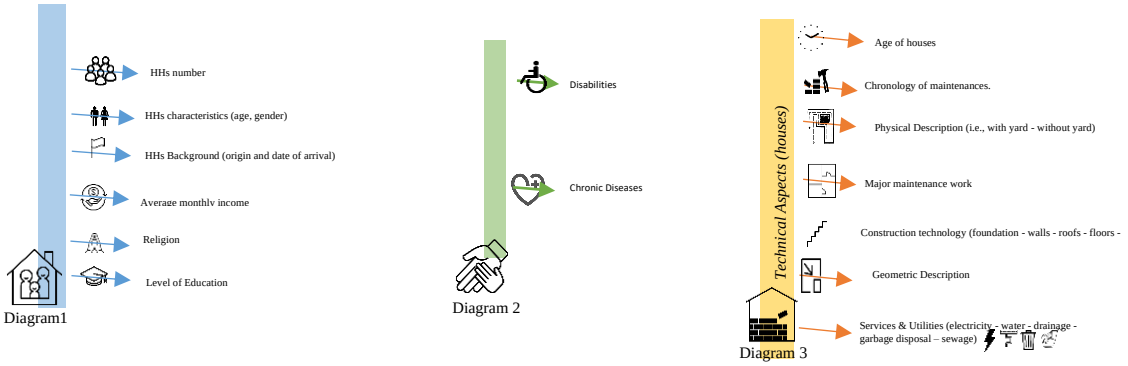


Figure 5: *Diagrams1,2,3 illustrate the sections of the survey and the associated questions. Source: Designed by author*

The survey was concerned with the chronological damage of the houses, as it traces the constructive activity and thinking of the users, the age of recycled materials in use and the attitude adopted towards certain problems (e.g., over flooding). (Check Figure 9)

Figure 6: *Old and new Mandella houses investigated, numbered & highlighted in yellow Source:* (AICS 2021), *edited by author.*

SURVEY RESULTS

This section will handle discussing the detailed results and the common problems and their magnitude.

Classification of Problems in Mayo Mandella:

Problems could be divided into 3 categories: a) Architectural: concerned with the house as a mass; b) Services : concerned with the urban facilities; c) Social: concerened with the people/families and their personal problems. In general, all problems could somehow be related and leading to one another, in a sort of a loop, yet the light here is spotted over the architectural damages in the houses, which in turn contributes to the vulnerability of the living environment.

Most Common Architectural and Technical Problems:

A) Collapsing Housing Elements and Vulnerable Materials Use:
Houses lose their ability to function as a shelter when primary elements like the walls and roofs fall or become liable to falling, featured as bulging walls and sagging roofs. Consequently, protection as an essential role of sheltering is lost or threatened and privacy is robbed away.

The walls collapse due to:

- Insufficient depth of foundation and inconvenient use of material (unplastered mud brick)
- Loose bricks and insufficient adhesives between the wall members.
- Loads distributed unequally, due to absence of essential support members (wall pillars across full wall length for example)
- Walls unprotected against dampness and moisture.
- Unmaintained wall cracks

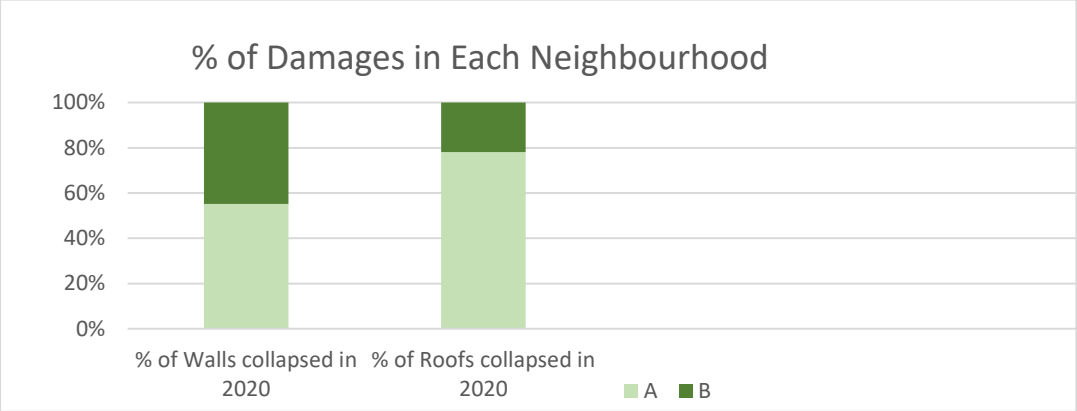


Figure 7: *Chart showing the % of collapsed roofs and walls. A &B refers to the old and new plots respecitvely. Source:* (AICS 2021).

Houses in Mayo are built mostly of mud; together with animal manure (mainly cow dung - Zibala) and hay, in a combination known locally by the name Jaloos. Jaloos is either used as the main building material, or the plastering cover to building elements, with the latter creating a covering protective layer to the main element below. The resilience of these materials could last for long periods of time only when they get regularly maintained, otherwise they are liable to moisture saturation which weakens their endurance and leads eventually to its wreckage. Other materials serve as complementary materials, depending largely on the economic status of the family. This range of materials could expand to include; Adobe bricks, steel mesh, zinc sheets and most importantly timber/hay strays, used primarily for roofing sheds and room roofs in other cases. Materials are not to be blamed fully for construction weaknesses, for in some cases, it is the accuracy of the construction method that proves to be inefficient. Take for example the absence of deep foundations or/& enough adhesives like mortar which leads to loosen members hence it becomes very easy to shift position from time to time before they eventually fall forever.

Figure 8: *Picture showing the variety of materials used in building, one builds on top of another as each follows a collapse event. Source: Taken by Stefano Rosso, November 2020, edited by author.*

B) Over Flooding: During rainy seasons and because of the water leakage through permeable roofs, stagnant water dam inside rooms and even yards, and are left to dry naturally or manually by the house members leading to much unrest. Remnants of walls left after its collapse and constant sand mounding in yards to dry leads to an uneven yard ground that traps more water. This water stagnation majorly causes health problems.

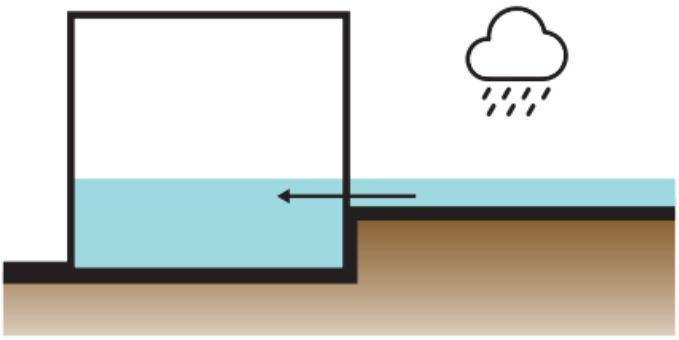


Figure 9 *Sketch drawing shows the idea of water overflooding into rooms from elevated yards. Source* (AICS 2021).

C) Thermal Discomfort: Use of concrete blocks, zinc and steel sheets and joists. These materials are more durable than mud brick and wooden joists, but they are thermally uncomfortable. To compensate for this environmental eccentricity, and to houses where it is affordable, people would use thermal proof sheets in roofing, or in the very rare cases, an AC.

D) Lack of Natural Daylight and Ventilation: blocked openings for safety and privacy measures cause dim and unventilated interiors. Stacking of random spaces due to the frequent changing needs eventually leads to a blocked room in between other space too (Figure10).

Figure 10: *Plan belongs to one of the investigated houses,it shows an example of a stacked up distribution, and rooms rented separately as a means of income to the owners. Source:* (AICS 2021).

Proposed Solutions:

Solutions were meant to be capacity building and relate to the surrounding fabric of Mayo, whether it be through the cultural embracement or the technical /construction approach. Having to consider fixing the materials' distribution and construction method and allowing people to be included in the construction of the school itself, as suggested by ARCò - Architettura e cooperazione (Italy), the school design focused on the simplicity of the techniques to be in

hand to all the Mayo people. The school was more of a workshop to all those who were into the profession of labor.

A) *Solution Targeting Construction:*
   Proper Material Distribution and Material Mix Proportionality:
B) Environmentally Friendly:
C) Other advices: the project's solutions also included advices on the best type of soil to use (not the directly topping soil), the ratios between elements in adhesives and material combinations. Also check figure 12.
D) Tools in hand: The solutions suggested tools that are as simple as human feet and hand, shovels and soil screens. (Other tools can be included depending on what type of construction is taking place, figure 13).

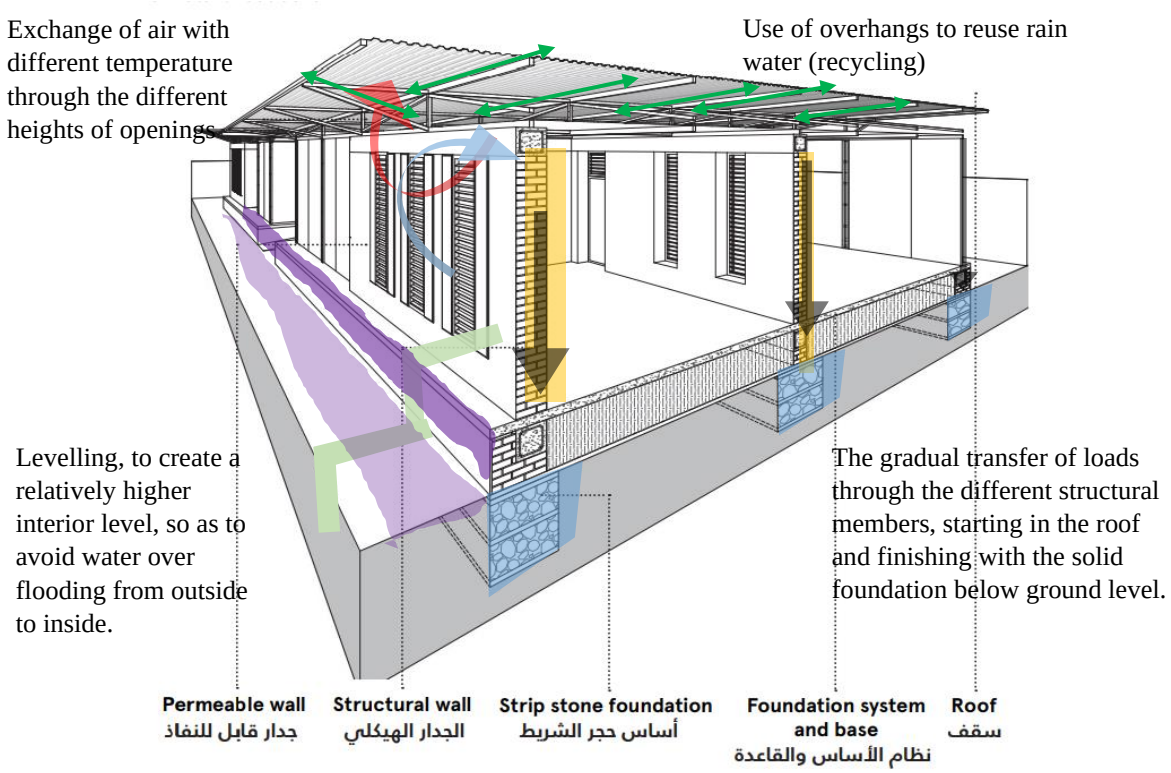
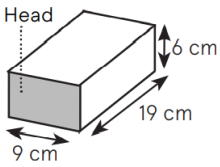
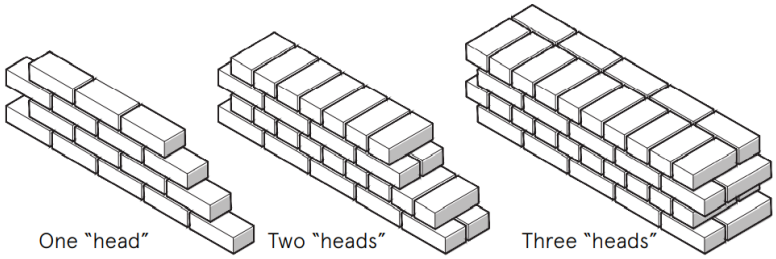
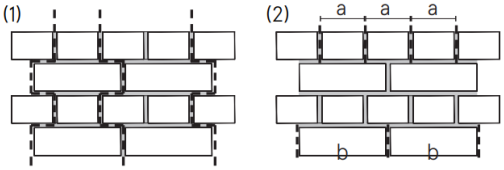


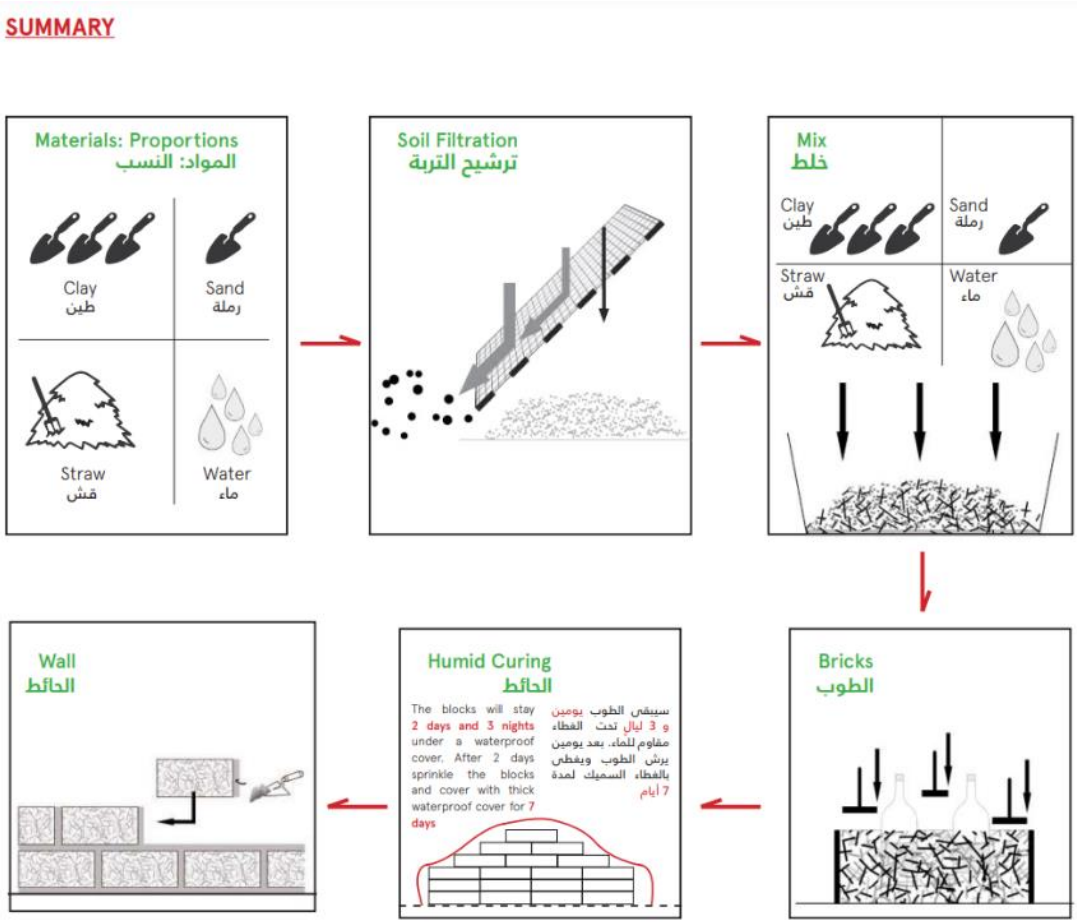
Figure 11: *Isonometric explains the solutions in the school that can be applied in the construction of the houses . Source:* (AICS 2021), *edited by author.*





The joints must always be appropriately staggered in order to avoid creating parts of lower resistance. (1)
The thickness of the mortar joint is the same in all layer of the wall. (2)





Figures 12, 13: *(Respectively) explains the appropriate materials' ratio and positioning of bricks to maximise stability. Source:* (AICS 2021).

Community Participation and Inclusiveness:

The passing on of those solutions did not happen theoretically alone, but practical classes in a sort of small workshops were given to the residents with applied examples for simple techniques. Yet the school itself was the main live token for the demonstration of those

techniques. To set a further stronger depth, labors from the community's houses were called to labor the school and attend the construction from the scratch as to be witnesses and spread the knowledge

Figure 14: *Picture Showing members of the labouring community during a break time, with one of the site engineers. Source: Taken by Stefano Rosso, December 2020.*

CONCLUSION

The gap in the work of the residents in building their own houses, is about reaching to the healthier and more suitable solutions. The assisting of the NGOs in covering this gap was focused on presenting appropriate solutions that matches the context of the area and fits itself to the available resources. This was accomplished through presenting an example (Ghaar Hiraa School) and allowing the part of the community to involve in the construction. The real investment is when the part of the community joined in the construction pass on this knowledge to the rest of the residents. Additionally, the idea was also to equip the residents with a lifetime solution, the process rather than the end result, in such a way that guarantees a standby response present today and for the coming future. Moreover, the quest for a smart use of material, the relatively best practice in regard with the place and the available resources, to introduce the sustainability concept to the current construction. This approached revealed to the residents which material fits better in a specific place and for a certain function, considering environmental aspects. In most of the solutions suggested the construction tools are already available (shovel and sieves), sometimes they just need muscle work (feet and hands). It is majorly about performing the processes precisely and carefully, rather than involving high-tech approaches. The approaches that were suggested by the project were meant to be very simple and practical, introducing the best practice basic idea and underpinning a sustainable architecture through varying introductory steps which could be used by the citizens of Mayo in dealing with the slightest obstacles of an everyday life. In order to acquire best results that are beneficial for future projects and use them to help convey these approaches to other communities, Mayo community should be investigated on the results of these sustainable architecture approaches, after having implemented it, where they could show how they were able to benefit from it and were the weaknesses have been. Through this feedback, there could

be further development of techniques and a research material to ensure best results and eventually acquire peace in our communities, through implementing an appropriate technology.

ACKNOWLEDGEMENT

We would love to acknowledge with much appreciation the financial aid of the AICS (The Italian Agency for Development Cooperation) their guidance and moral support. Acknowledgement also extends to ARCò - Architettura e cooperazione (Italy) team for their engineering work and community training, Hope Sudan and the SDDRC. Further thanksgiving to the University of Khartoum members for their educational role in performing the field research and the survey.

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ACHIEVING RESILIENCE IN COASTAL COMMUNITIES: A CASE STUDY OF JABAL AWLIYA LOCALITY, KHARTOUM-SUDAN

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Abstract

Flooding has become a global concern, as flood risks are causing extensive damage and are threatening the lives of many people around the globe. Since July 2020, heavy rains and flooding combined with the historical overflow of the river Nile and its tributaries have affected most of the states in the Sudan, causing devastating damage alongside riverbanks in the northern, central and eastern regions of the country. More than 100 people have lost their lives due to the floods and displacement. Massive destruction of infrastructure has been reported, (some 9,000 families along the Nile across the country have had to leave their homes as a result of the floods, and 4,288 families were affected in Khartoum State). This study aimed to assess flood risk on the study area through performing a vulnerability and exposure analysis to enhance understanding of what makes cities resilient, and to raise awareness of the important role that good planning and architecture play in achieving flood risk management. The study focused on the most vulnerable areas to flooding in Khartoum State, taking Ash-gelab-Al-Hasaneia neighbourhood in Jabal Awliya Locality as a case study. This study conducted questionnaire survey, field survey mapping, and personal observations,150 questionnaire survey was randomly distributed covering around 20% of the selected area households.The results revealed that there is no treatment for the Shoreline and surface drainage, and the current houses in terms of design and building materials used are unable to combat flooding.The study recommends stabilizing the shoreline with proper embankment, re-plan the land use zoning to place neighborhoods entirely outside any flood hazard area, suggest building design to include elevated ground floors, pitched roofs, impervious building materials and advanced construction techniques in order to achieve resilient cities objectives.

Keywords: Resilient Cities, Building Design, Building Materials and Techniques.

INTRODUCTION

There is no agreed meaning of a resilient city. However, a strong view represents a city that is able to continue to function in severe circumstances and crises, and recover from disruptions (Stevens et al., 2010). It promotes the development of a self-reliant community that sustains people's livelihoods using adequate technology. Recently, debates about the possibilities and desirability of resilient cities took place against several phenomena backgrounds, such as climate change. Climate has been changing significantly, and this will result in rising sea levels and further flooding risks, consequently increased health risks, decreased agricultural productivity and freshwater supply issues will occur (Metz et al., 2007). Floods have become a global concern, with flood hazards causing extensive damages, and are responsible for more than half of all disaster-related deaths and a third of economic losses from all-natural disasters (Bradford et al., 2012). In Sudan the severity of the 2020 flood event caused devastating damages, almost 900,000 people across 18 states were affected in the country, over 140 people died, 94,000 homes were destroyed, and 83,000 homes were damaged. An estimated 2.2 million hectares (26.8%) of agricultural land were flooded, as well as US$3.34 billion was lost. In Khartoum State, the capital of Sudan around 100,000 people are affected and need urgent

shelters (OCHA, 2020). Therefore, on 4th September 2020, the Transitional Government of Sudan declared a three-month state of Emergency and formulated a higher committee headed by the Ministry of Labour and Social Development for disaster response. Flooding at Khartoum occurs as a result of three distinct types: flooding from the Nile; local ephemeral streams, and diffuse urban runoff. Nile flooding is influenced by the total of summer rainfalls over the Blue Nile headwaters area in Ethiopia, while the two latter types of flooding are caused by intense rainstorms over the Khartoum region (Walsh et al., 1994). The floods of 2020 have been caused by unprecedented torrential rains mostly in Ethiopia that have caused the Nile to overflow downstream in Sudan the River Nile reached 17.58 meters - the highest level in 100 years. The rates of floods exceeded the records set in 1946 and 1988. To address this gap, this study aimed at answering the following questions:

(i) What are the urban planning principles pertaining to integrated flood risk management?

(ii) What are the facilitators and barriers in Sudan to the implementation of urban planning and building design processes related to integrated flood risk management?

(iii) How best to formulate an urban planning technique associated with flood mitigation in Sudan to achieve resilient and sustainable development?

The answers to the above questions enable the following objectives to be achieved: a) to enhance understanding of what makes cities resilient, and b) to raise awareness of the importance of good planning and architecture in achieving flood risk management. The vulnerability analysis includes determining the building's elements' sensitivity to the floods' damage and building types in terms of construction materials. The exposure analysis includes the physical attributes and location of the neighborhood in addition to the extent and depth of the floods.

LITERATURE REVIEW

Globally, urban flooding is increasing and is expected to be more damaging in the future as a result of global warming and climate change (Muller, 2007; Munich, 2009). Furthermore, urbanization impacts the process of controlling the streamflow of the channels of the river (Baoshan, et al 2009). This trend will increase significantly the hazards risks related to climate and would aggravate chronic and periodic water shortfalls and generate an increase in the intensity and frequency of extreme weather hazards (Mujumdar, 2008). However, urban flooding is also associated with unplanned urbanization, and low investment levels in flood risk management and flood-resilient infrastructure (Tazen, et al, 2018). Flood risk management aims to have a positive impact on reducing human, social and economic losses. It involves both structural and non-structural strategies (Figure 1); the structural measures mitigate flooding by reconstructing landscapes such as levees, embankments, and floodwalls, while Non-structural measures reduce damages by removing people and property out of risk floodplains such as improved land use planning, relocation, flood forecasting, and warning. Non-structural measures are considered more effective cost when compared to structural measures. Also, it can be sustainable in the long term with minimal cost in operation, maintenance, repair, rehabilitation, and replacement (Tehmeena & Saini, 2019).

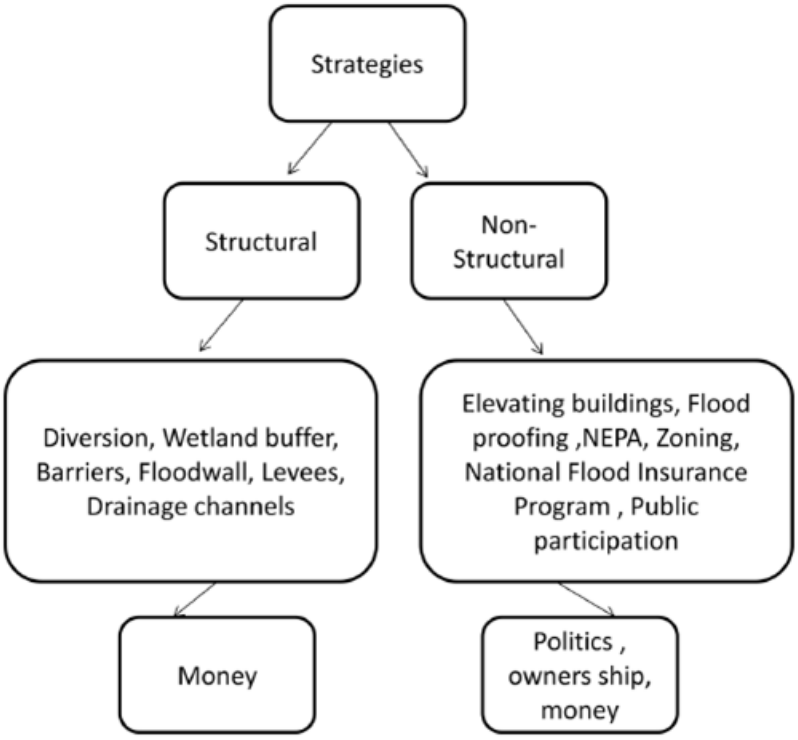

Figure 1**:** *Flood Management Strategies classification (Source: Adapted from Pin-Hao, Huang, 2014).*

Few attempts have designed artificial networks comprising storage ponds, and water channels and constructed wetlands in order to discharge urban floodwater (Wang et al 2006). However, the large infrastructure used to reduce flood risks has not been effective (Evans et al, 2006). Thus, the need for an integrated approach consisting of both structural and non-structural responses to combat flood risks and also to maximize various functional chances for land use is essential (White, 2010). The urban planning approach to manage flood risks is now perceived as an effective method of decreasing flood risks (DCLG, 2009). Flood risk management is categorized as large-scale, medium-scale, and small-scale. Large scale takes a broader approach to reduce the impact of floods (Jha, et al 2012). This includes dredging, adding conveyance channels, and modifying rivers with dams. Installing retention ponds also assists to handle overflowing river water. Further flood risk management mechanism is to restore floodplains or wetlands to act as a buffer zone for the river. These multiple large-scale methods to manage flood risks are costive but are highly effective. The medium-scale includes smaller strategies, such as constructing sustainable flood control parks to catch rainwater runoff. Small-scale flood risk management includes urban planning and design and usually functions at street level, for example, building elevations, wet and dry floodproofing, and installation of devices on the sewer drains to prevent backflow. This could also include structural soil cells, porous pavement, and swales (Huang, 2014). Flood modeling and mapping represent a novel approach to flood risk management in Dar Es Salaam, Tanzania, these included community mapping projects in flood-prone areas in the city using Open Street Map as a data source. Engaging the community with the flood modeling and mapping activities from inception to completion has led to more accurate results in portraying urban flood risk (Gebremedhin, et al., 2020). In Mozambique, non-structural flood measures reduced the rural vulnerability of communities to floods. These included increasing the people's awareness of preparedness and flood. Furthermore, rainwater harvesting infrastructure is adapted to provide a clean water source during floods (Lumbroso, et al 2008). In Egypt, flood risk management for roads included

constructing in the upstream catchments a chain of contour stone bunds with reduction dams further downstream (Monsef, 2018). In Sudan's capital Khartoum, the UN-Habitat implemented emergency flood response for vulnerable communities as part of the 2003-2016 country program development. The objective of the program is to conduct emergency construction of necessary public utilities and infrastructure by adapting flood-resistant urban planning and construction techniques. Over 170,000 people have benefited from project interventions in terms of accessibility, flood protection, access to basic services, and capacity building (UN-Habitat, 2016). Furthermore, the Regional Science and Technology Advisory Centre and the National Council for Civil Defense 2021 organized the first National Platform for Disaster Risk Reduction in Sudan, with the cooperation of the Federal Ministry of Government, the Arab Science and Technology Advisory Group, and UNESCO, have tackled the disaster risk reduction concepts, early warning system, rain forecast for July, August, and September, the future vision of the valleys in reducing disaster risk, the role of reservoirs in reducing flood risk, the impact of GERD dam on floods in Sudan, the impact of floods on archeological sites, ministries roles in reducing flood and flood risks (UNDRR, 2021).

This study focused on risk as an interaction between flood hazards and the vulnerability of communities, systems, and areas. Therefore, the risk is seen as an outcome of exposure, resilience, and susceptibility (Percival, 2019). Yet the detailed assessment of risk is associated with the interaction of inherent characteristics of population and area at risk (vulnerability) (Lindley et al. 2011; Birkmann et al. 2013). Understanding levels of flood vulnerability in a region is vital to effectively reduce flood risk and improve resilience. The concept of vulnerability emphasizes the social construction of risk and can be used to help understand the risk associated with a given situation (Birkmann et al., 2013). The hazard event is no longer regarded as the only determinant of risk. In fact, adverse effects are also driven by society's vulnerability and its systems, and this can be categorized into three distinct components: (exposure) physical vulnerability, (susceptibility) socio-economic vulnerability, and limited resilience. Consequently, in order to determine vulnerability and risk, in the study presented here, the traditional risk hazard and vulnerability relationship have been addressed by combining these three components into one. The result is a formula that can be tailored to cover the many facets of vulnerability since vulnerability entails a variety of relationships and elements that are susceptible, exposed, and unable to recover from harm or adapt to it (Percival, 2019).

METHODOLOGY

To achieve the research objectives, the study used a triangulation approach including:

(i) Desk Review Research

This comprises the review of primary and secondary documents related to the field of study to *achieve Resilience in Coastal Neighbourhoods;*

(ii) Quantitative Method - The Survey Questionnaire

A semi-structured survey questionnaire was conducted on 150 respondents from the *Al-Shuqilab Al-Hasaniyah* neighborhoods in Jabel Awliya Locality. The survey included a random sample of house locations, household size, length of time living in the area, house ownership, gender, age, educational level, employment status, income level, housing condition, the level of public services in the area, flooding damages, and flood mitigation techniques. The survey took place in a period of three months between March 2020 and June 2021.

(iii) Qualitative Method-Personal observation and interviews

CASE STUDY SELECTION

The study focused in the most vulnerable areas to flooding damage in Khartoum State (Figure 2), the Jabel Awliya Locality has been affected with highly flooding damage, 1.500 households and 2.000 pits larine in the Locality have faced a strong impact of destroyed properties and displacement. This study presents *Al-Shuqilab Al-Hasaniyah* neighborhood in Jabel Awliya Locality as the case study. The criteria of selection for the study area is based on choosing a flood-vulnerable neighborhood along White Nile River with considerable damage caused by the flood to assess the flooding damage and enhance the understanding of what makes neighborhoods resilient.

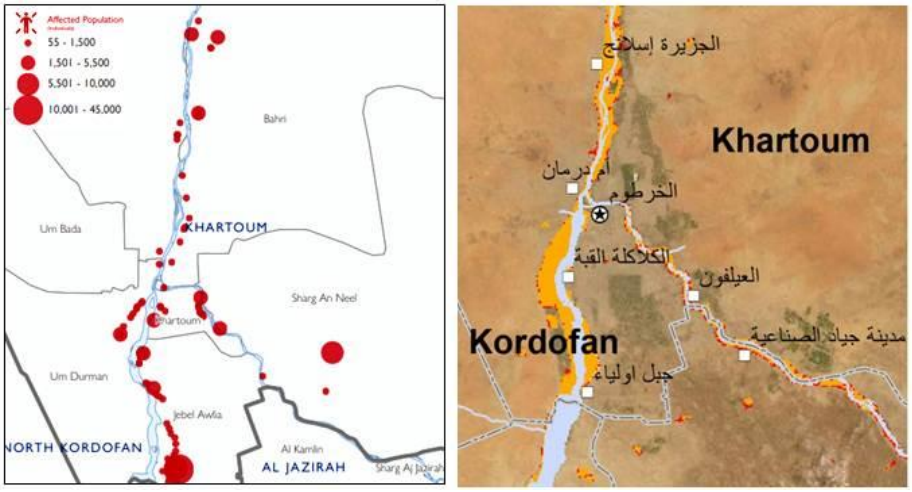

Figure 2: *Left: Depicts the affected population for the flood risk on 2020. Right: Flood water over Khartoum (Source: https://reliefweb.int/map/sudan/flood-waters-over-khartoum-state-sudan-20-august-2014).*

In this initial study, we select to analyze only a portion of the community because dealing with the possible hazard mitigation strategies for a larger portion of the community acquire various actions, such as displacing and relocating public infrastructure. Although the selected neighborhood is not vast, nevertheless it is a complex system of buildings with different typologies and functions, in addition to the civil infrastructure systems comprising lifeline networks and transportation systems. Therefore, this pilot study focused on residential buildings because of the high physical damage and the socio-economic vulnerability caused by floods. Physical vulnerability encompasses the physical assets, which are exposed to the risk of floods due to their proximity to the coastline, such as buildings, roads, critical infrastructure, etc. (Kaźmierczak and Cavan 2011; Cardona et al. 2012; Menoni et al. 2012).

To investigate the area's physical vulnerability, the physical characteristics were classified through observation and assessment. Risk is expressed by the equation of: Risk = Hazard+ Vulnerability + Exposure (Percival, 2019). This equation was utilized to analyze the flood risk of buildings; the adopted steps of analysis is diagrammed in Figure 3.

On the above equation of the urban flood risk taking the building as an evaluation unit, the essential factors in the equation can be expressed as the following:

(i) The exposure of the building to the upcoming floods is determined by its location from the shoreline and the physical elements' characteristics of the building in itself.

(ii) A vulnerability analysis presupposes a non-structural factor index, which represents the amount of physical, social, and economic damage that can result from flooding in a

building (expressed in the building as a whole). Subsequently, the physical and economical damage of each building is assessed by collecting the data directly from the damaged areas.

(iii) The hazard analysis is based on identifying the precipitation data and terrain data, where the flood depth in the flooded areas can be determined. The distance of the shoreline from the neighborhood and the elevation level of the neighborhood from the shoreline.

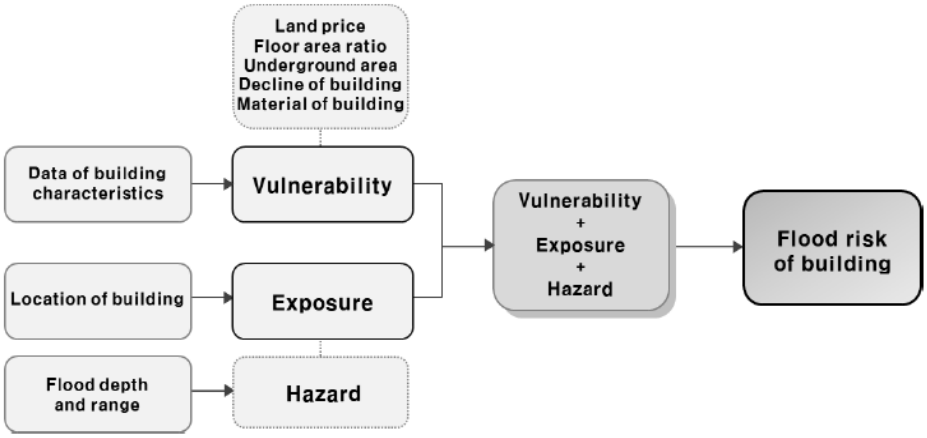

Figure 3: *Analysis Framework of Floods Risk Building Source: Percival, 2019.*

Al-Shuqilab Al-Hasaniyah Neighbourhood

The selected neighbourhood is located at Jabel Awliya Locality (Figure 4), which occupies an area of 615 sq.km. It is situated at South of Khartoum at a distance of 40 km along the White Nile River. The total population of locality was estimated 942.429 people according to the 2008 census. The locality has a composite climate which is divided into three seasons. winter season (December-February); average temperature is 26.8 °C, summer season (March- September); average temperature is 31.7° C, the rainfall occurs between mid-July and September; the wettest weather is in August with 120 mm; the maximum rainfall is 522 mm in August (Sudan Meteorological Authority, 2010).

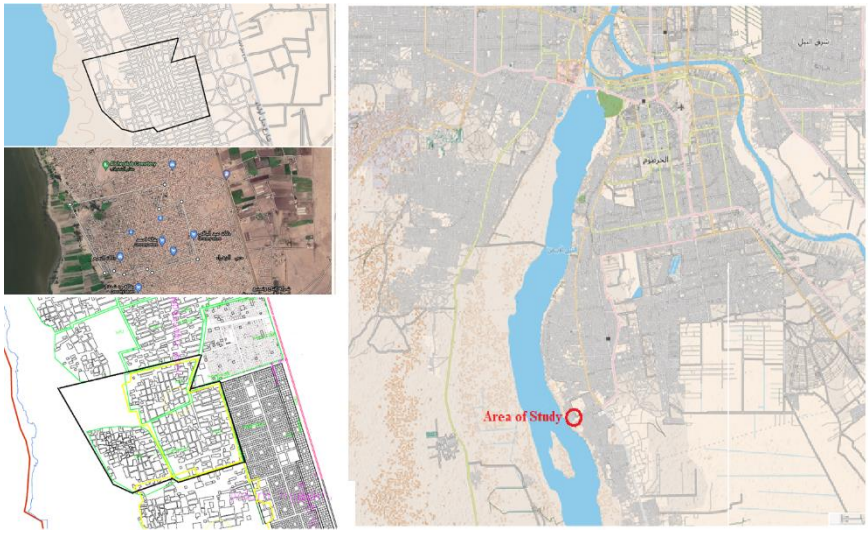

Figure 4: *Mapping the Neighbourhood. Source: www.openstreetmap.com.*

SURVEY FINDINGS

(i) Assessing the Neighbourhood Exposure and Expected Hazard

This assessment implies the analysis of the physical setting of *Al-Shuqilab Al-Hasaniyah* neighborhood. The terrain has a few scattered rocky heights and sandy formations flat with seasonal khors that drain the stormwater in the river Nile; there is an alluvial fertile soil along the White Nile River. The land use is divided into three main zones; 60% residential, 30% agricultural, and 10% services (Ministry of Planning and Public Utilities, 2020). The neighborhood pattern is an organic pattern (informal growth), the informal growth of residential fabric was guided by social customs and norms. The satellite map shows that the elevation of the neighborhood is varied between 382m to 388 in comparison to the elevation of the adjacent White Nile at 377 m (Figure 5). Several residential blocks are in adjacent elevations to the shoreline's elevation with a difference of fewer than 10 m heights. According to the Sudan Meteorological Authority, the flood level in 2020 exceeded 17 meters. The area then is highly exposed to the hazard of any floods. In addition to that, the study examined the Nile River shores and riverfronts; the findings illustrate that the Shore of Jabel Awliya Locality has no proper embankment for protection (Table 1). According to the field survey, the distance between the shoreline and the neighborhood is 300 m, this indeed increases the extent of the exposure to the floods, from questionnaire results, 95% of the respondents suffer from the hit of the floods. The interview with the committee representatives reports the full damage and loss for 187 houses in the whole area. The exposure of building elements to the floods mostly affects the Mastabas (Pavement in front of the building), where 78% of the houses' *mastabas* were hit by the floods. The floods cover 28% of the houses' front yards (*housh*), (chart 2).

(ii) Assessing the socio-economic vulnerability (susceptibility)

The socio-economic environment information was based on a questionnaire and interviews; a questionnaire was conducted on a sample of 150 households; it covered 20% of inhabitants in Ash-gelab-Al-Hasaneia neighbourhood. According to the survey finding, the population of *Al-Shuqilab Al-Hasaniyah neighbourhood* is around 6.009 persons; The population density is about 46 people per hectare (4.622 people per km^2); the density is low due to the settlements sprawl in wide area with landed properties. 45% of the respondents are males and 55% are females, the household size range between 3 and 9 people, giving an average of 6 persons per household. The number of extended families is close to the number of nuclear families by a percentage of 47% and 53% respectively. 55% of the respondents are aged between 18 and 35 years and represent the more productive groups in the neighbourhood. There are about 860 housing units, of which 90% are owner-occupied, units and 10% are rented. The monthly income of the people varies between 100US$ to 200US $. 80% of the inhabitants earn less than 100 USD per month, which indicate and reflect the level of poverty among these groups; (survey findings, 2020). The economic losses caused by the flood damage may reach 1,000 USD at the minimum estimation to renovate the damages per house unit. This estimation is based on the assumption of renovation of the fence wall, where 72% of the respondents suffered from severe damage to their houses' fence walls. The losses then may increase in line with the extent of the damage that affect the building elements (chart 1). Government financial support is very scarce as only 4% of the inhabitants have been compensated by the government. Most of the inhabitants, at a rate of 90%, depend on self-financing to support the maintenance or reconstruction. This is despite their poor economic situation. In 6% of cases, community support occurs, which reflects the strength of social bonds between members of the community.

(iii) Assessing the physical vulnerability

To assess the physical vulnerability, the physical condition of the buildings and their elements, fragility to damage must be assessed. The field survey examined the different building elements, such as foundations, walls, roofs, fences, floors, and *Mastabas* to categorize the construction method, materials, and resistance to floods. The level of the building also is examined in comparison to the level of the street. As depicted in chart 3, the survey reveals that 90 % of the houses in the neighborhood are one-storey buildings which may be linked to poverty and deteriorated economic conditions. Nearly 40 % of the houses have no well-constructed foundations named in this study as the shallow foundation. Only 8 % of the buildings were based on Reinforced concrete footings, while the rest were constructed on a traditional strip foundation. The commonly used structural system is the load-bearing walls, 48% of the houses' walls are constructed from adobe (compacted unfired brick), while 18% are built of red bricks with sand mortar. Therefore, nearly 60 % of the buildings' walls are fragile to damage, especially due to the risk of floods or rain storms. 36% of the buildings were constructed of red brick with proper cement mortar. 80% of the utilized roofs are under the category of light roofs, the traditional roofs made of tree stems, reeds, and thatches in the common roof type at the rate of 60 % of the neighborhood. The other 20% is gone for the metal corrugated sheets. The jacked arch roof represents 10 % and the reinforced concrete slab roofs are 20%.

The fences are the first defense line to stop the runny floods from invading the houses' inner spaces. Nevertheless, 50 % of the fences' walls are fragile because of the construction method and materials. All the fences are load-bearing walls constructed by the usage of mud in 20 % of the houses, adobe in 40%, and fired brick with sand mortar in 8%. Neither the construction method nor the materials are considered flood resistant, consequently, the amount of vulnerability is high. In addition to the social role of the *Mastaba (*front pavement) that acts as an extension to the inner spaces of the house. It has a secondary role of protecting the fence's wall from the hits of floods and rain storms. It is found that 78% of the houses' *Mastabas* were hit by the floods. Despite this role, but 65 % of the housing units have no front *Mastaba* and 25% are applying compacted sand to create the *Mastaba*. Just 10 % of the houses are protected by well-constructed *Mastabas*.

The houses' fences are the most element that showed a high rate of damage at 72%. This was caused by the fragility of the walls' materials and construction methods and also the inexistence of the *Mastaba*. The inner yards of the houses (*Alhoush*) are in common finished by a layer of laid sand. Only 3% of the inner yards' floor finishes are tiling. The level of the inner yards is in most cases lower or on the same level as the street. Consequently, the exposure probability to floods is increased, 92 % of the houses are overflowed by the streets' water. The extent of damage is in most cases rated as medium, which means damage on the fence and one or two rooms' walls or roofs. 28 % of the houses experienced a high rate of damage. The families tend to repair the damaged building parts in 34% of the cases and rebuild it using the same technique and materials in 38% of the cases. 84%. The extent of damage is in most cases rated as medium, which means damage on the fence and one or two rooms' walls or roofs. 28 % of the houses experienced a high rate of damage. 84% of the respondents described their renovation as temporary and not durable when they asked about their level of satisfaction with the maintenance of the damaged parts.

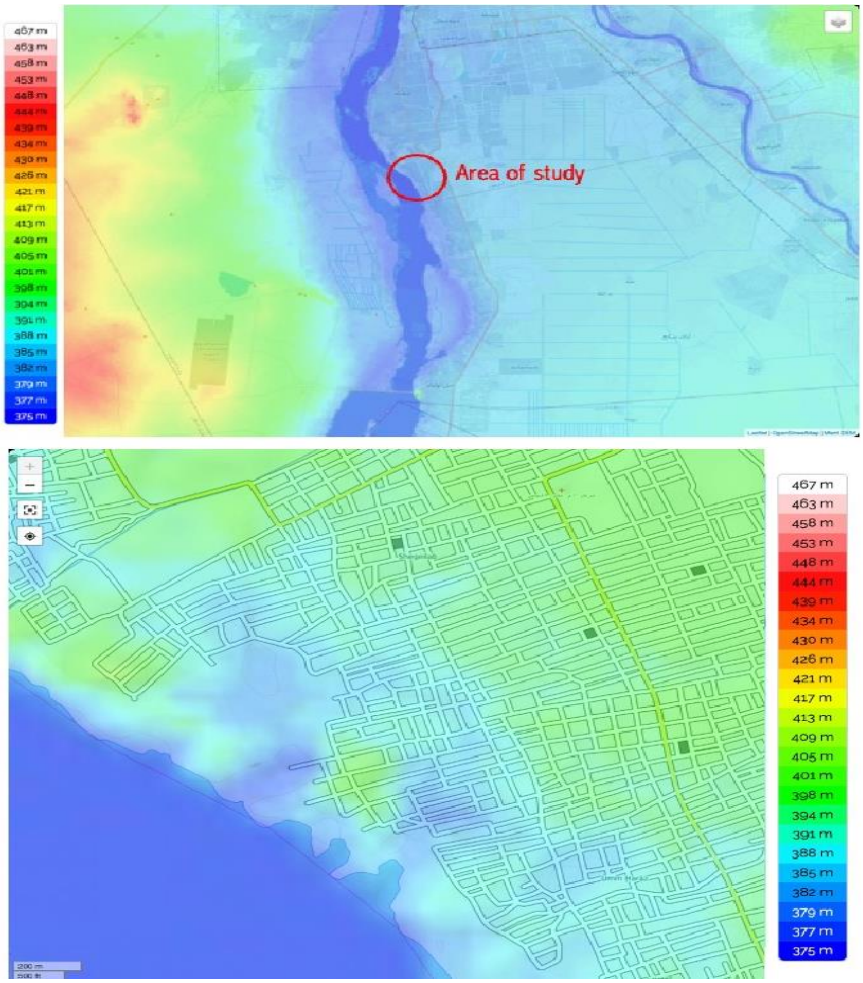

Figure 5: *Neighbourhood's Topographic Map, Elevation, Relief. Source: https://en-in.topographic-map.com/maps/l24h/Khartoum.*

Description	Shoreline
Location of the Shore and its Riverfront	Western Locality edge From Saliha Bridge to Jabel Awliya Dam
Length	32 km
Area of Floodplain in acres	185 Sq.km
Floodplain land use	Agriculture and fish industry
Land ownership	Governmental and Private
Existing Bank Protection	None
Soil Type	Clay Loam
Stability	Unstable
Accessibility to River Shore	None
Length of Asphalt Street in km	None
Important Buildings on Riverfront	Private Housing Building
Recreational Facilities	Around Jabel Awliya dam
Storey Height of Riverfront Buildings	One Story
Panoramic View of Riverfront	Regular Low Height

Table 1: *The General Condition of Jabel Awliya Locality Shoreline.*

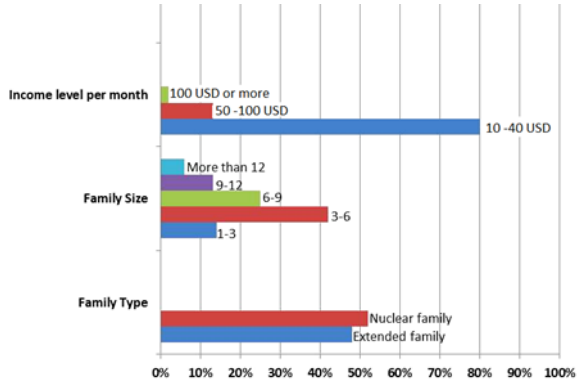

Chart 1: *Depicts the Demographic Information of the Population in the Neighbourhood.*

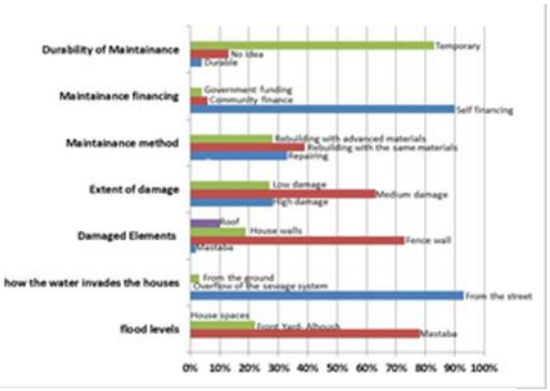

Chart 2: *Depicts the Physical and Economic Vulnerability by Analyzing Different Damage and Maintenance Measures.*

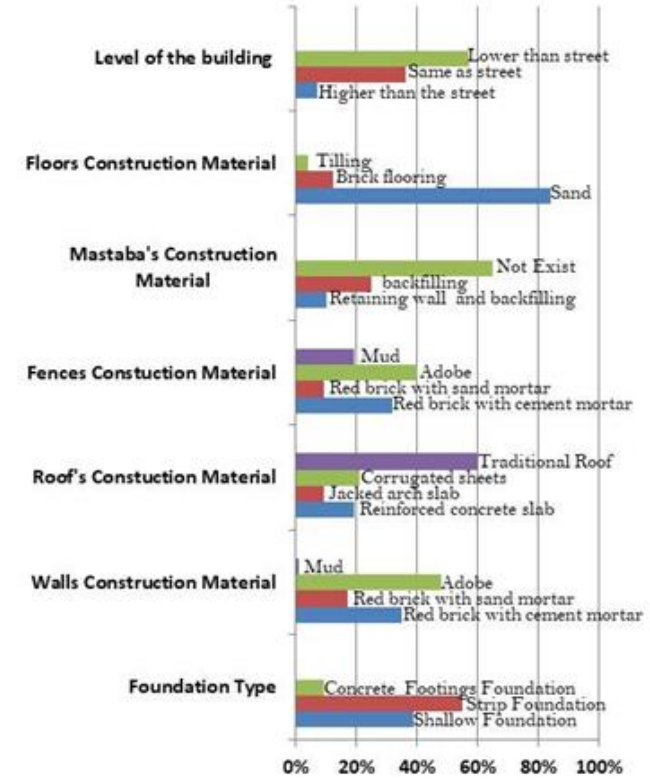

Chart 3: *Depicts Different Construction Methods and Materials of the Different Building Element.*

RESULTS AND DISCUSSION

The results showed that inadequate planning and house design plays a major factor in increased flood vulnerability. The lack of vegetation to absorb large amount of flood water increases the area's vulnerability. Flood risk management begins with proper zoning maps. The zoning maps should include open spaces along the Nile shore that can be used as flood risk management without trespassing on private property. Constructing retention ponds along the shore line of the neighbourhood presents a low-cost flood risk management in *Al-Shuqilab Al-Hasaniyah* Neighbourhood. There could also be flood control parks with infiltration basins along the shore. Most of the houses are located close to the shore line and are not elevated and have no storm water facilities or barriers. Temporary flood barriers are low-cost and can be easily and quickly placed. They can be placed along the residential streets to protect the houses or each house can

place an individual barrier as the houses are detached. More trees should line the street to absorb more floodwater. The sidewalks should be of porous material to further increase flood water absorption. The existing street network is insufficient in managing flood water runoff. The results showed absence of drainage system. Channels or ditch systems should be constructed to allow flow of flood water runoff.

Most of the houses in *Al-Shuqilab Al-Hasaniyah* Neighbourhood have front yards which can easily operate as infiltration basins to decrease flood water runoff. From the front yard excess water can flow to the swale and then to the ditch. This system could much improve ability to manage flood water runoff.The results also showed that the levels of houses are same as the street level. This increased the vulnerability of houses to be flooded or eroded by the flood. Elevated houses showed great effectiveness in protection against flood. The survey findings showed that the majority of the residents are from the low-income group 80%. Consequently, they could not afford to construct elevated houses, due to the high cost of building materials and construction. Furthermore, the government do not assist in constructing such houses. Therefore, the study recommends elevating the houses only to be above the max. rainwater threshold level to be reached during the flooding season (max. rainwater threshold level recorded throughout the flooding was 203.5 mm 5 August, 1988 (Walsh et al., 1994), and in 2020, the Nile water level at Khartoum reached an unprecedented level (380.65 m asl) as reported by Elagib et al. (2021). At a larger scale the Nile shore should be lined with wooden debris at locations where water floods into the neighbourhood to protect the shore line from erosion and provide suitable habitat for native animals and plants. Building materials should reduce the flooding impact, regardless of the orientation and height of the house.

CONCLUSIONS AND RECOMMENDATIONS

Globally, climate change resulted in extreme weather events. Consequently, flood extent and frequency will increase. For almost two centuries, people relied mainly on structural measures, such as levees, dams and floodwalls to control floods. However, in the mid-20th century, flood damage was on the rise even with significant structural approaches use (Evans et al, 2006). Flood risk management strategies should consider integrity, regional characteristics and ability to cope with extreme future flood conditions. Therefore, non-structural measures, such as, risk mapping, Land-use planning and zoning and building codes and construction standards were used. Resilience strategies should be used to inform sustainability and suitable strategies. The recent flood events in 2020 exceeded the highest levels previously recorded in 1946 and 1988, and it caused massive loss to property and lives. The future of flood events is predicted to increase in frequency and intensity. These huge damages revealed that are gaps and defects in Sudan's disaster management system. Nonstructural measures of flood mitigation are considered more effective cost when compared to structural measures as found by Huang 2014 and White, 2010. Huang (2014) recommended that flood damages can be reduced by raising structures above the expected level of flood. Wet and dry flood proofing can greatly reduce damage to structures. Wet flood proofing incorporates making uninhabited parts of buildings resist floods by enabling water to flow through the building. Dry flood proofing involves seals in buildings to prevent water from entering, such as, wall reinforcement to withstand pressure of flood water, use of sealant to decrease flood water leakage through walls, installing waterproof shields over openings, doors and windows. Adequate land use planning remains the heart of non-structural flood mitigation techniques and an effective planning tool for mitigating flood damage at the community level (Gebremedhin, et al., 2020; White, 2010). Land-use planning involves the implementing public policy to direct use of land in a given area. This is

managed by zoning ordinances and takes place in various government levels. In Sudan, when stakeholders develop flood prone areas and are not aware of the potential flood risk, they suffer when flooding occurs, because they are unaware of the risk in locating lower areas occupants at safety and economic disadvantage as found by Birkmann et al. 2013. In Sudan, the study area and many deprived neighborhoods are located along the Nile River, and the inhabitants depend on it for their livelihood such as agriculture, fishing, etc., therefore, residents cannot leave those areas. In this study we studied flood risk management strategies in flood prone neighbourhood *Al-Shuqilab Al-Hasaniyah* Neighbourhood from an urban design and architectural perspectives and proposed flood risk management techniques. The main purpose was to consider solutions without destroying the character of the community. The attempts included integrating flood risk management with design aesthetics. In this study adapted and considered three management strategies recommended by Huang 2014: shoreline retrofit (placing wooden debris to improve erosion resistance), green street design (Using house front yards as high-water absorbent plant and swales) and individual housing unit design (elevated house unit). Hopefully, the proposed solutions can be applied likely to similar localities.

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THE ROLE OF SUDANESE PRIVATE SECTOR IN PEACEBUILDING IN WASH SECTOR: INITIATION OF INFRASTRUCTURE FOR PEACE PRACTICES

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Abstract
The recent progress in the transition towards democracy in Sudan enables the private sector to open up new opportunities for several economic sectors; this transition incorporates violence prevention and conflict management through the resilient peace-building. Peace-building encompasses a wide range of development and humanitarian programs, such as securing sustainable infrastructure services. Peace infrastructure plays an important role in fostering inclusive and resilient development in conflict-affected countries. The role of engineering consultancies and contracting is to develop sound infrastructure planning, management, and implementation, to eliminate the barriers and revitalize the Sudanese economy. This economic revitalization should be strengthened with crucial peace enablers in the immediate aftermath of conflict to provide the necessary foundation for sustainable development. The aim of this paper is to refute the opposing arguments over the private sector as profiteers of conflict. The paper reviews the root cause of conflicts associated with lack of adequate clean Water, Sanitation, and Hygiene (WASH) services in conflict-affected areas in Sudan, and how to engage the private sector as a third party for sustaining peace in the country. The mainstreaming of the private sector in Conflict Prevention and Peace-Building (CPPB) is studied internally through exploring the potential entry points for the private sector in WASH projects and the adoption of Conflict Sensitive Business Practices (CSBP). The external influence of the private sector actors in sustaining peace examines the integration of Corporate Social Responsibility (CSR) policies as a logical starting point for more ambitious peace-building goals. Action plans for engaging the Sudanese Private Sector in The African Peace and Security Architecture (APSA) operation are recommended. These action plans will strengthen the accountability of the private sector in conflict context by contributing to broader social goals which sustain peace, and enhance the role of business as peace actors.

Keywords: Private Sector, Peace-building, WASH, Engineering Firms, Conflict Sensitive Business Practices CSBP.

INTRODUCTION

Building Peace in countries emerging from conflicts and approaching democratic consolidation is very complex, because it involves a myriad of different players and stakeholders. The Peace-building process should stretch out the security, political, institutional, and socio-economic elements in a coherent and inclusive way (UN-Peacebuilding Support Office 2010). The Peace-building process should bring together all actions into the three phases: conflict prevention, conflict resolution, and post-conflict reconstruction, and these actions should reflect the three essential features of peace-building: (i) The National Ownership, (ii) The National Capacity, (iii) The Common Strategy. The contribution of human rights to peace-building has been increasingly acknowledged globally in recent years. Peaceful societies are built on the protection and promotion of human rights, for example, inadequate access to basic human needs can boil over the clashes in these societies especially adequate access to Water, Sanitation and Hygiene (WASH) services, which is often compromised due to the decline and

destruction of water and sanitation systems (UN Office of the High Commissioner for Human Rights 2020). Peace-building and sustainable WASH systems is inextricably linked, because inadequate WASH services threaten the survival of citizens in conflict affected states and undermine peace building and social development processes at all levels, and contrariwise, adequate access to WASH services can't be achieved without reviving fragile conflict affected states and sustaining peace in-order to spur economic growth that could ameliorate future conflict resolution.

As mentioned, effective partnership and synergistic efforts between major key players in conflict prevention is the key to sustain peace in war-torn societies; especially in human-rights-driven conflicts. The Private sector is one of the key players in the conflict prevention process, because it exists in all conflict situations and has the potential to both exacerbate and stave off conflict (Peschka and Emery 2011). Development dimensions such as political, economic, social, governance and security can be directly linked to private sector growth; therefore, this sector has potentials to contribute to peace-building in post-conflict states at the macro, meso and micro levels. Private sector engagement in peace-building has a spectrum of activities; this includes contribution to economic growth and social cohesion, principled job creation, infrastructure development, and the supply of different goods and services. Engineering firms, the leading private sector in infrastructure development, are not only the providers of technical solutions, but also the legitimate actor in resolving conflicts and analyzing post conflicts, related to frictions over natural resources and inadequate WASH infrastructure, especially in developing countries.

In recent years, several practitioners have developed different terms that concern the donors and Non-Governmental Organizations (NGOs), and describe Interactions between processes and paradigms which help develop cohesive social relationships and enhance social resilience against the risks of relapse into violence, by bringing together interdependent structures, mechanisms, institutions and capacities (J. Giessmann 2016). One of these terms is (Peace-building Infrastructure) which refers to the processes, policies and institution which are applied by government, private, international and national actors: judicial, legislative and executive, as well as financial system. Peace-building Infrastructure are characterized by depending on domestic capacities, through vertical and horizontal integration within all tracks, as well as providing a legal foundation and appropriate budget for peace infrastructure; establishing a governmental body dedicated to peace-building and providing guiding policy. Peace Infrastructure can be guided by internal and external activities within the engineering firms to support the complementary role of governments and donors in the peace-building process (Hopp-Nishanka 2012).

The state of WASH services in Sudan is grossly inadequate due to under development and the legacy of a protracted civil conflict. Lack of adequate access to WASH infrastructure in Sudan presents enormous challenges that include: geographic isolation, long distances, inequitable distribution of facilities, and in some cases weak governance and institutional setup (The African Development Bank 2016). As a consequence of poor or lack of adequate WASH infrastructure facilities and services in conflict affected states, economic activity has barely kept pace with growth in population, leading to the increase in unemployment rates (The African Development Bank 2016). The recent classification of the World Bank has listed Sudan among the countries with high institutional and social fragility due to the deep institutional crises, this classification indicates that conflicts are still looming in the country, and the government should foster the role of the external parties in spreading the culture of (Business for Peace) practices through adopting a sustaining peace lens to conflict response.

The partial lifting of the US economic sanctions on Sudan in October 2017 has unlocked new opportunities for the country to achieve greater and faster social and economic development. The recent efforts in Sudan make headway in transition towards democracy through shifting away from short-term peacekeeping and liberal peace transitions towards long-term peace-building. Despite these efforts, very modest attempts to engage the private sector in Conflict Prevention and Peace-Building (CPPB) process exist, and none looked at the significant role of private engineering firms in CPPB through infrastructure development, especially in the conflict prone states, hence making this study a pioneering one.

The aim of this paper is to break new ground in mainstreaming private sector business practices to peace building in the Fragile and Conflict Affected States (FCAS), through highlighting and projecting the globally-acknowledged Conflict-Sensitive- Business-Practices (CSBP) to the engineering sector. The potentials of engineering firms in peace action are examined by the integration of peace-building in Corporate Social Responsibility (CSR) activities in code of ethics. Action plans for engaging the Sudanese Private Sector in The African Peace and Security Architecture (APSA) operation are proposed for more peaceful business goals.

RELATED STUDIES

Donors and funding agencies experience with engineering projects in developing countries came to a conclusion that engineering firms have had to be developed beyond their technically-defined boundaries and be dedicated to work with civil societies and other volunteering trans-disciplinarity in resolving possible conflict effects. Peace-building practices conducted by private sector actors represent concrete ways through which they can contribute and involve peace-building processes. These practices were initiated in many conflict areas within Kenya, Uganda, Sri Lanka, Nepal, El Salvador, Northern Ireland and Somalia. REDROC Which is a local NGO working in Kasese district, introduced private sector actors involved in the Gravity Fed Schemes to the principles and methodologies of conflict sensitivity, so they become more aware of how their presence and interaction could contribute to conflict situations. In addition to providing background information on Mahango and Rukoki communities, REDROC emphasized the importance of gaining community confidence to facilitate their work. The consulting engineering firms had initiated inception and regular feedback meetings to communicate with beneficiaries and to change the way they work to accommodate their concerns. Consequently, the private contractors' work in Kasese was facilitated and they were increasingly under pressure to deliver high quality work, in response to greater awareness gained among beneficiaries of their duties, which enables them to monitor their work more closely (CECORE, *et al.*, 2008).

METHODOLOGY

Desk research and literature review are the predominant methods for data collection. The desk research explored documents published by NGOs, funding agencies, relief organizations and government authorities, captured the root causes of WASH conflicts in Sudan. Case studies and lessons learned from different countries are reviewed to introduce contemporary perspectives on how the engineering private sector and CPPB efforts have intersected and could intersect in sustaining WASH services in FCAS. The potential entry points for engineering firms are identified to demonstrate multiple instances for the contributions of these firms within different social, environmental and economic contexts in their operational areas. Scoping the

role of engineering private firms in conflict prevention, certain internal business practices are proposed to contribute to the achievement of peace-building throughout the life cycle of the engineering projects. The reinforcement of these core conflict sensitive practices by the development of internal responsibility standards and initiatives are studied, so that engineering firms (i.e., consultants and contractors) can then proceed to mobilize their human, logistic and financial resources to facilitate constructive and proactive actions during the stages of conflict escalation as well as in the immediate post-conflict period.

RESULTS AND ANALYSIS

Root Cause Analysis for WASH-Related Conflicts

Root Cause Analysis (RCA) for WASH-Related-Conflicts is an inter-disciplinary framework used to find the long-term invisible factor underlying causes for WASH conflicts in FCAS in Sudan. Fishbone diagram is an RCA schematic that becomes more integrated in social and economic development to solve various problems. RCA points out the causes of WASH conflicts in Sudan following the question: What are the interchangeable causes might potentially contribute to WASH conflict in Sudan? And what can be the potential entry points for WASH services in relation to peace-building that can be further adopted by the engineering private sector?

Regarding the above questions, Water scarcity is not what causes tensions, but rather how it is governed and administrated. The Inefficient utilization of available water sources, aging infrastructure, and inappropriate legal, political, institutional, and economic frameworks feed the chronic tensions arising from the scarcity of water (African Development Bank Group 2015). These factors can be predominantly beyond the control of particular state (Exogenous) factors, or can stem primarily from specific conditions within a particular state (Endogenous) (Jütersonke, *et al.*, 2015).

Data and information related to WASH status were researched. Situation analysis carried out NGOs and development banks were reviewed for the aspect of Operation and Maintenance (O&M), Monitoring and Evaluation (M&E) and the adequacy of WASH infrastructure to the projected demands considering climate changes and other uncertainties. Descriptive analysis of these documents revealed that major causes of conflicts in WASH sectors are attributed to: (i) Failure in WASH services (ii) Political factors (iii) Socio-economic factors (iv) Weak governance (v) Rules/Policies/Procedure factors (vi) Environmental Degradation. Figure (1) summarizes these causes using the fishbone diagram.

Entry/Influence Points

Entry points for the engineering private sector in peace-building should be carefully selected to avoid the exacerbation of conflicts. These points should be identified according to a certain level of influence (macro, meso and micro). The macro level of influence is concerned about the national actions that can be conducted and initiated by the engineering firms and are legalized by the government. Meso level of influence will focus on communities and are endorsed by community partners, while the micro level influence relates to internal business activities that are conducted by the staff (Louise Strachan 2017).

From the fishbone diagram (Figure 1), it is found that conflicts are triggered by social, environmental, institutional or even ideological causes. The following entry points are suggested to raise the influence of engineering firms in peace-building based on factors identified in the RCA:

1. *Business Practices (Micro Level):* Entry/Influence Business practices should emphasize the role of engineering firms in promoting poverty alleviation and social cohesion, and to be integrated into the internal management system and in the daily activities. Engineering firms should also demonstrate the concept that capitalism is not about the exploitation of people and that its benefits can reach poorer communities if consciously directed to do so.

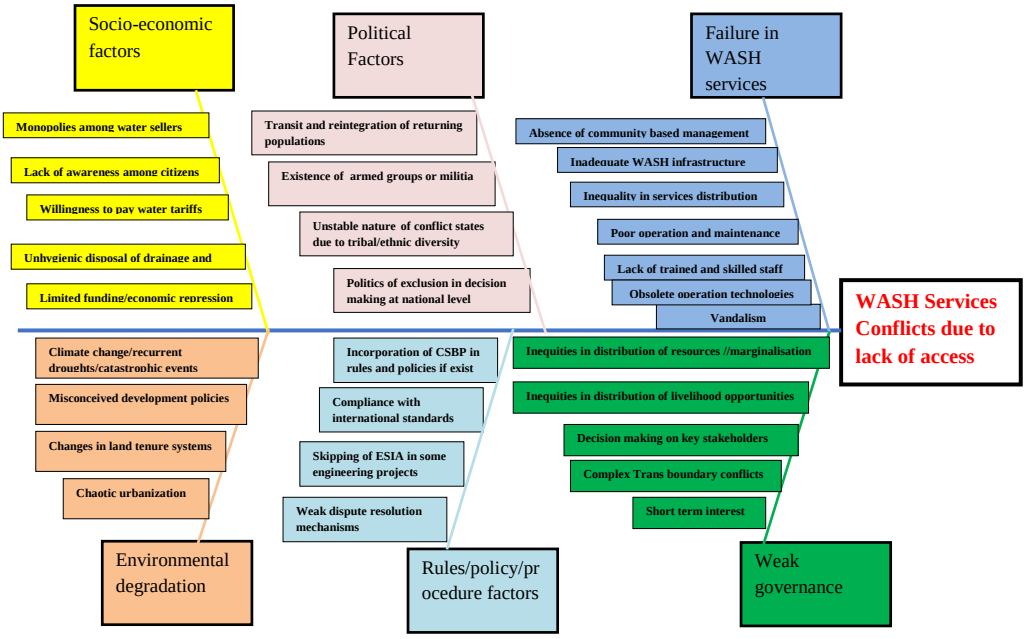

Figure 1: *Fishbone Diagram for WASH conflicts causes (Compiled by the author).*

The following business practices can be introduced by the engineering firms as proposed by International Alert (International Alert 2000):

1. The code of ethics for engineering firms should include conflict sensitive policies, guidelines, and operating standards. Human rights policies should explicitly reference the commitment to conflict and security resolution as part of a project's lifecycle.
2. Establishment of good relationships with local communities in areas where the company operates, and recruiting community developers where necessary.
3. Consideration of minimizing the environmental degradation and social disruption during projects O&M phase.
4. Increase tolerance and diversity in the workplace and at construction sites, and more widely in their host countries and communities via activities such as multi-ethnic and minorities hiring policies.

2. *Investment in new operation Technologies and practices (Micro level):* Recent operation technologies and practices were obtained as potential inclusive mechanisms in peace-building practices, by providing alternative and supplementary approaches to offline approaches and initiatives. Central peace-building models can be adopted by the engineering firms in the social studies associated with WASH projects, this includes:
    1. Early Warning & Early Response and Disaster Response (EWDR).
    2. Social /Attitude change.
    3. Policy change.
    4. Mapping for SDGs and International development.
    5. Technology for M&E.

3. *Job creation (Meso level):* It is generally assumed that peace-building can only be reached if socio-economic triggers are minimized through achieving sustainable growth for a prosperous life of all fragile communities. The creation of decent job opportunities falls under grievance-based theories of change for CPPB, because it improves social cohesion between these communities and breaks down the sources of division and increase trust. Engineering firms working on WASH projects usually adopt cost-effective approaches in implementation phases; these approaches support labour-intensive public works that employ large numbers of skilled and unskilled workers from local communities to ensure sustainable and efficient supervision as well as O&M of these projects. WASH projects require the use of heavy equipment and therefore needs labour-based method for construction planning, to restore the needed infrastructure for local economies. To anticipate bottlenecks that may arise from limited aid inflows and private sector recovery after prolonged conflicts, the government should collaborate with engineering firms to formulate proactive policies to train and re-locate available labour and to strengthen the local suppliers and contractors' network.

Conflict Sensitive Business Practices

Rationale

Engineering firms either consultants or contractors are one of the most conflict-affected business sectors, because conflicts charge a range of significant increase in direct and indirect costs for their proposed or ongoing projects. Engineering firms working in conflict-prone areas usually witnessed a drop in their market value from time to time, because unstable conditions jeopardize the ability of the engineering firms to generate profits in short and long terms. Economic sanctions and suspension of aid flows from development banks can cause future cash flows to fall short of expectations and increase the value of cash flow at risk for engineering firms. These drops in market value, can eventually lead to the impairment of the intangible assets, if managers are not dedicated to adopt engineering practices that can help to damper the flames of these destructive dynamics to the mutual benefit of their business and communities. International engineering firms located in conflict-affected areas may experience an impairment of their goodwill; high profile clients usually prefer the services provided by engineering firms at conflict-free zones, to avoid logistic constraints and delays in project delivery (J. Muscat 2014).

CSBP in project's life cycle

Conflict Sensitive Business Practices impose a wide range of techniques and conflict-management strategies to decrease the likelihood of the engineering project acting as a flashpoint for conflict, by avoiding negative impacts and identifying opportunities to promote stability in the operating environment. In yearly planning models for WASH engineering projects, peace-building objectives at the national level should be taken more into account and sometimes contribute to peace-building goals at the national level. The following guidelines should be followed during the engineering project's life cycle as proposed by Tearfund organization and relief organization (Tearfund 2018).

Engineering firms, especially contractors, can play a significant role in the development of CSBP because they are responsible for the implementation of the 'on the ground' activities, beside their continuous interactions with the local communities. Consultants and Contractors also can be responsible for the employment and the procurement processes and they are at the fore of decision-making regarding the location of WASH infrastructure to ensure equitable access for all beneficiaries. The attitude of engineering firms in planning, design and

implementation of WASH infrastructure considering conflict sensitivity, has a significant impact in the amelioration of conflicts.

Project Phase	Activities
Bidding Phase	Consideration of safeguard cautions provided by the funding agencies and development banks.
	Check whether the project is located in internationally contested areas, or in border-spanning resource development to avoid trans-boundary conflicts.
	Financial planning for the firm to measure the probability of cash flow at risk if the project is awarded.
Planning	Transparency about project plans, schedules and prospects.
	Verification of any impacts of the proposed project that will have on ethnic (or religious, etc.) divisions at the project site.
	Early, consistent, meaningful and empowering stakeholder engagement, including partner staff and community members.
	Finding out who the key players are and what their main concerns.
	Environmental and Social Impact Assessment, including involuntary Resettlement, cultural property or impacts on indigenous peoples, or affect access to natural resources mitigation and management plan.
	Study the possibility of establishment of an office at the project area to facilitate the monitoring and feedbacks from community members.
	Assist in preparing the compensation plan payments/projects for people in consultation with citizens.
Design	Integration of (Do no Harm) lens in design process.
	Inclusion of provisions for stakeholder consultation in feasibility studies.
	Evaluation of the potential impacts of the project before the commencement of activities.
	Use the conflict analysis to gain a full range of opinions and regularly update the conflict analysis and monitor its context.
	Establishment of accountability concept by creating effective channels through which stakeholders can provide feedbacks
Implementation	Implement transparent, equal opportunity approach in recruitment and employment of competent staff, and clear communication regarding recruitment decisions among the participants in the process.
	Consideration of ethnicity, religion, gender, political affiliation and nationality of staff.
	Establishment of community-based management committees for O&M purposes.
	Staff and citizens should receive continual training in theories of change for peace, conflict prevention, resolution, analysis, and management.
Monitoring and Evaluation (M&E)	Involvement of partner staff and communities in the monitoring and evaluation phase.
	Making necessary changes to the program design and strategy on a regular basis.
	Monitor the influx of people and animals and mass movement of refugees during the operation to act immediately upon land degradation and possible conflicts with the host communities.
	Evaluation of engineering projects should consider both peace-building and employment impact explicitly.
	Ensure immediate responses to stakeholders' feedbacks.

Table 1: *Conflict-Sensitive-Business-Practices during project life cycle (Compiled by the author).*

Public-Private Dialogues (PPDs) for WASH Development

Public-Private Dialogues (PPDs) are structured engagements that can be led by engineering firms and are oriented to the development of WASH services. These engagements aim to generate trust between diverse groups of stakeholders and the government, by improving transparency and confidence through collaborative governance practices and institutional reforms to improve the business climate and prospects for growth in conflict-prone areas (World Bank Group 2014). The main objective of PPDs is to ensure that government (i.e., client) is comfortable to collaborate with engineering private sector specialized in WASH development (contractors and consultants), and to bridge the gap and lay the foundation for joint problem analysis on a long-term and sustained basis, not simply around particular projects or interventions.

The wide experience of working in conflict-prone areas, enables the engineering firms to capture the potential clashes due to inadequate WASH services in these areas, and thus to assist the government and policy makers to point out triggers and make the optimum prioritization plans to tackle these clashes before boiling over. Well-planned and prioritized infrastructure development supports governments' decisions to allocate limited financial resources for WASH projects. Setting out prioritization plans for WASH development through PPDs consists of the following interaction:

1. Identification of capacity and resource limitations.
2. Collaboration with civil societies and NGOs in training and capacity building for stakeholders and government staff in conflict analysis and peace-building.
3. Dissemination and sharing of lessons learned and project appraisal reports for the completed engineering projects through workshops, seminars and regular forums.
4. Collaboration with governmental firms and authorities in the preparation of ministerial memos, budget planning and revision of WASH infrastructure development plans.
5. Participation in fund raising activities and provide the guidelines for the Memorandum of Understanding (MOUs) between government and NGOs, to ensure the optimum allocation and management of funds.
6. Collaboration with governments to strengthen the capacity of governance institutions at federal and state level to manage the renewable water resources and preserve biodiversity and eco-systems.

Corporate Social Responsibility (CSR)

Corporate Social Responsibility (CSR) in peace-building context aims to encourage businesses to invest in stakeholders' development and human right focus initiatives, as well as supporting entrepreneurship among youth, and boosting local development that further contribute to economic and social development. The trend to adopt CSR policies in improving and strengthening peace is emerging, and has gained traction among a growing number of business groups in conflict-laden areas, as a modern business tool which comprises a new bridge to peace-building goals (International Association for Humanitarian Policy and Conflict Research (aisbl) s.a.). Business theories believe that integration of peace-conflict-lens through CSR is a total deviation from profit maximization and promotion of the interests of the internal shareholders, leaving the external welfare of the larger society is less important. Some scholars have opposed the shareholder theory, corporations have a negative impact on the environment and thus, on the social lives of the people in that environment, therefore, integrating the socio-economic, cultural and political needs of these affected communities into a company's objective, as well as reframing business outcomes in the language of peace, is a way of responding to the needs of the society.

CSR is a practice which should be followed by all businesses, and it incorporates a set of ethics upon corporate behavior, the principles of CSR (ISO 26000) impose corporate to conduct the following practices (International Organization for Standardization (ISO) 2010):

1. Acknowledge the importance and universality of human rights.
2. Reconcile conflicts involving its own interests, those of its stakeholders and the expectations of society as a whole.
3. Make use of alternative dispute resolution, conflict resolution and redress procedures that are based on national or international standards. The procedures should be free of charge or are at minimal cost, and do not require stakeholders to waive their rights to seek legal recourse.
4. The creation of jobs, as well as wages and other compensation paid for work performed are among an organization's most important economic and social contributions.

Membership in International Associations

In July 2002, the Peace and Security Council Protocol (PSC) was agreed upon, establishing the African Peace and Security Architecture (APSA) which became a regional body. This body is the blueprint for the African Union and is responsible for formulating structures, objectives, principles and values, as well as decision-making processes relating to the prevention, management and resolution of crises and conflicts, post-conflict reconstruction and development in the continent (The African Peace and Security Architecture (APSA) 2012). Engineering firms must undertake the following action plans that comply with APSA agenda:

1. Participate in building early warning systems and in the development of conflict prevention techniques.
2. Support national and international peace-making, peace support operations, peace-building and post-conflict reconstruction and development.
3. Assist government promotion of democratic practices, good governance and respect for human rights.
4. Invest in humanitarian action and disaster management techniques.
5. Strengthening the capacity to prevent structural conflicts by intervening before large-scale violence occurs with a direct eye on the causes of conflict.
6. Collaborate with governments and legal authorities in issuing a manual for conflict sensitive business practices that should be adopted by all engineering projects.

LIMITATIONS

This study only reviews the aspects of peace-building engagement for engineering private sector by tapping into the potentials of this sector. These aspects of engagement may be incorporated implicitly within the engineering practices, but this paper aims to advance the frontiers of the engineering field by encouraging cross-disciplinary initiatives. It goes without saying that sustainability of infrastructure is taken as given. It is worth mentioning that peace-building is not an (either-or process), however, these initiatives and practices may vary and can be prioritized according to the strategic plan of the firm.

CONCLUSION AND RECOMMENDATIONS

1. Root Cause Analysis is conducted to ascertain the causes of WASH-Driven conflicts in Sudan. Review of documents and appraisal report showed that the major causes of tension over WASH critical services sectors are attributed to: (i) Failure in WASH services (ii)

Political factors (iii) Socio-economic factors (iv) Weak Governance (v) Rules/Policies/Procedure factors (vi) Environmental Degradation.

2. WASH projects can feed recurrent instabilities, therefore engineering firms as well as regulators should start asking the right questions to be alert to the relevance of WASH projects to potential conflicts. Conflict-Sensitive-Business-practices (CSBP) should consist of guidance on implementing projects in fragile societies for engineers and whoever involved in project's lifecycle.
3. Public Private Dialogues (PPDs) are important to promote private engineering development and to ensure transparency about business plans and conflict reduction. Dedicated leaderships by government of Sudan and relevant ministries promote government legitimacy in WASH sector and furthermore, assist in setting appropriate prioritization plans for infrastructure development.
4. External Business Practices for engineering firm should adhere to ISO-26000 for Corporate Social Responsibility (CSR) to assist in addressing their social responsibilities while respecting peace-building and contributing to economic development. CSR also aims to increase confidence and satisfaction among governments and community members.
5. Entry/Influence points for engineering private sector are identified based on RCA. Four potential entry points are proposed at macro, meso and micro levels, this includes:
    i. Business Practices (Micro Level).
    ii. Investment in new operation technologies and practices (Micro level).
    iii. Membership in International Association (Macro level).
    iv. Job creation (Meso level).
6. Development of Conflict Sensitive Business Practices should consider that engineering firms might also be confronted with humanitarian crises or other circumstances that threaten their efficiency, furthermore, disrupt community life, aggravate social and economic community problems and may also increase risks of human rights abuse.

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EDUCATION, KNOWLEDGE, AND TECHNOLOGY TRANSFER

PAPERS

THE BAREFOOT WAY TOWARD "FREEDOM, PEACE, AND JUSTICE": A QUIET REVOLUTION

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Abstract

It is a contradiction that rich people use up more of the world's resources and incur more environmental degradation than its poor people who bear the brunt of climate change ramifications but without the privilege of consumption. In fact, some of the poorest are even alleviating degradation through appropriate technologies (ATs). In this conceptual paper, I discuss the Barefoot College's (BC) approach of equipping the poor with ATs alongside the know-how to utilize them and improve their own conditions, thus contributing to environmental protection. In the main analysis, I use the foremost slogan of the 2018/19 (ongoing) Sudanese Revolution, "freedom, peace, and justice," and draw on Sudan's BC project experiences to highlight elements of the approach that has the potential to realise this slogan. Through interpreting theory from political philosophy and economic development discourses, an analysis of BC's approach and impact, as seen in Sudan's projects, is presented. The contribution of this analysis is argued as twofold. First, it illustrates the potential of BC's approach, rooted in AT and focused on rural development, to provide useful and innovative ways of interpreting and analysing various social realities such as freedom and justice. Second, it promotes the grounding of abstract notions that define revolutions, the utmost exercise of human agency, as an approach to raise leaders' awareness of what implementing slogans entails for guiding post-revolution thinking and doing. By connecting abstract and concrete levels, or the imagery and reality in this conceptual analysis, the paper creates both a scholarly and comradely conversation amongst simultaneous, co-located revolutions.

Keywords: Rural Development, Climate Change, Human Wellbeing, Sustainability.

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AFRICAN ETHICS AND AN IDENTITY FOR GLOBAL SUSTAINABILITY

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Abstract

In this paper, we address the concept of an identity for global sustainability. We consider what such an identity might look like and how its emergence and implementation could be intentionally encouraged at the individual and collective levels during participation in collaborative education networks, such as those developing and implementing appropriate technology in Africa. We propose that an identity for global sustainability could 1) improve participation in the development and implementation of appropriate technology in a feedback loop fashion, and 2) modify human attitudes and behaviors such that they are more conducive to enhancing peace and well-being. In our world of growing social interactions and social tensions, certain dimensions of identity are better suited for well-being than others. Delineating what these dimensions are can enable them to serve as targets for education, similar to certain other competencies, such as basic math skills. We will explore how African identity, and in particular African ethics, can play an important role in helping to further define these targets at both the local and the global levels.

Keywords: African Identity, Community Well-Being, Global Sustainability, Global Sustainability Inventory.

INTRODUCTION

From the local to the global level, a wide variety of novel education initiatives are playing a key role in helping move global societies toward peace and sustainable well-being (e.g., Focht, Reiter, Barresi, and Smardon, 2018; Post,Ward, Longo, and Saltmarsh 2016; Sibbel, 2009, Verharen, Tharakan, Bugarin, Fortunak, Kadoda, and Middendorf, 2014). Peace and sustainable well-being can be viewed as falling within the definition of what is more widely known as global sustainability (Clark and Harley, 2020). Global sustainability includes the many challenges of adaptation to and mitigation of climate change.

Many of the novel education initiatives combine collaborative social learning, traditional classroom learning, and research. Some engage the local corporate community. Some seek to establish community-based non-profits. In one of their more comprehensive formats, the initiatives connect university teachers and their students in classroom learning and collaborative research-based knowledge exchange with the local communities they are seeking to serve. Many of the initiatives utilize learning networks across scale from the local to the national and the international to facilitate collaborative project objectives. An excellent example of this combination in Africa is the collaborative development, dissemination, and implementation of Appropriate Technology (AT) through the Songhaï agroecological sustainable development model (Tharakan, 2020).

There remains a gap in knowledge, however, as to whether classroom education for sustainability, in general, and community-engaged action learning for sustainability like AT education, specifically, generate more than just technical knowledge and skills in learners (see Sonetti, Brown, and Naboni, 2019). They certainly seem to have the capacity to do so (see for example, Elkjær, Horst, and Nyborg, 2021; Fracchiolla,Prefontaine, Hinko, 2020).

Therefore, our research question has been: Are we preparing our next-generation graduates to be psychologically competent and motivated to take on the complex challenges of our world in a manner that supports peace and sustainable well-being? In our work we explore this question along the categories of leadership, resilience, and connectedness. We ask, do they have the psychological competencies for effective leadership? Do they have the resilience to deal with highly complex, so-called wicked problems (Waddock, 2013), that lead to transitions towards sustainable well-being over the long term? Are they sensitive enough to the many nuances of collaborating with people across differences of culture and scale in a sincere and empathic manner?

Of course, by the mere process of going to school, students not only develop their technical skills but, at least to some degree, their psychological character. They develop who they are, their identity (Lannegr and-Willems and Bosma, 2006; Verhoeven, Poorthuis, and Volman, 2019). Thus, many teachers will (or at least would like to) use the opportunities that arise from community-based collaborative learning, as well as the various social movements coursing through the young in society today, to intentionally seek to develop young students into publicly engaged scholars (Post *et al.*, 2016). They seek to empower young learners with a diverse constellation of the twenty-first century competencies for collaboration and knowledge transfer, which includes the optimum deportment and temperament for working across complex issues and cultures (Pellegrino and Hilton, 2012). It is during community-based collaborative learning that individual change toward a more prosocial identity can be encouraged, one perhaps approximating an idealized identity for global sustainability. This can occur by intentionally addressing the "who we are" and "who we need to be" questions with students during AT and sustainability projects (Chabay, 2020; Chabay,Renn, Van Der Leeuw, and Droy, 2021;Dentoni,Pascucci, Poldner, and Gartner, 2018; Trott, 2021).

We seek to build on these efforts by developing an assessment tool we call the Global Sustainability Inventory (GSI). We are researching and developing the GSI through its implementation in community-based collaborative learning initiatives for sustainability across cultures (Wensing, 2012; Wensing, Wensing, and Virgo, 2018). The research and development of assessment protocols and instruments in education for sustainability is an area of robust ongoing research (Caeiro, Sandoval Hamón, Martins, and Bayas Aldaz, 2020; Waheed, Khan, and Veitch, 2011).

The GSI is a psychological test battery with which we seek to capture the various dimensions of an individual's character that are most equitable with helping move communities toward peace and sustainable well-being across global societies. Thus, we seek to develop the GSI as an assessment instrument that measures the various dimensions of what can be framed as an identity for global sustainability. We theorize that an identity for global sustainability can be optimized during participation in community-based collaborative learning initiatives such as those involving AT implementation. Using the GSI, then, we are looking to monitor the emergence, development, and durability of an identity for sustainability within participants of community-based collaborative learning initiatives such as those that seek to create, develop, and implement appropriate localized technologies. Additionally, the GSI and its nascent components can serve as points of discussion and reflection, and thereby, provide goals for personal and collective identity change in research-based community-based collaborative learning initiatives. Thus, the design and composition of the GSI can serve as a framework for the exploration of what an identity for sustainability is, and to conduct its measurement at the same time.

Indeed, the utility of the GSI in various settings such as responsible rice farming in Uganda (Karubanga,Okry, Kibwika, Agea, and Sseguya, 2019) and the implementation of rural electrification AT in the Amazon River Basin, Brazil (Del-Río-Carazo,Iglesias-Pradas, Acquila-Natale, and Martín-Fernández, 2021;Del-Río-Carazo, Acquila-Natale, Iglesias-Pradas, and Hernández-García, 2022) is becoming increasingly recognized.

It is the design and composition aspect of the GSI that will be discussed in this paper, especially as it relates to the African context. In this paper, we address what influence African identity and African ethics can have on the design and implementation of the GSI and the identity for sustainability it seeks to portray. A comparison of an African identity with an identity for global sustainability will be made. A critical review of the GSI in terms of Africa's colonial past combined with the imperialistic forces of the present will be offered. Interestingly and thankfully, as described in this paper, the literature on African identity and its ethics may provide a further dimension to the design of the GSI and the identity for sustainability that it seeks to measure. The literature discussed also provides an important reminder of the challenges of authentic community representation in knowledge and technology transfer initiatives and provides insight with regards to the prospect of creating a genuinely African identity for sustainability.

The global sustainability inventory

The GSI is a test battery comprised of various measures that seek to capture those qualities of character that we theorize are most suitable for moving knowledge into action for sustainability across cultures and various challenges, along scale from the local to the global (Wensing, 2012; Wensing *et al.*, 2018).

Born out of a heuristic analysis of the literature, cross-sector interviews of social entrepreneurs (Dees, 1998), and observational studies in the field across various indigenous and non-indigenous cultures, the GSI has been initially subdivided into a self-report and a community feedback component (Wensing, 2012). The self-report includes a test battery of previously published psychometrics. As the name suggests, psychometrics are multiple choice test measures that are developed through psychological research to capture various dimensions of human character. In the case of the GSI, the initial three general dimensions that have emerged from our research are those of leadership, connectedness, and resilience as they relate to an individual's ability to move knowledge into action for sustainability across cultures and various challenges, along scale from the local to the global.

Each of these three dimensions is described by several psychometrics. Importantly, the psychometrics that measure the three dimensions do so in a way that measures each dimension in relation to oneself and in relation to another person. Thus, each dimension of leadership, connectedness, and resilience as they relate to sustainability is subdivided into two categories. For instance, leadership in relation to self is measured by the Brief Self-Control Scale (Tangney, Baumeister, and Boone, 2004). In this sense, leadership in relation to oneself is seen as an inward ability. By contrast, leadership in relation to another is measured by the Authentic Leadership Scale (Walumbwa *et al.*, 2008). In this sense, leadership is seen as an outward ability. This inward versus outward distinction aims to improve the authenticity and comprehensiveness of the GSI, so that it truly captures the dimensions of an identity for sustainability. There has been recent recognition that this inward/outward duality in an identity for sustainability is a key dimension for those engaged in community-based initiatives for a better future (Wamsler, Osberg, Osika, Herndersson, and Mundaca, 2021). Additionally, the GSI is being designed to measure both changes in individual identity as well as collective or

group identity. As in the individual case, the emergence and durability of a collective identity for sustainability is measured through the use of specific psychometrics.

It appears to be increasingly certain that inclusive community-based collaborative learning though knowledge exchange at all societal levels and within a variety of contexts must play a role in helping generate sustainable futures (Norström, Cvitanovic, Löf, West, Wyborn, Balvanera, Bednarek, Bennett, Biggs, de Bremond, and Campbell, 2020). It appears that universities are particularly well situated to take up the many challenges of transitioning societies toward better futures. Some have called for intentionally teaching students values and abilities to "transform" communities toward sustainable development (Leal Filho, Raath, Lazzarini, Vargas, de Souza, Anholon, ... and Orlovic, 2018). Our contention is that universities can play an important role in the fostering an individual and collective identity in sustainability.

Most readers of this paper likely possess some understanding of human identity—what it is and how it works. Indeed, the topic of human identity has long been a point of discussion across a variety of disciplines within academia. Based on the nature and number of published works, however, it can be argued that how identity works to affect human existence has been most definitively explored within the domain of psychology.

From a psychological perspective, human identity helps us to distinguish constructs such as the self from the non-self (other). Some divide individual identity into three aspects, namely, our self, our relational social identity, and our collective self (Sedikides, Gaertner, and O'Mara, 2011; Sedikides, Gaertner, O'Mara, and Gebauer, 2013). Identity Process theory (Breakwell, 1993; Jaspal and Breakwell, 2014) links identity with social action. Briefly, the greater the self-esteem, distinctiveness, continuity, and efficacy an identity provides an individual, the higher is the motivation required to enact that identity in social behavior. In psychology, identity is often viewed as having both fixed and fluid dimensions. Identity change need not displace all dimensions of an individual's identity. Through processes of so-called assimilation and accommodation, individuals will integrate new aspects of expression into their identity. Most individuals can balance various, sometimes conflicting, social identities (McAdams et al., 2021; Leary and Tangney, 2011). Thus, in development of the GSI, we seek to include the self, relational self, and collective dimensions of identity.

Additionally, the GSI includes a community feedback component. Community feedback allows us to test whether those students engaged in community-based initiatives have a positive impact during and after their initiatives along various dimensions. Community feedback makes the GSI a so-called 360-degree assessment instrument. This is important because, community feedback can provide the opportunity for all involved in both a traditional knowledge transfer sense (Drew, 2009), as well as in a collaborative exploratory recursive hermeneutic loop manner to learn (McKemmish, Burstein, Manaszewicz, Fisher, and Evans, 2012).

African identity and global sustainability

As has been stated, identity is a multi-faceted phenomenon. Thus, we can have a variety of concurrent dimensions to our identities that permit individuality, cultural, and other collective aspects.

There is of course no doubt that Africa is not one country, which has led some to question how Africa can be seen under a single collective identity (e.g., Eze and Van der Wal, 2020). However, it appears that a growing number of people are beginning to see the benefit of a shared African identity for a sustainable future.

What Africa is and what it will become might very well be up to modern day Africans. For instance, as described by Anyachie,

> The search for African identity should not focus on exhuming her past culture and lamenting her experiences, but on discovering the latent prowess of Africa that will help her to positively and effectively confront her existential challenges. Colonialism and neo-colonialism are part of Africa's existential challenges which she has to tackle to define her identity. For sustainable development, Africa has to wake up from her slumber of eulogizing her cultural heritage and blaming others for her predicament, and brace up critically, constructively and pragmatically evaluate her past. Confront her current challenges and take responsibility for the effect of her actions and inactions. (Anyachie, 2013:150)

As they conclude, "Africa should take her destiny into her hand and be ready to take full responsibility of her predicament" (Anyachie, 2013:153). This view can and should be stated by all global societies, with the caveat that societies must work together across boundaries of culture, national identities, and policy (Clark and Harley, 2020).

What is an African identity and how can it participate in sustainable development? To offer anything, according to one African writer, it would need to move out of its current identity crisis in which there is little to no shared identity, and find a collective identity (Isife, 2021). Whether in crisis or not, local African identities and knowledge need to be heard and integrated into collaborative initiatives for sustainable development (Maweu,2011; Owuor, 2007).

As Nadasdy (1999:1) wrote some time ago about the Arctic case and the Indigenous people's Traditional Ecological Knowledge,

> As a result, aboriginal people have been forced to express themselves in ways that conform to the institutions and practices of state management rather than to their own beliefs, values, and practices. And, since it is scientists and resource managers, rather than aboriginal hunters and trappers, who will be using this new "integrated" knowledge, the project of integration actually serves to concentrate power in administrative centers, rather than in the hands of aboriginal people.

Over the last decades, great effort has been made across diverse initiatives to include the identities of local communities: their knowledge, their culture, their way of life, and their ontologies in local to global knowledge exchange and action networks for local and global sustainability. Research in this so-called cross boundary work is seeking to optimize the synthesis of local indigenous knowledge and identity with non-local knowledge and cultures in different locations like the Arctic (Ludwig and Macnaghten, 2020; Ford and Furgal, 2009) and Caribbean (Alexander, Armitage and Charles, 2015).

African ethics and an identity for global sustainability

While African Identity may be a contested concept, the aspect of African Identity we propose that may provide broad utility in the design and implementation of our GSI assessments tool, and hence the concept of an identity for sustainability is African ethics.

In particular, descriptions provided by Verharen and colleagues of Survival Ethics (Verharen,Tharakan, Bugarin, Fortunak, Kadoda, and Middendorf, 2014), African Philosophy (Verharen, Gutema, Tharakan, Bugarin, Fortunak, Kadoda, Liu, and Middendorf, 2014), and, more recently, an African Environmental Ethic (Verharen, Bugarin, Tharakan, Wensing, Gutema, Fortunak, and Middendorf, 2021)of the GSI. We propose a modification to the structure of the GSI, which is currently based on leadership, resilience, and connectedness, to include a measure of each of the ethics described by Verharen.

In the case of survival ethics,

> The primary instrument of the survival ethics model is a checklist system that enumerates the basic conditions for survival—clean air, temperature control through clothing and shelter, potable water, nutritious food, basic healthcare and education. The optimum guarantee of survival is through pursuit of the conditions for flourishing—rationality through continuing education, heightened community bonding, intelligent use of pleasure as a mechanism for guiding behavior, freedom defined as the potential for creativity, and introspection defined as the rational control of attention. (Verharen, Gutema,*et al.*, 2014:136)

Survival ethics addresses "the extreme challenges of the world's poorest by increasing access to the basic necessities of life." (Verharen, Gutema, *et al.*, 2014:135). This checklist fits nicely into the quantitative nature of the GSI. We would utilize this checklist in the initial community assessment portion of the GSI instrument.

In the case of African philosophy, like the Arctic and Caribbean examples mentioned earlier, it is essential that someone with an identity for sustainability be able to merge Western and non-indigenous knowledge with the local cultural contexts during initiatives for sustainable development. Thus, we would include the awareness of African philosophy as a measure in the GSI.

Lastly, we must consider the African Environmental Ethic as described by Verharen *et al.* (2021). In this paper, Verharen *et al.* propose a collaboration and integration between ethics and the sciences to promote sustainable futures. In particular, their vision is to draw from African ancestorial wisdom rooted in Egyptian and Ethiopian history, as also portrayed by the Senegalese scholar, Cheikh Anta Diop, and translated into a model of ecovillages for sustainable development in Africa's rural regions by Professor Godfrey Nzamujo, a Nigerian Dominican priest. Again, here we would include an awareness of African philosophy as a measure in the GSI.

In their view, community sustainable well-being is contingent upon its connection to its organic and inorganic environment through sustainable technologies. These communities are rooted in African environmental ethics so that they are based on traditional local knowledge. By contrast, modern Western knowledge forms what they call a "superstructure" while, at the same time, communities that resist relevant changes to their long-standing traditions exercise autonomy at the risk of disrupting the natural rhythms of their environment (Verharen *et al.*, 2021:7).

The multitude of challenges of moving communities towards sustainable well-being are shared across societies worldwide. To address these challenges, educators, policy makers, industries, and entrepreneurs can network together to co-develop strategies via collaboration along international learning networks. In fact, to take on the complexity of the challenges, they

absolutely need to do so (Norström *et al.*, 2020). No society stands alone in our highly connected co-dependent modern world.

There will always be inherent challenges, such as differing ontologies (for an interesting discussion see Yates, Harris, and Wilson, 2017) and those related to languages, and culture. However, as described in the previous section, there are many researchers studying how to best overcome those challenges. Given the mounting issues in our world, we appear to have no other choice but to try to do so (Rockström, Steffen, Noone, Persson, Chapin, Lambin, Lenton, Scheffer, Folke, Schellnhuber, and Nykvist, 2009; Steffen, Richardson, Rockström, Cornell, Fetzer, Bennett, Biggs, Carpenter, De Vries, De Wit, and Folke, 2015).

The global deployment of community leaders for sustainability, those that will represent their culture and their communities, across boundaries of culture and worldview and maintain community-based action research locally are key to these efforts. In essence, nothing less than a globally-connected collaborative social movement toward sustainability must be initiated and maintained (Bernstein and Olsen, 2009). With all its bountiful human and natural resources, it may be self-evident that Africa can play a key role in saving our world for future generations. It is the ethics emerging out of Africa as described by Verharen, however, as we tried to argue in this paper, that provides our best hope for a shared global future. We propose that an assessment tool like the GSI that measures the emergence of an identity for sustainability is key to monitoring our progress towards that future.

Importantly, we view that the integration of an African Ethic as described by Verharen and colleagues with the GSI, in addition to its already comprehensive design, takes the assessment instrument and the identity for sustainability that it seeks to measure, and helps create, instead of a "systems thinking" individual as described by Leventon (2021), a "systems being" person, that is, an individual who has integrated sustainability transitions into their very being, their very identity, a subject that requires deeper study (Warburton, 2003; Wiek, Withycombe, and Redman, 2011; O'Brien and Sarkis, 2014).

CONCLUSION

Assessment is a key part of any education process. This includes the various approaches to education for sustainability. Education for sustainability includes developing responses to climate change, generating effective political policy, and implementation of appropriate technology. What is clear however, is that without the will to act out knowledge and utilize technology in an appropriate manner, all the education and political policies in the world will not generate the changes in large-scale behavior necessary to support that knowledge and technological innovation. For this reason, it is important to have assessment tools like the GSI that monitor behavior and attitudes, as they emerge and evolve, their impacts, as well as their durability over time. Using this data, education can target behaviors, attitudes, and other key components of identity to be more aligned with the actions necessary for generating sustainable futures acrossglobal cultures. African ethics can play a significant role in the design of the GSI assessment tool, not only for the benefit of African nations, but also for the rest of the world.

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RE-ENGINEERING ENGINEERING EDUCATION FOR SUSTAINABLE DEVELOPMENT

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Abstract
Engineering educators have an ethical responsibility to nurture and develop the coming generations of critical and innovative thinkers who will be the problem solvers capable of not only taking on the grand engineering challenges facing humankind but also of developing the innovative technologies, products and processes that will address the critical sustainable development goals that humankind needs to address to move towards social justice. In this paper, we propose a paradigmatic shift in conventional engineering education curricula, transforming out of the currently widespread and common conventional chalk-and-talk lecture based pedagogical approaches, which are also accompanied by attendant and limited assessment methods aside from traditional problem sets and exams. This paper suggests that engineering programs and curricula need to implement a number of changes to update and upgrade their curricular and programmatic approach to ensure that the programmes will indeed be able to create transformative thinkers and creative problem solvers: Project based learning (PBL) pedagogies must be developed and incorporated into each course - PBL can be realized and articulated through the utilization of open ended design (OED) projects; Service Learning (SL) should be integrated into engineering curricula by requiring that the projects be community-based and socially beneficial, addressing unmet needs and challenges that are being faced by community members in and around the engineering institutions' communities. Community based projects can be as variegated as installation of a solar photovoltaic (PV) based energy supply system for a remote rural village community to construction of water treatment and collection systems in rural areas, to the education and training of self-help community women's groups to address their community's water quality and availability issues. This paper will discuss some of these projects, while outlining PBL, SL and capacity building through community-based student-driven projects.

Keywords: Engineering, Education, Pedagogy, Project Based Learning, Service Learning, Sustainable Development.

INTRODUCTION

It is common for Engineering college Dean's to welcome the freshman class at which the Dean often tells the story of how when he (usually it is a he) was a freshman and sat in those seats, the then Dean said to them, "Take a look to your left and to your right, only one of the three of you will make it through our program in four years," but what the Dean now wants to, and does, tell today's freshman is, "Take a look to your right and your left, and make sure that ALL three of you work together to graduate in four years." The shift in this introductory narrative should also be a signifier for a shift from the conventional pedagogical approach in engineering education of lectures (chalk and talk) and problem sets followed by exams or tests with all students competing against each other, to a pedagogical approach where students work collaboratively in groups to cooperatively solve real world problems applying the theories they learn in the chalk and talk components of the curricula to real problems faced by the communities that surround them. Engineering education must respond to this challenge through much needed transformation, integrating project-based learning (PBL) into as many courses as

possible in their curricula, enabling service learning (SL) through community based and driven service projects, and integrating open ended design into faculty's pedagogical approach to teaching their students.

The state of pedagogy and pedagogical approaches in engineering education appears, for the most part, to be stuck in old models that no longer address current needs (Sorby et al, 2021). There are exceptions, such as the Olin School of Engineering, but for the most part, engineering curricula (and faculty) emphasize theory over practice, rely on a lecture and problem/set exam approach, and are embedded in the pipeline model with sequences of courses in math and science that students must take resulting in many students being precluded, not just excluded, from getting an engineering degree, and the implications this has for equity. The need for transformative change in engineering curricula has been recognized and discussed before (Apte, 2021), including curriculum redesign to break calculus's bottleneck hold on student progress (and thus also addressing equity issues by allowing students with inadequate and insufficient preparation to still envision engineering as a career), course redesign to be able to omit irrelevant material from our course syllabi with feeling neither that we have short changed students nor that we let student's get off easy!

It is important, to remain relevant to today's youth, who are not content to merely address social justice and equity issues in their private lives but also in their work, that our engineering curricula and pedagogy must reflect this. Engineering education has to address the needs of our rapidly changing society, which is diverse, digital and global, preparing our students not only for career's that exist today, but to be able to prepare themselves for career's that are yet to be created. Engineering education and curricula must incorporate modern tools that enable students to solve messy real-world problems that require the synthesis of concepts from multiple disciplines, and where students apply logical boundary conditions with rigorous assessment of outcomes. In fact, engineering education needs more integrative, hands-on problem solving, which would address issues described earlier as well.

To be relevant and provide students the ability and capability to address and sustainably solve problems faced by their communities, engineering programmes need to support faculty efforts to transform their courses to incorporate Project Based Learning and requiring open-ended design thinking in student work. These are approaches that will nurture and develop critical and creative thinking skills in students while enhancing their problem-solving abilities (Tharakan, 2020).

In this paper, we elaborate on Project Based Learning, Service Learning and Capacity Building, and the transformations in engineering education that are necessary to develop the engineers of today and tomorrow who will be able to innovatively and creatively address the Sustainable Development Goalsand Grand Challenges that we are faced with and that participants at this conference are individually and collectively focused on addressing and developing the frameworks for solutions for these challenges.

This paper proposes service learning, implemented through PBL, incorporating community-based projects addressing community needs through open ended design thinking, should be a requisite (sic!) inclusion in engineering curricula to address the issue of capacity building in developing and under-resourced communities. Service learning and capacity building are discussed and developed as a potential benefit from service learning projects that have not been tapped for community development and capacity building. This paper argues that capacity building from the ground up in these diverse developing countries can be dramatically

enhanced and expanded if curricular community-based service learning experiences are made a regular and mandatory component of engineering, technology and social science program curricula in the country's universities and colleges.

PROJECT BASED LEARNING

Project Based Learning (PBL) is a teaching method in which students learn by actively engaging in real-world and personally meaningful projects. PBL is a teaching method in which students gain knowledge and skills by working for an extended period of time to investigate and respond to an authentic, engaging, and complex question, problem, or challenge. Students work on a project over an extended period of time – from a week up to a semester or longer – that engages them in solving a real-world problem or answering a complex real question. Students then demonstrate their knowledge and skills by creating a public product for presentation to a real professional audience of their peers.

The benefits to students are broad and deep: they develop deep content knowledge while developing critical thinking skills. Having students work in groups enhances collaboration skills while the real-world community-based problem will ignite creativity and collaboration. Communication skills are developed with expectations of the students for written reports and oral presentations of their projects.

For PBL to be successful, these are some of the essential components, including a challenging problem/question that is based on a real-world context providing the authenticity needed. PBL programs and projects must be rigorous enough to require sustained inquiry and rigorous research. Students must have a voice and choice in the selection of the problems and projects, and all programs should be configured to provide students ample opportunity for reflection, critique and revision prior to presentation of a public product such as a report and presentation.

SERVICE LEARNING

The definition of Service Learning, or SL, is an academic and/or curricular activity that is both course based and credit-bearing, and that includes two major components: engagement of students in a self-selected, driven and planned, but professionally and academically supervised and mentored, service activity, *and* an opportunity and requirement to engage in scholarly reflection and writing on the service activity in an academic context (Bringle and Hatcher, 2007; Bringle et al, 2004). Service learning has been deemed of great value to a diverse set of stakeholders, delivering benefits of academic and experiential nature to students, faculty, community partners, and society in general. It has been shown over the past several decades that SL experiences promote independent and critical thinking skills and greatly improve educational outcomes (Eyler & Giles, 1999, 2001).

An earlier paper focused on SL (Tharakan, 2011) described the extension of Engineers Without Borders project activities into an academic service learning experience that could be incorporated into regular engineering curricula. As demonstrated in that paper, engineering curricula had space for incorporation of service activities into academic curricula through the development of focused independent study courses, where the student service volunteer works closely with a faculty member to fashion and configure an academic credit bearing course of study focused on the engineering and technology that the student's had engaged in as part of

their service activity. A second paper (Tharakan, 2012) described this in the context of a renewable energy implementation project that students had engaged in as part of a broader research project (Tharakan et al, 2008).

These service activities were built around Engineers Without Borders-USA (EWB-USA, 2021) projects that the Howard University Student Chapter of Engineers Without Borders (EWB-HU, 2009) were engaged in. The focus of the EWB-HU projects were the development and implementation of rainwater harvesting systems and bios and water filtration systems in a rural community in Kenya that suffered from water quantity and quality issues. These service site visits of EWB teams to communities in need provided a model for academic and curricular based service learning experiences that could be incorporated into standard engineering curricula. This was proposed as mechanism to expand the pool and provide all students in an engineering program with the benefit of these types of educational and practical experiences. Those studies also demonstrated that capacity building within the communities served was possible if the service learning project was design and developed with appropriate mentoring that ensured that community education, outreach, engagement and empowerment was an integral part of the service project design and implantation plan.

CAPACITY BUILDING

The term "capacity building" has become a buzz word in the development field but it is grounded in the fundamental idea that in order for real sustainable development to take place, the capabilities of the community must be enhanced, increased and expanded, giving the community the capability, whether in terms of training, knowhow, or skillsets, to address their own developmental needs from the ground up. **Capacity building (CB)** refers broadly to a conceptual approach to development that focuses on understanding the obstacles that inhibit people, governments, international organizations and non-governmental organizations from realizing their developmental goals while enhancing the abilities that will allow them to achieve measurable and sustainable results.

In the language of development, United Nations Development Program (UNDP) outlines that CB can take place on an individual level, an institutional level and on the societal level. At the **individual level** - CB requires the development of conditions that allow individual participants to build and enhance existing knowledge and skills. At the individual level, CB will require the establishment of conditions that allow individuals to engage in the "process of learning and adapting to change." (UNDP, 2006).

From a scholarly perspective, the emergence of CB as the leading developmental concept occurred due to a confluence of several factors including Paolo Freire's *Pedagogy of the Oppressed* which showed that education couldn't be handed down from the heights of master to student but had to be achieved through dialogue on an equal footing; Freire went further to validate and legitimize the knowledge and experience of the oppressed to give them voice in their own education. Additional developments such as the Capacity and Vulnerabilities Analysis (CVA) which posited that: development was a process whereby vulnerabilities were reduced and capacities were increased; no one could develop anyone else; and, relief programs were never neutral in their development impact (Eade, 2005). Renewed emphasis was also placed on the idea of sustainable development with its emphasis on community engagement and sustainability – resulting in one of the main lessons learned that development had to be

participatory to be sustainable and hence the focus had to be on building capacity in the target communities themselves.

SERVICE LEARNING AND CAPACITY BUILDING

Bringing service learning into the suite of tools available to address CB efforts is a natural fit. Kapucu and Petrescu (2006) have demonstrated the success of service learning for CB exploring the history and characteristics of service learning at two universities, University of Central Florida and Eastern Michigan University and presents service learning as one way for the community and institutions of higher education to engage in CB. Although not a systematic scientific inquiry, the paper is a critical reflection on field experience and demonstrates the importance of service learning for the community's CB. What is actually done through service learning is the promotion and sustenance of the common good through civic engagement, which in turn builds social capital. Their service learning projects helped to foster development of a sense of caring about others, positively impact civic participation, and sustain social capital and hence everybody involved in the SL learns: most importantly, social capital is developed, and community capacity is built.

From the perspective of this paper's approach, we argue that engineering service projects that are community centered and focused on extension of engineering curricular content outside the laboratory and classroom to engage communities in addressing development problems, will foster capacity building in the target community. A recent implementation site visit of the EWB-HU Student Chapter (EWB-HUSC) will serve to illustrate an example of capacity building in a community as a dedicated and project design target of the implementation plan. The EWB-HU SC recently conducted an implementation visit as a follow-up to an earlier assessment visit to engage with the Choimim community in the Nandi Hills region of north western Kenya. The earlier assessment visit resulted in the community requesting EWB-HUSC intervention to help them address the dire water quantity and quality resource issue in the area. The implementation visits thus focused on addressing the community prioritized need for improved water quality and quantity. The EWB-HUSC team worked with the community, developing through education, training and technology transfer, a set of community engineers (CE's) who would be the node points for the initial implementation of the suggested technology solution of bios and filtration (BSF) systems. The EWB-HUSC team engaged with a local NGO in sourcing local materials for the implementation and raised the funding required for the purchase of components for six BSF systems. The components were then transported locally and assembly and deployment of the BSF's was conducted with the engagement of the CE's. The development within the community of a set of "community engineer's" capable of maintaining and operating the implemented technology is the building of capacity within that community. These CEs are now engaged, along with the NGO in monitoring and evaluation of the BSF's functioning and are also capable of expanding and dispersing the BSF technology to other members of the community, thus further building community capacity. In addition, the EWB-HUSC implementation visit resulted in the installation of two additional 10,000L tanks that greatly enhanced the community's water storage and quantity issues.

Hence, in this instance, the service learning engagement of the EWB-HUSC team resulted in the community of Choimim village building their capacity to address their water quality and quantity resource issues. Students in a graduate environmental engineering program addressed water resource and availability issues enhance water availability and access literacy in women's self-help groups and community-based organizations (George et al, 2020). This is a model that should be considered in universities and colleges, especially in developing

countries. Following the model of CUJAE in Cuba, where senior design projects in all engineering departments require community engagement and real-world problem solution through the execution of the senior design project. In this instance the built capacity addresses water quality, and hence health, issues that the community has with water quality and quantity.

CONCLUSION

Service Learning has been discussed in the context of community development projects that are engaged in by student volunteer groups from the engineering and technology disciplines. It was previously demonstrated that service projects that had been extended into academic credit bearing independent study courses could positively impact quality of life issues in underserved and rural communities. Here, we have argued for the transformation in engineering education moving away from the chalk-talk approach, to using PBL and SL in engineering curricula that has an impact on community capacity building efforts, providing technology transfer and training that has been vetted through adequate and appropriate mentorship and professional guidance built into the engineering programs. What is suggested, and what reaffirms earlier indications, is that the SL pedagogy, appropriately implemented in engineering curricula across educational institutions and programs, using PBL, open ended design thinking and community-based problems as their target could have tremendous potential to positively impact community capacity building efforts from the ground up.

Channeling the energy of our youth through appropriate academic guidance and mentoring should be an integral component of national capacity building policies and strategies. This project-based transformation in engineering education must be appropriately configured so that the experience for the students results in enhancing their skills at team-work, communications, understanding of ethical and professional responsibility as well as their understanding of the importance of appropriate technology and engineering in a global social development context. Linking students with the community requires students' team together and take leadership in community engagement, community selection, project conceptualization, development and implementation.

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DEVELOPING RESILIENT COMMUNITIES: THE ROLE OF HIGHER EDUCATION INSTITUTES

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Abstract
Many peripheral residential neighbourhoods in developing countries (DCs) face the problems of chaos in planning, resulting in densely populated communities with limited poor services. The political and socio-economic context within which higher education institutes (HEIs) in DCs operate; significantly influence the role they could play in improving the quality of life in vulnerable communities. This paper aims to highlight the possible and appropriate approaches through which HEI in DCs contribute to the development of resilient communities. As a case study, it reviews the partnership between the Faculty of Architecture (FoA), University of Khartoum (UofK) and the Italian Agency for Development Cooperation (AICS) as they jointly worked on projects – MayoUp and Dictorna - aiming to improve the quality of life of local communities. The paper will illustrate the significant role the FoA, UofK played in improving the quality of life of targeted communities based on solutions adopting a participatory approach. The study will manifest the sustainable development goals achieved through the involvement of the FoA in two projects. The research conclusion will highlight the key factors contributing to the success of collaborative projects in which HEI stay involved. It will elucidate the best ways to manage limited resources available for HEIs in developing countries.

Keywords: Higher Education Institutes, Developing Countries, Resilient Communities, Vulnerable.

INTRODUCTION

Many societies in developing countries and 3rd world countries are facing problems on several levels recently as a result of instability and various conflicts in these countries. The United Nations organizations and various international non-governmental organizations have worked to support the governments of these countries to help mitigate the effects on these societies. Among the most prominent of these effects, besides traumas and loss of sense of safety, is the problem of loss of home. Therefore, many communities were forced to migrate and change their place of settlement within the same country or between countries. The above-mentioned organizations are working to assist these displaced persons to find better-studied solutions to provide a better accommodation environment for stability than the ones they create in an improvised and usually random manner due to their lack of experience or due to the factor of time. These organizations usually face difficulty in integrating into these communities - due to several factors that will be mentioned later on - so they use a mediator from the state itself, such as civil society organizations or higher education institutions, which is what this research paper is about to address.

The General Objective of the Paper

This research paper reviews the role that higher education institutions play in developing resilient societies. In particular, it sheds light on the role played by the University of Khartoum,

Faculty of Architecture, represented by the team that participated in MayoUp and Dictorna projects in cooperation with the Italian Agency for Development Cooperation (AICS). The study aims to highlight the success story and lessons learned from collaborative projects between HEIs and international NGOs. It spots the light on the factors contributing to the success and effectiveness of such collaboration, alongside highlighting obstacles and challenges that aroused in the route of the project. The paper provides some suggestions for overcoming the challenges associated with similar collaborative initiatives in the future.

Generally Discussing the Political and Socio-Economical Situation of Sudan

The political situation in Sudan has witnessed noticeable tension in the recent period, which has resulted in turmoil in the economic situation in the country, leading to socioeconomic instability. In addition, with the emergence of disputes and conflicts in different regions throughout the country, large numbers of displaced people and refugees have migrated to the cities and the capital in particular. According to BBC News (Sudan country profile, 2019): "Sudan has long been beset by conflict. Two rounds of north-south civil war cost the lives of 1.5 million people, and a continuing conflict in the western region of Darfur has driven two million people from their homes and killed more than 200,000." The authors observed-during the field trips through the project- that these refugees established separate settlements and camps on their own on the outskirts of the Sudanese capital, Khartoum. The absence of oversight and regulation by the concerned authorities has led to the acceleration of the growth of these settlements into informal settlements that lack order, planning and provision of the most basic services. Houses' Residents in such neighbourhoods suffer from successive damages every fall of every year as those houses are merely an absurd result of the residents' improvisation. Those residents do not have sufficient knowledge of construction techniques and planning. They did not find bodies that monitor the accelerating unplanned construction processes.

METHODOLOGY AND SCOPE

Case Studies

The study will address the last two projects undertaken by the University of Khartoum, Faculty of Architecture, namely: MayoUp project in Mayo and Dictorna project in Alsahafa. The paper will review the collaboration between UofK and AICS, highlighting the role played by the university team in the city of Khartoum between November 2019 and October 2021.

Background: the current status of vulnerable communities and HEIs role in DCS - highlighting Sudan

The Causes behind the Formulation of Such Communities

The recent disturbances in the world, and the Arab and African region, in particular, has led to insecurity in a number of countries due to wars, conflicts and/or natural disasters. Since Sudan has historically been one of the countries that welcome visitors and immigrants at all times, (UNHCR The UN Refugee Agency , 2021) and because of its multiple borders and its openness to several countries, it has recently received many victims of these conflicts. Sudan is considered a host for one of the largest refugees' population in Africa. It hosts 1.1 million refugees and more than 3 million Internally Displaced Persons IDPs. The majority of this number is made up by South Sudanese refugees. Other refugees flee wars or persecution from neighbouring countries like: Eritrea, the Central African Republic, Ethiopia, and Chad.

Recently, refugees from further distances like Syria and Yemen came to Sudan seeking safety as well. (UNHCR The UN Refugee Agency , 2021)

The overall security situation in Darfur region remained tense and turbulent through the late years. West, North, and Central Darfur states saw increased inter-communal clashes involving nomads and several African tribes in the area. Culminating conflicts in the western state alone resulted in 88 deaths and the injury of 83 people. International Organization of Migration IOM estimates that 57,920 individuals in over 12 locations were displaced from the outskirts of El Geneina in West Darfur into the town. Thousands more people are experiencing the same situation in Central and North Darfur following inter-communal violence. (UNHCR The UN Refugee Agency , 2021)

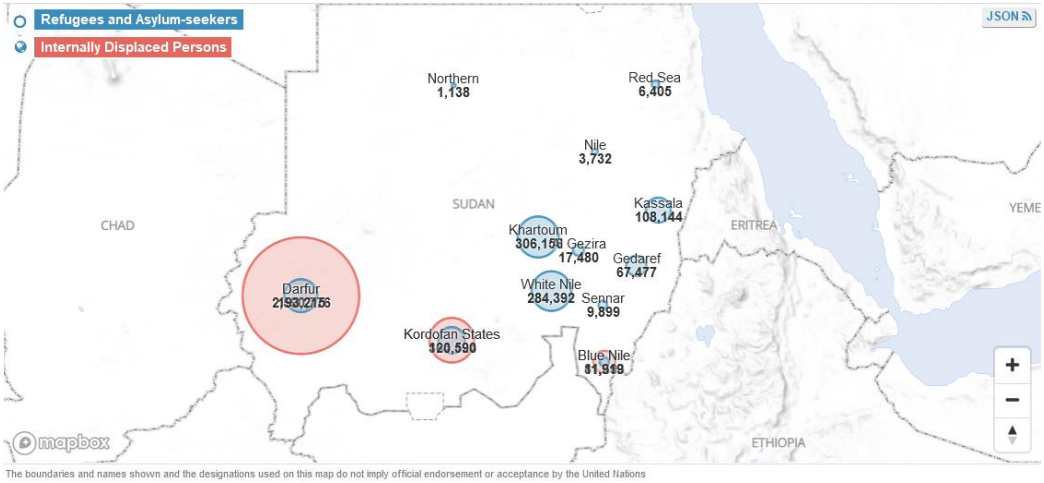


Figure 1: *Figure demonstrating the Refugees, Asylum-seekers and Internally Displaced Persons in Sudan as of 31 December 2021* (UNHCR Sudan, 2021).

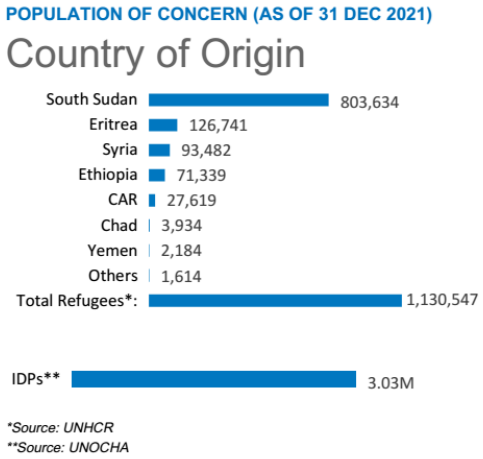


Figure 2: *Figure showing Countries of Origins the Refugees and IDPs in Sudan came from, as of December 2021* (UNHCR The UN Refugee Agency , 2021).

The Need and Urgency for Sustainable Solutions

The number of refugees is increasing annually at a frightening acceleration, according to UNHCR statics as of 2021. (UNHCR Sudan, 2021)

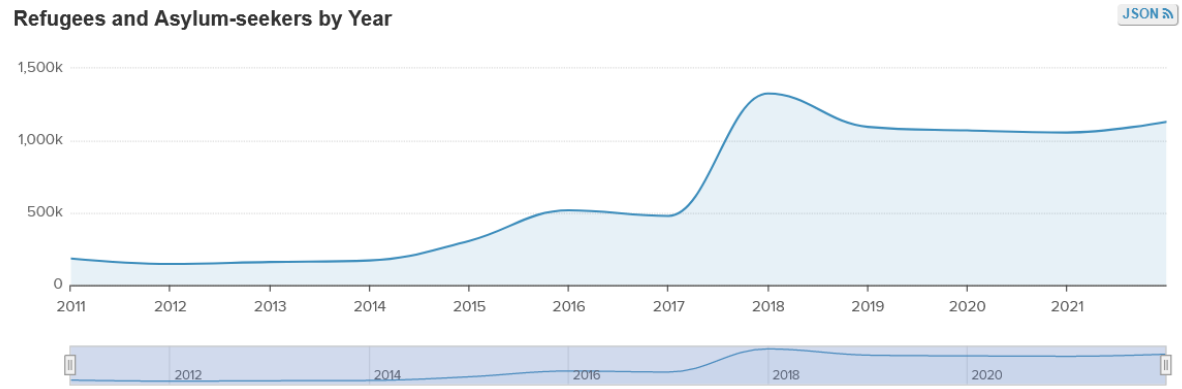


Figure 3: *Figure demonstrating the accelerating numbers of Refugees, Asylum-seekers in Sudan through the years as of 2021* (UNHCR Sudan, 2021).

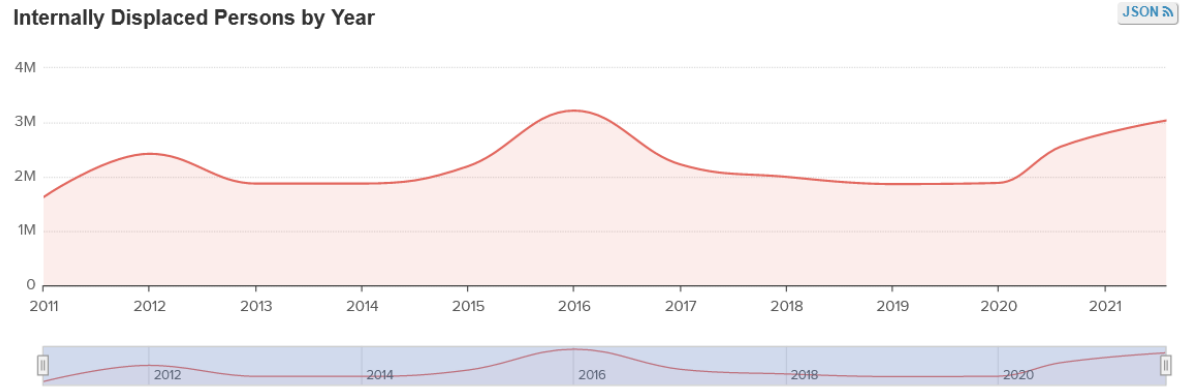


Figure 4: *Figure demonstrating the accelerating numbers of Internally Displaced Persons in Sudan through the years as of 2021* (UNHCR Sudan, 2021).

Until the last two years, new refugees kept arriving monthly to the country. UNHCR in Sudan recorded 94,831 new arrivals in 2020 and 109,014 arrivals in 2021. (UNHCR The UN Refugee Agency , 2021)

Figure 5: *Figure showing the recorded number of new arriving refugees through the months of 2020 and 2021 in Sudan, as of 31 December 2021* (UNHCR The UN Refugee Agency, 2021)

The majority of refugees stay in out-of-camp settlements, host communities and urban areas (61%) (UNHCR The UN Refugee Agency , 2021). The refugees are distributed over different states of the country, with a clear agglomeration in the states of Khartoum and White Nile. Among all the states, Khartoum has the highest sharing of refugees' population (UNHCR The UN Refugee Agency , 2021).

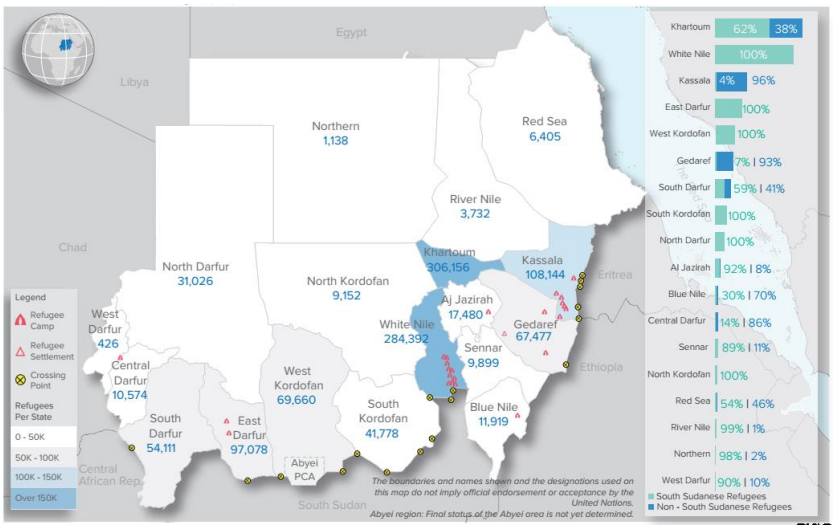
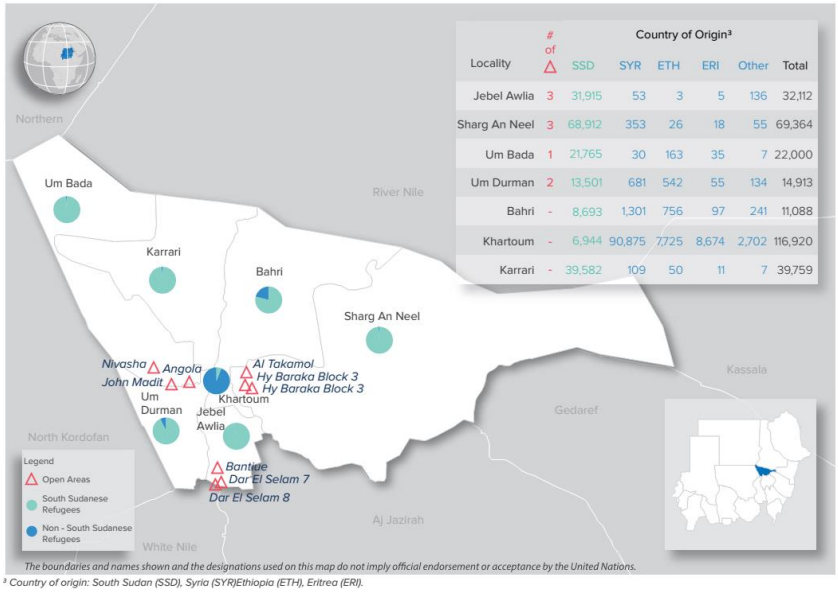


Figure 6: *Figure showing the recorded distribution of refugees over the states of Sudan as of 31 December 2021.* (UNHCR The UN Refugee Agency , 2021)

In Khartoum state in particular, 100% of the total distribution of displaced people live outside the camps. 23,112 IDPs live in the Locality of Jabal Awlia in the southern part of the capital, where Mayo, the area targeted in the project MayoUp is located. (UNHCR The UN Refugee Agency , 2021)



Locality	# of △	Country of Origin³ SSD	SYR	ETH	ERI	Other	Total
Jebel Awlia	3	31,915	53	3	5	136	32,112
Sharg An Neel	3	68,912	353	26	18	55	69,364
Um Bada	1	21,765	30	163	35	7	22,000
Um Durman	2	13,501	681	542	55	134	14,913
Bahri	-	8,693	1,301	756	97	241	11,088
Khartoum	-	6,944	90,875	7,725	8,674	2,702	116,920
Karrari	-	39,582	109	50	11	7	39,759

³ Country of origin: South Sudan (SSD), Syria (SYR)Ethiopia (ETH), Eritrea (ERI).

Figure 7: *Figure showing the recorded numbers and locations of refugees in Khartoum State as of 31 December 2021.* (UNHCR The UN Refugee Agency , 2021)

Through observation and frequent visits to Mayo area, and the team hearing various families in the neighbourhood complaining about the damage they suffer annually during rainy season, from the condition of the homes and the region as a whole, the two teams were assured of the necessity of providing emergency solutions to this problem. The fact that families live in homes they have constructed with poor quality materials or have installed in an unstable way puts them annually at risk of homes demolitions on their occupants. Also, their living in poorly planned houses with inappropriate internal configuration put their privacy in jeopardy, as several families sometimes share the same yard, services and facilities of the same house. Homes lack security for their residents, which is one of the basic principles for which a person

seeks a shelter of his own. The improvisation way in which they built those neighbourhoods, resulted in the crooked street with surface levels varieties. In addition to all of that, the absence of a surface drainage system in the area lead to the annual accumulation of rainwater every autumn. Therefore, residents suffer of inaccessibility to their homes at that time. In addition to frequent health problems resulting from the fact that these puddles constitute a fertile environment for the reproduction of flies and mosquitoes.

Image 1: *Showing a house in Mayo partially damaged after the rains season.* (The Italian Agency for Development Cooperation AICS - Khartoum office, 2021)

The Importance of a Participatory Approach

Multiple experiences in community development around the world demonstrated the importance of community involvement in many different fields. In (Ann Marie Crosse, 2021) case of study, the community is considered a critical stakeholder to work with. That is referred to factors like holding community knowledge and having a sense of place. Described by the authors' words, "the community is perceived as being the population that lives, works, and plays within the research landscape". In this example the author has tested different methods, to mention a few, the use of the walking interview and the participative group reflection was effective for provoking participants' awareness of their own knowledge as well as helping in encouraging the members in sharing it among the groups. Various presentations of their knowledge included information, knowledge of local places, as well as personal experiences, events, memories, and connections. The findings of another phase of the experiment set the foundation for further exploration of influencing factors leading to different levels of community awareness, knowledge, and understanding of the social and ecological interconnections of health at the place level. The use of a "community co-production research process" resulted in facilitating a cognition of the advantages, impacts, and importance of integrating the community in solutions resolutions. The members' awareness of the ecological determinants of health will contribute to improving local community planning and realizing sustainable development.

General Background about Higher Education Institutes (HEIs) Role in DCs Highlighting Sudan

Higher education institution (145 institute as in a press release of Ministry of Higher Education and Scientific Research (2021)) have long worked in Sudan since the colonial and post-colonial period to raise the level of education and intellectual development of the people of Sudan and

the neighbouring region. Its role was not limited to providing education and guidance in its institutions and facilities only, but it also sought to develop curricula and continuously enrich the scientific content in the country through scientific research in various fields. It also sought to integrate the society as a whole in this development and the educational process by carrying out various projects solo and in forms of collaboration with local and international organizations and destinations. Focusing on architecture as an example, the various schools of architecture have always sought to develop the profession and transfer the accumulated knowledge to the community, practitioners of the profession of architectural design, builders, workers and landlords from different backgrounds at different levels. They have worked through the years on monitoring the profession and its development, observing the various construction and adaptation techniques, and providing different ways and solutions to advance it via theoretical and experimental research, in field and its labs and facilities.

Background of the Collaboration and UofK Part in It

The administration of the University of Khartoum received a generous invitation from AICS, as it is the most prestigious educational body in the country, with leadership in the field of academic research. The university welcomed the invitation to cooperate. AICS and FoA directors selected a group of university teaching assistants to form a team representing the university under the supervision of the Dean of the Faculty of Architecture. UofK signed an agreement with AICS that aimed at setting a foundation of collaboration in aspects like inclusive architectural design, developing local communities and the built environment therefore to work together to contribute in reaching the Sustainable Development Goals SDGs. The collaboration intended in contributing to the realization of the following SDGs: 3.Good Health and well-being, 4.Quality education, 6.Clean water and sanitation, 8.Decent work and economic growth, 9.Industry, innovation and infrastructure, 11.Sustainable cities and communities, 16.Peace, justice and strong institutions. The signing of a memorandum of understanding (MoU) between the UofK and AICS, followed by signing a technical agreement between the FoA and AICS to collaborate in realising the two projects was held at the end of January 2020. Beside UofK (FoA) other partners were involved, including the Commission for Disarmament, Demobilization and Reintegration (DDR), the Locality of Jabal Awlia and Hope for Friendship and Development – Sudan, Italian Civil Protection, ARCò Architettura & Cooperazione. (Italian Agency for development Cooperation- Khartoum Office, s.a.)

Image 2: *United Nations Sustainable Development Goals targeted by the collaboration.* (The United Nations Foundation, 2015)

Image 3: *Logos of the partners involved in MayoUp Project.* (The Italian Agency for Development Cooperation AICS - Khartoum office, 2021)

Examples Background/Introduction: Mayoup Project

The MayoUp Project is a huge project that focuses efforts on raising the standards of living of Mayo people (they are originally displaced and refugees from different regions) by improving the built environment through investigating the problems and crisis issues there with providing solutions in the form of research and published publications to urge government agencies and various organizations to provide further investigation and adopt the proposed solutions. The project includes a theoretical part, such as making various surveys and analysing data, and implemented part, such as construction of services such as schools and providing clean water supplies and surface drainage systems.

Examples Background/Introduction: Dictorna Project

The Dictorna project focuses on upgrading the pre-existing health facilities in different areas of the capital so that they can provide better quality services to health care recipients of all ages. In the beginning, the project aims to explore the shortcomings or shortages in meeting the needs in a specific residential area, and then make an assessment of the facility's buildings and compare their suitability to meet the desired purpose. A team consisting holistically of specialists from various related fields proposed solutions and presented designs. The team is keen that the solutions adopted are effective in all respects: economically, socially and sustainable wise.

The Influences and Benefits of a Community Participatory Approach

The authors clearly noted- through carrying out these two projects- the effective impact of involving the community itself in dealing with their own issues. For example, when community members were included in the stage of collecting information about the problem and its impact, the residents and community leaders cooperated excellently in providing information and assistance, which eventually resulted in an excellent set of data and a more comprehensive view of the issue, which helped in understanding it and thus describing it in a deeper way. In the implementation phase, the involvement of local workers from Mayo region in the construction process gave those new experiences and skills set that could help them as a source of livelihood or at least in improving the quality of the environment in which they live. It also enhanced their sense of responsibility and the importance of their role in implementing the solutions provided to them and ensuring their sustainability by encouraging their keenness to do so by developing their sense of belonging to the solutions instead of considering them as alien bodies.

Community Participatory Approach is considered one of the appropriate technologies as it is inspired by the community itself. At the same time community member contribution is crucial the whole process from the creation of the suitable technology in the beginning all through to the implementation in field. The bond created during the above-mentioned process encourages the members to ensure the sustainability of the solutions and creation of new adaptations to future implications of any kind.

MAGNITUDE OF COLLABORATION

Outcomes by the End of the Two Projects

The presence of UofK team constituted mediation between the organization and the local community. Where foreign organizations usually face a barrier or repulsion by local communities due to several factors, for example the language barrier and difference in cultural and professional backgrounds team members descend from.

Fortunately, the Mayo community trusted the university team, welcomed them into their homes and provided them with required information. This confidence was further reinforced by the team's introduction to the community by the community leaders themselves.

While in Dictorna project, the university team played a considerable role in the evaluation and appraisal phase. The knowledge of the team members helped in collecting data of all kinds. The organization now has an integrated set of data and information about the efficiency of the health centre and whether it covers the needs of the surrounding community whose members visit seeking health care. A large part of the collection is metadata of the condition of the buildings of the centre as a whole and accurate documentation of all dimensions, spaces and physical capabilities. The team also participated, in cooperation with specialists and engineers from various fields, in creating holistic designs and finding sustainable solutions, with a focus on economic suitability through cost efficiency.

Faced Limitation in Collaboration, In Implementation, Documentation and Results Publishing and Demonstration

The presence of members from different disciplines and research backgrounds helped to explore issues from different angles, and contributed to creating more creative solutions and more flexible proposals. The work of two parties on one project helped make it more effective in implementation, as the need for fewer members and relatively less time was observed.

However, some challenges and limitations faced the partners such as: The two groups had problems checking and categorizing the data as both groups did not pay attention to establishing a fixed agenda between the two partners prior to the actual site survey. This results in several ways of dealing with data when it is collected or documented.

The team also faced some coordination obstacles in several phases of the project, which led to changes in the schedule. Thus, disabling completion due prior stated date somehow. Other limitations that can be stated are misunderstanding due to lack of communication at several stages of the project between the two parties, which may be attributed to language and cultural barriers. One of the problems that was somewhat hindering the facilitation of work between the two parties was the lack of clearly defined roles and responsibilities. Among the factors that often disrupt progress are bureaucracy and poor conflict management.

Like many projects and plans that have been disrupted in the past two years due to the novel coronavirus pandemic (COVID19), this project has been negatively affected by its disruption as well. The lack of backup plans and slow adaptation of a replacing timeline and work style lead to delays and miss achievement at some stages of the two projects.

RESULTS AND DISCUSSION

It has become clear by the end of this analysis that the diversity in the composition of the work team resulting from the cooperation of several partners in a project is a double-edged sword. Where this diversity constituted a strong point in terms of its effectiveness in producing more innovative and comprehensive solutions. But on the other hand, we find that the diversity of the team and the decline of team members from different specializations sometimes led to obstruction of the workflow in cases that lacked a clear division of roles and tasks.

Team members from local higher education bodies are usually familiar with the context in which these communities are suffering. They also have sufficient awareness of the backgrounds and reasons that necessitated the creation of such issues. In addition to that, they speak the language of the country and the targeted communities, all of these are factors that made them efficient mediators to play the role of moderator between the organizations and communities involved in the projects that aim to communities' resiliency.

CONCLUSIONS

It is crucial for the university to contribute in similar projects of such various collaborations to generate additional resources to its pool of knowledge. As this helps in availing data and case studies for research and identifying specific challenges related to community service. The developed solutions, on the other hand, will enrich the knowledge pool of appropriate technologies in Sudan and similar communities. As the knowledge of similar technologies enlarges and normalised through the different parties and the community it will be easier to carry them out and normalised as well.

Key Factors of a Successful Collaborative Project

A clear and detailed agreement on the intended outputs by the two parties to the cooperation at the beginning in general, and its confirmation before starting the project and at each pivotal point across the timeline is an essential and effective factor in the success of any cooperation between institutions and bodies of all kinds.

Installing a clear ground for discussion and communication between the parties, in the beginning, is an important factor for the smooth flow of the work. The presence of regular, frequent and organized communication between the parties certainly contributes to making it easier to produce projects of this quality. It is also suggested to document this communication as much as possible, which may enhance the clarity of communication and ensure that all parties are on the same page along the timeline. It is also advised to agree on some details such as the method of documentation, the purpose of the collected data and how it is placed and sorted, in order to avoid any contrariness that may arise in the future.

Current Limitations and Recommendations

The world is still floundering in light of this pandemic, as many parties and institutions are trying to reconcile their situation as much as possible to avoid disrupting businesses and projects. In the studied case, the team members tried their best and did what they could with the possibilities available at the time to adapt to the situation that was imposed unexpectedly. However, it would be good and practical to have research or investigations in this area in order to help the partners in the future to adapt faster, but in a more practical and professional manner, which may protect against negatively affecting the project plan.

The authors suggest that in order to benefits from the limited resources in DCs, it is more efficient for HEIs to join forces in similar collaboration when intending to carry out similar projects as they notice how similar joints between partners with different sources contribute to magnifies the available source on hand. By combining the accumulated knowledge provided by academics and experienced researchers at HEIs with the fervour of voluntary glimpse provided by organizations, we can smoothly and efficiently deal with many problems and challenges facing Sudanese society now and in the future. Further researches are better done before engaging in projects specially in the area of management and coordination to avoid the above-mentioned limitations in the future.

The authors faced minor issues in retrieving feedback from the team members as all went their own ways. The authors suggest step-by-step documentation through the process via a logbook or similar tools to annotate all the important details on feedback and faced obstacles for better analysis and future study.

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EQUIPPING FUTURE DESIGN ENTREPRENEURS WITH APPROPRIATE SMALL-BATCH MANUFACTURING TECHNOLOGIES

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Abstract

The current pandemic has exposed the flaws of centralised global manufacturing, supply chain systems and the stability of permanent design employment opportunities by illustrating the fragility of these established systems. This has shed light on the ever-growing need for locally developed and produced products that address potential gaps in local markets through the economy-driven consideration surrounding minimal setup and input costs. Adapting already existing prototyping and manufacturing processes to be better suited to the local context offers the potential for a higher level of sustainability and economic viability, stability and growth in the long term. This paper details the first-year Industrial Design student projects undertaken that demonstrate the use of appropriate prototyping processes such as 3D printing (additive manufacturing), thermoforming, patternmaking (hand techniques and subtractive manufacturing), silicone tooling and material casting. These processes are addressed through a theoretical underpinning surrounding method for identifying cost-effective prototyping processes; the technical intricacies and design considerations for these processes, and their optimisation and adaption for small-scale batch manufacture. These techniques are considered around developing a foundation of skills, knowledge and innovative thinking to equip and empower future design entrepreneurs. The pertinent factors are: the low input costs of batch manufacture, the embracing of appropriate technology, access to affordable prototyping and batch manufacture materials and the incorporation of rapid prototyping processes. These techniques are strategically considered to be able to work within local market contexts or manufacturing hubs. The student work was undertaken through the aesthetic and conceptual design for existing brands or businesses to contextualise the application of the outlined skills in a practical manner that facilitates future potential entrepreneurial ventures.

Keywords: Small-Batch Manufacturing, Local Manufacturing, Industrial Design, Prototyping.

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DETERMINANTS OF SUSTAINABLE COMPETITIVENESS IN AFRICA: ANALYSIS WITH THE OPEN QUINTUPLE HELIX MODEL

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Abstract
The aim of this study is to analyze the determinants of sustainable competitiveness in Africa from the factors of the open quintuple helix model. Thus, the factor analysis technique of the study variables was performed, followed by the estimation with the system generalized moment method during the period from 2012 to 2016. The availability of scientific and engineer, high technological export as a percentage of manufacture export, firm-level technological absorption and fixed telephone lines/100 population are the main factors which contributed to the global sustainable competitiveness increasing in Africa. Thus, government must prioritize the opening up of the innovation system through the above-mentioned factors to increase trade policy effect on sustainable competitiveness achievement in Africa.

Keywords: Innovation System, Competitiveness, Africa, International Relationships.

INTRODUCTION

The current global knowledge-based economic dynamic suggests broad policy directions for science, technology, and innovation (STI) towards the sustainable improvement of the developing countries competitive performance in relation to those which are developed. The generation of technological innovation requires production, use and networking of technology and knowledge by economic agents. The non-linear models of innovation, therefore, constitute adequate frameworks for defining technological innovation policy for the sustainable improvement of countries' competitiveness (Peris-Ortiz et al., 2016; Page & Tarp, 2017).

Indeed, emanating from the forms and multiple sources of innovation, the nonlinear models have been the subject of the development of the national innovation system (Freeman, 1987; Lundvall, 1988, 1992; Nelson, 1993), the "mode2" of knowledge production (Gibbons et al., 1994) and more recently the triple helix (Etzkowitz & Leydesdorff, 1995, 1997; Leydesdorff & Etzkowitz, 2000) of the relationship between university, industry, and the government. The triple helix unlike other models is based on university as the main helix and integrates societal and environmental contributions to the quadruple helix and quintuple helix respectively (Carayannis & Campbell, 2009, 2010) for countries sustainable competitiveness improvement by creating favorable conditions for technological innovation (Etzkowitz & Leydesdorff, 1995; Leydesdroff, 2000; Peris-Ortiz et al., 2016).

However, in recent years, Africa has had a wide disparity in low competitiveness in regards to many indicators. According to the latest reports of the World Economic Forum on the Global Competitiveness Index (GCI), European and Asian countries occupy the majority of higher places while those of Africa is for the most part in lower positions (WEF, 2018). In other words, Sub-Saharan Africa recorded the lowest average score of GCI (46.2) as compared to all other regions of the world. This score is based on its weak average performance in 10 of the 12 pillars that the GCI takes into account. This report contains thirty-three (38) African countries out of a hundred and forty (140) in total, of which the highest-ranked have recorded mostly

underperformance. Among these countries, there are Mauritius (49th against 40th in 2017), South Africa (67th against 61st in 2017), Seychelles (74th against 107th in 2017), and Morocco (75th against 71st in 2017). In addition, 17 of the 20 economies with poor performance are from sub-Saharan Africa. There is also a very weak performance of African countries as compared to those of other parts of the world in terms of sustainable competitiveness despite the continent's strong endowment of natural resources. In fact, on the 180 countries included in the 2017 (GSCI) Global Sustainable Competitiveness Index report, the top four in Africa are Ethiopia (64th), Ghana (68th), Côte d'Ivoire (77th), and Kenya (80th). There are also 8 African countries in the last 20 of the ranking (SolAbility, 2017). Thus, it emerges from the analysis of the evolution of economies according to the development phases that no the African country has been able to reach the third phase of development driven by innovation (WEF, 2016).

Indeed, in terms of innovation performance, according to the latest report of the global innovation index, which covers 126 countries in the world (including 28 African), many developing countries have shown impressive performances. Asian countries are particularly well-ranked with Singapore (5th), Republic of Korea (12th), Japan (13th), Hong Kong (14th), and China (17th) in the top 20. However, the scores of African countries are modest. The top-ranked countries are South Africa (58th), Tunisia (66th), Mauritius (75th) and Morocco (76th) and 13 of the 20 lowest-ranked countries are African (WIPO, 2018). These results are the consequence of the weak performances of innovation capacity, characteristic of the level of the African countries innovation system efficiency. This can be explained in particular by the fact that the Sub-Saharan Africa region comes in the last position with an average score of 28.4 against the highest score of 58.1 for Europe and North America (WEF, 2018). According to this WEF 2018 report, South Africa ranks first in the 38 African countries at the 46th position (against 38th in 2016) in the rankings. This country is followed by Seychelles (49th), Mauritius (62nd against 53rd in 2016) and finally Egypt in the 64th position. These performances can be explained by the results of a national innovation system in developing countries (particularly in Africa) (Gu & Whewell, 1999; Casadella & Benlahcen-Tlemcani, 2006), and an important synergistic contribution from the foreign world (Mezouaghi, 2002; Mêgnigbêto, 2015; Lundvall, 2015). Moreover, African countries are the most affected by environmental consequences, especially by climate change.

However, apart from the study ofPeris-Ortiz et al. (2016), which was the subject of the multiple helix ecosystem frameworks of sustainable competitiveness elaboration, most of the studies noted in the literature was interested in the triple helix analysis in the context of globalization by using opening factors (Leydesdorff & Sun, 2009; Lengyel & Leydesdorff, 2015; Leydesdorff et al., 2006; Ulanowicz, 2009; Strand & Leydesdorff, 2013; Smith & Leydesdorff, 2004; Mégnigbêto, 2015). Thus, the question arises of how the opening of the innovation system (in term of Open Quintuple Helix) can contribute to the sustainable competitiveness in Africa?

The aim of this study is to extend the quintuple helix model in terms of open innovation system (i.e., open quintuple helix model) in order to provide an adequate sustainable competitiveness framework. This framework is necessary for strategy definition to the benefit of developing countries in general and African countries in particular. Thus, this work follows a three-stage methodology: Definition of different international sources of innovation; Presentation of the two mechanisms of the triple helix generation that are self-organization and coevolution are used respectively for the development of an opening helix and its connection with the helix constituting the quintuple helix model. Finally, the analysis of effects of the Open Quintuple Helix factors is made on the sustainable competitiveness in Africa.

LITERATURE REVIEW

Different systemic approaches of innovation favor the establishment of theoretical links with the concept of sustainable competitiveness according to the World Economic Forum (WEF). Indeed, it is understood as the set of institutions, policies, and factors that make a nation productive over the long term while ensuring social and environmental sustainability (Schwab, 2014). This clarification shows the importance of models derived from TH for the sustainable improvement of countries' competitiveness (Peris-Ortiz et al., 2016). Indeed, many studies based on these approaches focus on the characteristic factors of these systemic approaches to innovation in terms of improving country performance. As a result, unlike India, South Africa and Brazil recorded negative indicator values. Using the same types of indicators, Fred et*al.* (2013) benchmark the dynamics of TH evolution between developed and developing nations across sectors. They believe that TH interactions between the three UIG sub-dynamics become less intensive at times and diverge across different countries.

In contrast to the studies on TH that base international co-author relations on international collaboration as the fourth dimension of the system (by the inclusion of international co-authors' papers (Leydesdorff & Sun, 2009; Kwon, 2011; Kwon et al., 2012), the taking into account of intra-sectoral cooperation at the international level (Choi et al., 2015), and the combination of domestic and international collaboration of UIGs as well as their bi or trilateral output (Shin et al., 2012)). Rezaee and Jafari (2016) show that knowledge-based view, resource-based view, dynamic capability, core competencies contribute to the sustainable competitive advantage. Fernández et al (2020) found from their analysis that Air transport infrastructures, cultural resources, and ICT readiness are the key that explain the disparities of tourism competitiveness between countries. Hossain et al (2021) analysis revealed that team culture, competitive intelligence awareness, and absorptive capacity have significance impact on sustainable competitive advantage in addition to the entrepreneurial behaviour. Širá et al (2020) demonstrate that knowledge-based economy affects the growth of sustainable competitiveness in the EU countries. In the same line, Krstic et al (2020) found a strong correlation between higher education, economy competitiveness, and sustainable development. Lee and Yoo (2021) analysis focus on Korean firm's sustainable competitive advantages. Their findings reveal that market and technological resource input and marketing and innovation capabilities mediate the positive impact of market orientation on a firm's competitive advantage. Mégnigbêto (2015) considered three levels (domestic, foreign, and global) for assessing the effect of international collaboration on innovation systems in South Korea and the West Africa region. These results reveal that unlike the region of South Korea, the synergy operates more at the foreign level than the domestic and global ones in West Africa.

Moreover, following the evolution of TH in QaH, QiH, and more recently in ntuple helix of innovation, Peris-Ortiz et al. (2016) develop the theoretical framework of "multiple helix ecosystem of sustainable competitiveness" according to which, the dynamic of sustainable competitiveness is characterized by four cycles of operations that are Intake, Compression, Ignition, and Exhaust. However, the theoretical framework proposed by Pitelis (2011) to countries in terms of competitive advantage and catch-up emphasizes the role of openness (through FDI) in relation to Clusters and public policies. In addition to FDI, Lundvall (1992, 2015) focuses on trade and integration as the overriding determinants of countries' competitiveness in opening up the national innovation system. It is in view of these possibilities that this work proposes a theoretical framework of sustainable competitive strategies in a context of openness, i.e., from the transformation of QiH into an Open Quintuple Helix (OQiH). The OQiH is considered as a model derived from the triple helix ones and its extension

models of quadruple and quintuple helix (Carayannis & Campbell, 2009, 2010) as well as by their transformation into an open innovation system. Indeed, it improves the quintuple helix model by taking into account an opening helix related to various possible contributions in terms of strengthening the innovation system. Unlike the others additional helices of social and environmental contributions, this aperture helix does not induce the addition of economic agents at the national level for technological innovation development. It consists to transform the quintuple helix innovation system into an open quintuple helix innovation system. The choice of this model is related to the fact that it allows us to take into account the environmental constraints and external contributions which is necessary to strengthen the African innovation system. The OQiH is a specialized model in a country on the sum of the interactions between government, university, industry, civil society, and natural environment, which is reinforced by the foreign actors' participation in order to promote and create a knowledge cooperation system, know-how and innovation for sustainable competitiveness. Thus, we make a hypothesis in this study that *the opening factors of the OQiH innovation system contributes more to the sustainable competitiveness in Africa than other factors of the system.*

METHODOLOGY

In the view of this literature review, the opening of the innovation system in terms of OQiH model is important in the Africa context. Indeed, it is useful for an appropriate sustainable competitiveness framework elaboration for the definition of adequate technological economic policies in Africa. This new model improves the quintuple helix ones by taking into account an opening helix related to the different possibilities of external contributions for the innovation system reinforcement.

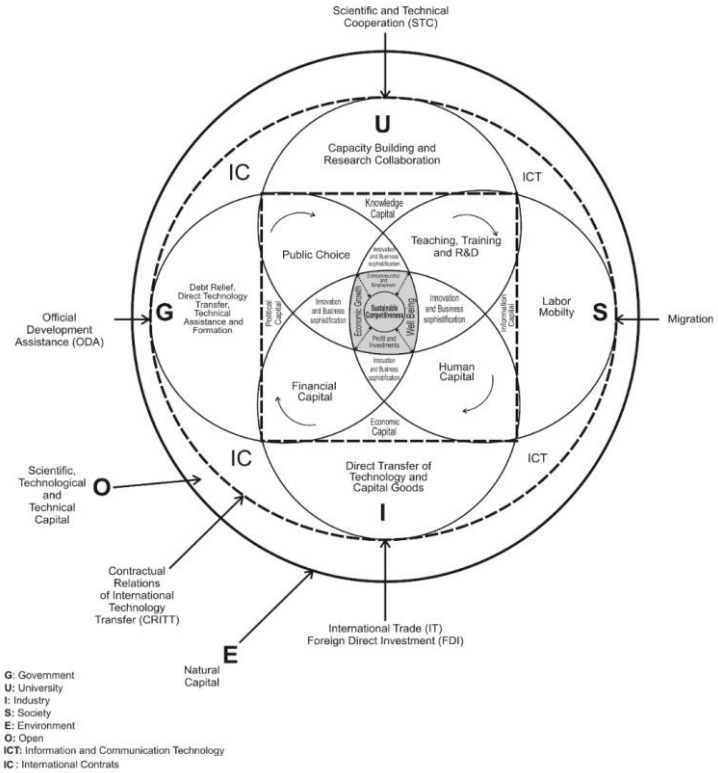

Figure 1: *Framework of Open Quintuple Helix Model Configuration for Sustainable Competitiveness Achievement.*

This opening helix made is up of a variety of international sources of innovation such as: foreign direct investment (FDI), international trade (IT), labor mobility (LM), information and communication technologies (ICT), natural environment (E), and international cooperation, which brings together, official development assistance (ODA) and scientific and technical collaboration (STC). Indeed, ODA helps governments to create favorable conditions for the attractiveness of FDI and the development of the IT, which in turn strengthens business activities and fosters LM. This set contributes to the development of contractual international transfer of technology relationships (CITTR) that involve both public and private actors. Similarly, the E according to its constraints, leads public authorities to take necessary measures for the transfer of green technologies and an incentive for green innovation, which is fundamentally the responsibility of universities that will be strengthened in their activities by STC and ICT.

Thus, in addition to the quintuple helix model, this opening helix contributes to reinforcing the coevolution between social, democratic, and economic knowledge for the achievement of sustainable competitiveness. According to the world economic forum, sustainable competitiveness is a set of institutions, policies, and factors, which improve countries productivity in the long term, while ensuring social and environmental sustainability (Schwab, 2014). Thus, the roles of the various economic actors in terms of economic policies for African countries sustainable competitiveness improvement are presented in the framework (see figure 1 above) which is deducted from the works of Farinha et al. (2014) and Peris-Ortiz et al. (2016).

According to this framework, there are three phases, which contribute to sustainable competitiveness improvement, namely International Interactions, National Interactions, and Performance Enhancement phases. The first phase of international interactions is characterized by interactions through IT, FDI, ODA, STC, and LM. These interactions favor the relationship development between national actors and their foreign counterparts according to environmental constraints through International Cooperation and ICT for innovation system reinforcement in terms of knowledge, economic, political, and information (or social) capital. The second phase of national interactions is marked by interactive relationships between various actors, particularly through R&D, financial capital, political choices, and human capital for innovation and business sophistication reinforcement. Finally, four types of competitiveness characterize the third phase of performance improvement. The university competitiveness, which is related to the development of entrepreneurship and job creation. Industrial competitiveness, which is materialized by, increased profits and investments. The government competitiveness, which is about improving sustainable economic growth and the well-being of civil society which is referred to as social competitiveness. These four types of performance are aspects of sustainable competitiveness.

Variables Choice and Data Sources

Following the theoretical framework of analysis, we consider different types of variables according to the three levels of international, national, and performance interaction. These are presented according to their source in the table1 below. It is noted, according to this table 1 that the variables coming from the WEF are the scores resulting from subjective surveys evolving on a scale of 1 to 7. Because of this, those obtained from the World Bank is database are in the form of a ratio in order to solve the problems of scale. Finally, we have used the global sustainable competitiveness index to measure sustainable competitiveness in Africa. We have chosen to use this indicator for the analysis compared to the global sustainable competitiveness index because it integrates data trends over time to allow for a better expression of future development potential. Apart from a few survey-based indicators (such as

the transparency international corruption index), all indicators are quantitative, derived from the World Bank databases. Its structure is in the form of index scores ranging from 0 to 100. It is therefore free of ideological bias.

The GSCI is a thorough alternative to the GDP to measure the real wealth of nations and to express the potential to sustain current wealth levels. It is based on a model that incorporates all pillars of sustained growth and wealth creation such as natural capital availability; national governance efficiency (the framework in which all players operate – the outcomes of policy directions and investments, e.g., the availability of infrastructure), intellectual capital (innovation and business capabilities), resource efficiency, and social cohesion. Thus, the GSCI expresses current and future development prospects and risks of nations. The results aim at serving as an alternative to commonly used metrics and measurements of competitiveness, such as the GDP or credit ratings, for academic purposes and decision making.

Dimensions	**Variables**		**Sources**
	International Interactions	**National Interactions**	
Government	Net ODA received % of central government expense (ODA)	Burden of Government Regulation (BGR); Infrastructure (INF); Government Procurement of Advanced Technology Products (GPATP)	World Development Indicators (WDI) and World Economic Forum (WEF)
University	Scientific and Technical Journal Articles (STJA)	Quality of Scientific Research Institutions (QSRI); Higher Education and Training (HET); Quality of math and science Education (QMSE); Availability of Scientists and Engineers (ASE)	
Industry	High-Technology Exports % of Manufactured Exports (HTEME); FDI and Technology Transfer (FDITT)	Company Spending on R&D (CSRD); Firm-Level Technology Absorption (FLTA); Intensity of Local Competition (ILC)	
Society	Individuals Using Internet (IUI); Fixed Telephone Lines/100 Population (FTLP); Country Capacity to Attract Talent (CAT)	Degree of Customer Orientation (DCO); Employment in Industry Sector % of total employment, modeled ILO estimate (EIS)	
Environment	CO2 emissions metric tons per capita (CO2)	Natural Resources Rents % of GDP (NRR)	
Performance	Global Sustainable Competitiveness Index (GSCI)		SolAbility

Table 1: *Variables of study (Source: Developed by the Author in 2021).*

However, the framework of sustainable competitiveness belongs to the model of the open quintuple helix, which is based on interactions between different actors for the sustainable improvement of the countries' competitiveness through the generation of technological innovation. Thus, the variables selected for econometric analysis are those that are subject to redundant information or to the existence of multi-collinearities. Thus, the factor analysis was used to identify the key variables according to each level of interaction. Indeed, the factor analysis is done according to the specific options "rotate" and "promax" which have the particularity of information on correlated variables. The study covers the period from 2012 to 2016.

Econometric Specification

Since sustainability is a dynamic phenomenon in which present behaviors determine those of the future, this study takes into account the fact that the present level of sustainable competitiveness of countries determines those of the future. Thus, we used the systems GMM estimator in Arellano-Bover (1995)/Blundell-Bond (1998). This approach makes it possible to take into account the problems of endogeneity, which we are tackled in this study. It consists of combining for each period, the equation in first difference with that in level. In the first difference equation, the variables are then instrumented by their level values delayed by at least one period. On the other hand, in the level equation, the variables are instrumented by their first differences (Guillaumont & Kangni, 2006).

In addition, to test the robustness of our model, we will perform two tests. The first is the Sargan/Hansen overidentification test. It allows testing the validity of delayed variables as instruments. It will be conclusive if we cannot reject the null hypothesis at the 10% threshold. We will favor the Hansen test in the Sargan test because it is robust in the presence of heteroscedasticity on the residues. The next test is the second-order autocorrelation test of Arellano and Bond. It will be conclusive if the null hypothesis (absence of autocorrelation of the error terms in first difference to order 2) cannot be rejected at the threshold of 10%.

Determinants of Sustainable Competitiveness

On the one hand, the results of correlated factor analysis show different factors according to the helix of the open quintuple helix model for the countries sustainable competitiveness improvement to the minimum threshold of 50%. Among other things, we note BGR for the government helix; ASE for the university; COD, FTLP, and EIS for the societal helix and FLTA for the industrial helix; CO2 for the environmental helix and HTEME for the opening helix. These different variables are obtained with a minimum correlation rate of 50% (see table 2 below).

On the other hand, the results from the estimates of these variables on the GSCI are presented in the table3. The table shows that taking into account CO2 leads to the non-significance of several variables, the non-display of information related to different validity tests as well as the cancellation of the coefficients related to the temporary dummy variable Y5. However, the estimation without considering the CO2 reveals results that are more significant with the validity of Sargan, Hansen and Fisher tests at the threshold listed above. From the last case, It is therefore clear ASE, HTEME, FLTA, and FTLP, which all have positive effects on GSCI but with different degrees of significance. Indeed, while HTEME have it at 1%, FLTA and FTLP are at 5% with coefficients of 0.359 and 0.152 respectively and finally, ASE has it at 10%. Thus, we confirm our hypothesis the opening factor (HTEME) contributes more to the African sustainable competitiveness than other factors of the OQiH. Thus, in terms of sustainable competitive strategies in Africa, States must prioritize the opening up of the innovation system through the HTEME increase, followed by the strengthening of the FLTA and the subscription to the FTLP before ensuring the ASE in terms of importance.

	System GMM	
Variables	**GSCI**	**GSCI**
L.GSCI	-0.147	-0.423***
	(0.109)	(0.116)
BGR	1.003	0.103
	(0.714)	(2.002)
ASE	2.017*	0.879

	System GMM	
Variables	**GSCI**	**GSCI**
	(0.982)	(1.466)
HTEME	0.351***	0.356**
	(0.107)	(0.167)
FLTA	0.359**	0.386
	(0.153)	(0.349)
DCO	-0.730	1.181
	(0.869)	(1.851)
FTLP	0.152**	0.0280
	(0.0631)	(0.207)
EIS	-0.00722	-0.0182
	(0.0400)	(0.0654)
CO2		0.565
		(1.265)
Y5	0.733*	0
	(0.395)	(0)
Constant	33.75***	44.15***
	(6.181)	(9.703)
Observations	91	46
Number of id	23	23
ar1p	0.459	.
ar2p	0.173	.
sarganp	1.15e-06	.
hansenp	0.164	.
Fp	0.00768	0.0549

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table 2: *Results of estimation of the OQiH effects factors on the index of sustainable competitiveness in Africa (Source: Author's Estimation on Stata in 2021).*

CONCLUSION

In this study, which is based on the importance of the innovation system opening for the African countries sustainable competitiveness improvement, the aim was to analyze the determinants of sustainable competitiveness in Africa from the factors of the open quintuple helix model. Thus, the factor analysis technique was performed on the study variables followed by the estimation with the generalized moment's method system. These estimates were made over the period expanding from 2012 to 2016. The results show that ASE, HTEME, FLTA and FTLP all have positive effects on GSCI with respective contributions of 2.017, 0.351, 0.359 and 0.152. Thus, in terms of sustainable competitive strategies in Africa, States must prioritize the opening of the innovation system through the HTEME increase followed by the strengthening of the FLTA and the subscription to the FTLP before ensuring the ASE in terms of importance. The main limitation of this study is the unavailability of data over a long period. Thus, it would be good to resume the study in a few years by a comparative analysis of the effects of the OQiH factors on sustainable competitiveness according to the level of technological development of African countries.

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UNIVERSITY-INDUSTRY COLLABORATION, LEARNING, AND INNOVATION IN AFRICA

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Abstract
This study aims to analyze the relationships between university-industry collaboration, learning, and innovation in the context of the openness of the knowledge production model. To do this, the autoregressive vector panel estimation technique was used over the period from 2006 to 2017 after the elaboration of an open knowledge production model. The results show that the lag of university-industry collaboration in research development has a positive effect on both innovation and learning via respectively business sophistication and high education and training. In addition, this lag value improves also the quality of mathematics and science education and the growth of internet access in school is contrary to the availability of scientists and engineers which he has a negative effect.

Keywords: Research and Development, Learning, Innovation, Africa.

INTRODUCTION

Today, the economic landscape is shaped by two major forces technology and globalization (Railean et al., 2012). There is therefore a gradual shift in the industrial world towards an increasingly immaterial world characterized by the development of the knowledge economy (Gummesson, 2002; Santoro & Chakrabarti, 2002; Bouchez, 2012). This economy is materialized by a new phenomenon that Maunoury (1972) calls the intellectualization of production, reflected by the increasingly close link between research, education, and production. Universities are the main actors in the intersection. To achieve this, they must modernize and adapt to new business requirements by providing learners with vocational training. Universities that succeed in building bridges to the workplace are referred to as entrepreneurial universities (Kitagawa, 2005; Amable & Askenasy, 2005). In this view, universities are increasingly considered key partners of companies, especially in the development of innovation (Muscio, 2012). Thus, we are talking about university-business collaboration. The need for innovation in today's business world and the ambition of decision-makers to commercialize academic knowledge encourage this trend (Rybnicek & Konigsgruber, 2019).

To do this, the recognition of knowledge and innovation is important for the development of economic performance and the development of linear and nonlinear models for their production, use, and dissemination processes. Arising from multiple forms and sources of innovation, nonlinear models have led to the development of a national innovation system (Freeman, 1995; Lundvall, 1992; Nelson, 1993); the "Mode2" of knowledge production (Gibbons, 1994), and more recently the triple helix of the relationship between university, industry, and government (Etzkowitz & Leydesdorff, 1995, 1997, 2000). Unlike the other models, the triple helix model centers on the university as the main actor and supposes its interaction with industry as a base for generating technological innovation. Thus, interest in university-industry collaboration increased significantly in the 1990s, reflecting the increased dependence of industrial policy on knowledge transfer as a tool for knowledge-intensive and

competitive economic development (Bozeman, 2000). Specifically, university-industry collaboration refers to the interaction between these two institutions involving common activities that can facilitate the transfer of new external knowledge in industries as well as the generation of innovation (Arvanitis et al., 2008; Bruneel et al., 2010; Perkmann et al., 2013; Maietta, 2015; Kunttu, 2017).

Given the World Economic Forum data, we see that majority of African countries (especially Sub-Saharan) come last in the world rankings for university-industry collaboration. For example, Cameroon was ranked 115th in 2013. In 2014 and 2015, this country saw her performance improve and was ranked 82nd. However, in 2016, we notice a drop in performance, ranking her 91st against an increase that ranked her 85th in 2017. Similarly, Ivory Coast which occupied the 124th position in 2013 saw its performance improve, thus ranking her 86th in 2014, 2015, and 2016. Mali left from 123rd in 2013 to 100th, 97th, and 78th places in the years 2015, 2016, and 2017 respectively. As university-industry collaboration is regarded as an innovation input, Africa's relatively poor performance can reduce the region's performance in innovation. Indeed, revisiting the Global Entrepreneurship Monitor data, we also see that some countries in Sub-Saharan Africa such as South Africa, Mauritius, and Kenya have made efforts. However, most countries in this area are at the bottom of the global innovation rankings. For example, in a country like Angola, the level of innovation was only 21.49% in 2012, 18.91% in 2014 and 17.80% in 2018. For Madagascar, it was 20.89% in 2017 and 13.38% in 2018. For Cameroon, the level of innovation was 13.97% in 2014, 14.80% in 2015, and 15.90% in 2016. Finally, Angola registered 21.49% in 2012, 12. 25% in 2013 and 18.91% in 2014 (see Table 1 below).

Countries	Global Innovation Index Rank	University-Industry Collaboration Index Rank
Algeria	108	125
Benin	116	109
Botswana	89	82
Burkina-Faso	120	-
Burundi	122	103
Cameroon	117	85
Egypt	105	117
Ethiopia	110	47
Gambia	-	135
Ghana	-	65
Ivory Coast	112	-
Kenya	80	32
Lesotho	-	98
Madagascar	111	76
Malawi	115	119
Mali	118	78
Mauritius	64	93
Morocco	72	105
Mozambique	107	87
Namibia	97	83
Nigeria	119	133
Senegal	100	56
South Africa	57	29
Tanzania	96	61
Tunisia	74	106
Uganda	102	52
Zimbabwe	121	131

Table 1: *Countries Performance in terms of Innovation and Collaboration (Source: WEF (2017) and WIPO (2017)).*

While the majority of innovative industries do not rely upon knowledge gained from the collaboration with universities (Laursen & Salter, 2004; Drejer et al., 2014), it is widely recognized that university research contributes greatly to industry innovation (Breschi & Lissoni, 2001; Feldman &Desrochers, 2003; Branstetter & Ogura, 2005; Breschi et al., 2007). It can be considered that the low level of innovation in Africa is due to the low level of collaboration between universities and industries. It is because of this fact that this study aims to analyze the effects and relationships between university-industry collaboration, learning, and innovation in Africa.

LITERATURE REVIEW

Universities are motivated to collaborate with industries to leverage additional resources to fund research and other academic activities (Cohen et al., 1998). However, previous research has shown that university-industry collaboration goes beyond traditional funding for research projects (Singh, 2019). Certainly, these collaborations are likely to develop when there is a need for specialized knowledge that has not existed before (Bstieler et al., 2015). Thus, universities facilitate knowledge creation, learning, and innovation (Laursen & Salter, 2004; Hanel & St-Pierre, 2006; Weckowska, 2015). It has been shown that industries that have close ties with universities have more patents and lower R&D costs than industries without such relationships (George et al., 2002). For example, large manufacturing firms that have collaborated with universities have higher incomes from new or improved products (Loof & Brostrom, 2008). In this regard, the learning process in industry-university collaborations has been recognized as a critical enabler of the transfer and integration of new external knowledge into industrial production. (Kunttu, 2017). This learning process also helps partners to jointly build new internal capacity for innovation and identify ways to jointly develop and use knowledge for business (Weckowska, 2015). By creating a new knowledge base and new ideas, universities offer the best education to entrepreneurs, businesspersons, and future leaders (Robertson and Olds, 2016).

According to Guimon (2013), university-industry collaborations can help coordinate research and development programs; stimulate private investment in research and development and harness synergies and complementarities of science and technology capabilities. However, university-industry collaboration faces significant challenges (Bruneel et al., 2010). While universities are primarily motivated by the creation of new knowledge, industries focus on capturing valuable knowledge that can be harnessed to gain a competitive advantage (Dasgupta& David, 1994). Thus, in addition to national exchange networks, interaction with international actors is important for learning and innovation. In fact, List (1841) recognizes the importance of interdependencies between domestic and imported technologies and believes that industries should be linked to formal science and educational institutions. He, therefore, calls for a particular emphasis on industry protection policies and learning based on new technologies from elsewhere that are accelerating industrial performance.

Globalization is important for the interaction between actors, specifically the university-industry collaboration following the opening up of countries. For example, using specific operationalization in a Japanese case study, Leydesdorff and Sun (2009) point to two major changes in international competition since the opening up of China and the suppression of the Soviet Union. Lengyel and Leydesdorff (2015) show how internationalization and ownership of foreign firms influence synergy in Hungary's regional innovation systems. To achieve this, they resorted to the studies of Leydesdorff et al. (2006) and Ulanowicz (2009) the indicators

such as the geographical distribution of firms, organizational size (number of employees), technologies, and ownership. Foreign direct investment was added to these indicators to capture the effect of internationalization. They led to the result that Hungary's regional innovation systems are characterized by a number of foreign firms that have strong positive synergistic effects. In addition, Strand and Leydesdorff (2013) find that in Norway, FDI via the industrial coast in the western part of the country represents the major source of synergy in the development of knowledge-based regions compared to those dominated by university centers (Smith & Leydesdorff 2014). Mêgnigbêto (2015a) considered three levels (domestic, foreign, and global) for assessing the international collaboration effect on South Korea and West African region innovation systems over the period 2001 to 2010. These results reveal that unlike the South Korean region synergy operates more at the foreign than the domestic level in West Africa. Thus, it is important that the analysis of the effects of university-industry collaboration on learning and innovation in Africa be carried out in a context of the openness of the knowledge-production model.

METHODOLOGY

Theoretical Framework

Following the evolution of the national innovation system (Freeman, 1987; Lundvall, 1992; Nelson, 1993) into the triple helix (Etzkowitz & Leydesdorff, 1995, 1997 and 2000) which describes the innovation mechanism as a complex system and recognizes businesses and universities as active recipients and main actors of the knowledge and innovation production, use and transmission, this framework is based on their development foundation model called mode2 of knowledge production. This latter innovation model is related to the study of Gibbons et al. (1994) who find that the way in which scientific knowledge, technological practices, industry, education, and society are organized and function contrasts strongly with their previous relationships and suggests mode1 and mode2 of knowledge production. Moreover, the special present-day constraints of environmental changes that hinder the sustainable improvement of countries' performance have led to the development of the "mode3" of knowledge production (Carayannis & Campbell, 2006). The mode3 is a new approach to a knowledge-producing system that is both the expansion and extension of the mode1 of basic academic research and the mode2 of knowledge application for solving economic problems (Gibbons et al., 1994).

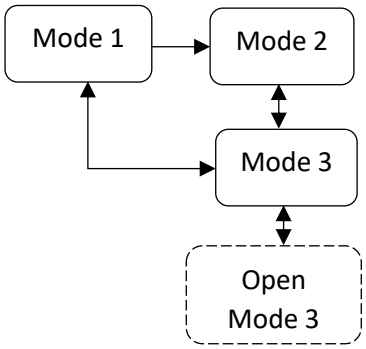

Figure 1: *Evolution of Knowledge Production Models.*

The diagnosis of the innovation mechanism in developing countries shows that the African countries are characterized particularly by university systems which largely correspond to the mode1 instead of the mode2 and the mode3 of knowledge production with very weak interactions between its different spheres. The contributions of external actors in terms of

foreign knowledge and technology dissemination, absorption and adaptation are important for the strengthening and effectiveness of the African countries' innovation mechanism (Mezouaghi, 2002; Mêgnigbêto, 2015). Thus, in the same evolution order as the different knowledge models presented above, this study proposes a new "open mode3" knowledge production. Actually, in the same way as the mode3 of knowledge production, the open mode3 encourages both interdisciplinary thinking and transdisciplinary application of interdisciplinary knowledge while allowing the coexistence and coevolution of different knowledge and innovation paradigms (Carayannis & Campbell, 2010). However, particularity, the taking into account foreign universities' participation through international collaborations in science and technology development (see figure 1 above).

Indeed, this open mode3 of knowledge production takes into account the national and international actors' interactions from innovation, technology transfer, and international knowledge international. These can be market-related (foreign direct investment, international trade, and labour migration or mobility), or non-market related interactions, that is contractual relations of international technology transfer, international cooperation (official development assistance and scientific and technical collaboration), environment (resources and constraints), and information and communication technologies (Keller, 2004; Leydesdorff et al., 2006 ; Strand &Leydesdorff, 2013; Ulanowicz, 2009; Drouvot& Verna, 2014; Leydesdorff& Sun, 2009; Kwon et al., 2012; Rogers, 2003; Carayannis& Campbell, 2010). Apart from the production of knowledge, the role of the university is also to satisfy the need for quality human capital (students, teachers, scientists and researchers, academic entrepreneurs, etc.). To do this, the universities provide education for the young population so that they can succeed in their careers. They also help young people following the attainment of the required levels of qualification to assume leadership roles in both non-profit and profit organizations.

Theoretical Model and Econometric Specifications

In the view of the framework presented above, this study used as the theoretical base model, the national idea production function derived from Romer's (1990) growth model which is as follows:

$$Å_t = \delta H_{A,t}^{\lambda} A_t^{\phi} \quad (1)$$

Where: $Å_t$represents the rate of technological progress or new ideas production, H_A the number of ideas workers, and A_t the stock of ideas available to these researchers. Specifically, in our case study of the analysis of the link between university-industry collaboration, learning, and innovation we adopt a specification inspired by the work of Furman et al. (2002) which is based on countries' innovation capacity determinants analysis. This specification is as follows:

$$Å_{jt} = \delta_{jt}\left(V_{jt}^{v}, W_{jt}^{w}, X_{jt}^{x}, Y_{jt}^{y}, Z_{jt}^{z}\right) H_{jt}^{A\lambda} A_{Jt}^{\phi} \quad (2)$$

With:

- ***j*** representing a country and ***t*** for a year;
- $Å_{jt}$ representing the level of the innovation which is approximated by the countries business sophistication (BS);
- V_{jt}^{v} representing the university-industry collaboration in research development (UICRD);
- W_{jt}^{w} use to capture the quality of mathematics and science education (QMSE);
- X_{jt}^{x} Corresponding to the growth of internet access in school (GIAS). These variable favours measuring of the effect of the opening of the knowledge production model;

- Y_{jt}^{y} Corresponding to the growth of the high technological export as a percentage of manufactured export (HTEMEG). This variable helps us to measure the research and development intensity in the country's exportation product. It is also considered as an innovation approximation;
- $H_{jt}^{A\lambda}$is used to capture the effect of the number of ideas workers which we approximate here by the availability of scientific and engineer (ASE);
- A_{jt}^{ϕ}Corresponding to the stock of available ideas is approximated here by the high education and training (HET).

The transformation of the model after the logarithm operator (L) application and change of variables is as follows:

$$LBS_{jt} = \delta_v LUICRD_{jt}^{v} + \delta_w LQMSE_{jt}^{w} + \delta_x LGIAS_{jt}^{x} + \delta_y LHTEMEG_{jt}^{y} + \lambda LASE_{jt}^{A} + \phi LHET_{jt} + \mathcal{E}_{jt} \quad (3)$$

All the variables are coming from the world economic forum and the World Bank databases. The study covers the period 2007 to 2016 taking into account 27 countries (see table in appendix). Thus, given that data related to the different variables are expressed in form of scores (ranging from 1 to 7) and ratios, it is not necessary for us to linearize them before estimation. However, before using them for the estimation, it is important to run the stationary and cointegration tests on them to make the appropriate econometric specification choice. Because of the fact that we are looking for the causal relationship between university-industry collaboration, learning, and innovation in the context of the opening of the knowledge production model, the econometric estimation technique that is retained is the one of an autoregressive vector. Actually, this method makes it possible to highlight the systemic effects and the mutual interactions between the different variables of the study. This estimation technique can be specified in terms of autoregressive vector panel (ARVP) or error correction vector panel (ECVP) (Holtz-Eakin and al., 1988) in accordance with the stationary or the cointegration of our variables of the study.

$$Y_{i,t} = \mu_i + \Omega_1 Y_{i,t-1} + \cdots + \Omega_p Y_{i,t-p} + \mathcal{E}_{it} \quad (4)$$

With: *Y is* defined as a vector of system components represented by our different variables of equation3 and $\mathcal{E}$ as the non-autocorrelated vector of errors. Once the choice of the appropriate specification has been made, the determination of the optimal delay number applied is made according to the majority of the set of identification criteria. We have identification criteria, the selection criteria, the Akaike information criteria, the Bayesian information criteria, and the Hannan-Quinn information criteria. After the determination of the optimal lag (which is equal to 1), we used an estimation approach using the Generalized Moment Method (specifically the "GMM-style" proposed by Holtz-Eakin et al (1988)). This is more practical than the ordinary least squares standard estimators or the within one in the presence of unobservable heterogeneity and endogeneity problem related to measuring errors, simultaneously or omission of relevant variables, and in the case of lack of data.

Empirical Analysis of the Link between University-Industry Collaboration, Learning, and Innovation

The analysis of the link between university-industry collaboration, learning, and innovation is done in terms of effects. The econometric effects of university-industry collaboration on

learning and innovation are presented in the table2 below. This table of the results of the estimation shows that the past values of university-industry collaboration in research development have a positive effect on both innovation and learning via business sophistication and high education and training respectively. In addition, these past values also improve the quality of mathematics and science education and the growth of internet access in school contrary to the availability of scientists and engineers which they have a negative effect. All these results are normal because of the fact that the university-industry collaboration in research development helps the companies to improve the technological strength related to their process and product. This increase in business sophistication can be considered as the cause of high education and training and of the additional labour force needed which can explain the decrease in the availability of scientists and engineers.

However, the past value of high education and training has a negative effect on the business sophistication as well as the university-industry collaboration in research development. The same effect is found in the quality of mathematics and science education and on university-industry collaboration in research development. This result can be explained by the fact that high education and training are oriented just on human resources formation and not on research and development in Africa. Because they contribute to increasing the availability of scientists and engineers. On the other hand, the past values of business sophistication and the high education and training have positive effects on the growth of high technological export as a percentage of manufactured export against the negative effects from the quality of mathematics and science education, the growth of internet access in school and the availability of scientists and engineers. This result can be justified by the fact that the African education system is not oriented toward an entrepreneurial university. To become entrepreneurial universities, African universities must emphasize the training programs extension, the implementation of repatriation policies for foreign-trained experts, and the reception of foreign specialists through scientific and technological cooperation. In addition, they must also develop international research collaborations by integrating researchers from developing countries into global R&D networks and thereby improving their skills and productivity. These actions are important because they will have the opportunity to work with their counterparts in industrialized countries on joint projects through ICT communication opportunities. Thus, the availability of scientists and engineers can contribute to strengthening the effects of university-industry collaboration on learning and innovation in Africa.

CONCLUSION

Based on the recognition of the importance of university-industry collaboration for improving learning and innovation performance, this study aims at analyzing the relationships between university-industry collaboration, learning, and innovation in a context of the openness of the knowledge production model. To do this, the autoregressive vector panel estimation technique was used and covered the period 2006 to 2017 after the development of an open knowledge production model. The results show that the past values of university-industry collaboration in research development have a positive effect on both innovation and learning via business sophistication and high education and training respectively. In addition, these past values also improve the quality of mathematics and science education and the growth of internet access in school in contrast to the availability of scientists and engineers which they have a negative effect. Thus, in terms of innovation policy, African universities must transform into an entrepreneurial universitiesby integrating researchers from developing countries into global R&D networks and thereby improving their skills and productivity.

Variables	(1) BS	(2) QMSE	(3) HET	(4) UICRD	(5) GIAS	(6) ASE	(7) HTEMEG
L.BS	2.281***	1.037***	0.963***	4.029***	0.355	-2.783***	1,941**
	(0.228)	(0.164)	(0.182)	(0.378)	(0.254)	(0.242)	(950.1)
L.QMSE	1.163***	1.178***	1.462***	0.321	-1.191***	0.130	-9,346***
	(0.117)	(0.0837)	(0.0895)	(0.211)	(0.162)	(0.141)	(472.0)
L.HET	-1.196***	-0.487***	-0.636***	-0.526**	2.236***	0.646***	13,797***
	(0.138)	(0.106)	(0.107)	(0.233)	(0.118)	(0.146)	(542.3)
L.UICRD	1.133***	0.781***	0.553***	3.317***	1.941***	-1.907***	42.67
	(0.105)	(0.0770)	(0.0771)	(0.193)	(0.146)	(0.130)	(398.3)
L.GIAS	0.0200**	-0.0112*	0.0410***	-0.0246	0.0997***	0.0104	-237.0***
	(0.00881)	(0.00663)	(0.00585)	(0.0173)	(0.00907)	(0.0119)	(18.70)
L.ASE	2.006***	1.617***	1.390***	4.021***	1.173***	-1.987***	-4,523***
	(0.0508)	(0.0368)	(0.0398)	(0.0844)	(0.0592)	(0.0535)	(207.8)
L.HTEMEG	0.000105***	7.72e-05***	9.24e-05***	0.000187***	4.84e-05***	-7.16e-05***	-0.423***
	(1.19e-06)	(7.96e-07)	(8.02e-07)	(2.17e-06)	(7.82e-07)	(1.47e-06)	(0.00254)
Observations	210	210	210	210	210	210	210
tmax	2015	2015	2015	2015	2015	2015	2015
tmin	2008	2008	2008	2008	2008	2008	2008
n	27	27	27	27	27	27	27

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table 2: *effects of university-industry collaboration on learning and innovation; Source: Authors Estimation on Stata.*

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FOOD WASTE, NOT IN GOOD TASTE: AN INVESTIGATION OF THE CAUSES OF FOOD WASTE IN THE NATIONAL SCHOOL NUTRITION PROGRAMME

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Abstract
School feeding programmes (SFP) have been at the forefront of attempting to alleviate hunger in many countries by providing school children with at least one nutritious meal a day. However, knowledge surrounding food waste within the National School Nutrition Programme (NSNP) of South Africa is extremely limited. Therefore, it is important to identify what preventative measures may be put in place to reduce the incidences of food wasted. This study aimed to explore the causes of food wastage in the NSNP of Johannesburg schools. Semi-structured interviews were conducted with participants, volunteer food handlers, principals, teachers, and NSNP coordinators. The results revealed that there were numerous factors that lead to food wastage. These factors included portion size, menu item preference and poor delivery services, all of which led to food wastage. This study identifies research gaps and challenges that need to be addressed in the design and implementation of the NSNP and the development of food waste management systems within the NSNP. This study further identified the need to implement waste monitoring/conversion systems, such as a biogas digester that was implemented in one participating school. This research further identifies the need for an increase in theory- and experiment-based literature for future studies.

Keywords: Food Waste, Sustainability, School Feeding, Developing Economy, South Africa.

INTRODUCTION

In earlier times, food wastage had truly little discussions surrounding it, as food was very readily wasted. The World-Wide Fund for Nature (WWF) stated, in South Africa, of the 31 million tonnes of food produced, 10 million tonnes are wasted which equates to a third of all food produced for consumption being wasted and of those 10 million tonnes, 70 per cent comes from cereals/grains, fruits and vegetables (WWF, 2017). Therefore, if the food service industry and households produce such exorbitant amounts of waste, it can be assumed that this trickles down to schools too. It is important to understand what these causes are in schools and institute educational methods of reducing, reusing, or recycling the food waste produced.

Everyday millions of children throughout the world attend school on an empty stomach; others are merely not attending due to their responsibilities in the household. According to the World Food Programme (WFP) (WFP, 2019), having a meal at school every day, through a school feeding programme, not only leads to an increased nutrient intake by the learners but also increases their overall attendance and success rates at school. Providing a meal to learners each day also provides families with a strong incentive to send their children to school (WFP, 2019).

School feeding programmes (SFP), however, face special difficulties when it comes to food waste such as the school programme and schedules that are rigid and set or serving meals on days when children are less hungry such as during school festivities or examination periods

and attempting to adapt meals to differing energy levels, preferences, and cultures of learners – all whilst using the available resources (Busby & Guthrie, 2002). As stated by Busby and Guthrie (2002), meeting learners' varying preferences and cultures is a challenging task especially in the "rainbow nation" (as coined by Archbishop Desmond Tutu) of South Africa (Handa, 2007).

There needs to be greater cohesion and better monitoring and evaluation of the NSNP as a whole. Although the guidelines state one thing, the reality is different from school to school. Greater emphasis must be placed on theory-based and experimental research on the causes of food wastage in the National School Nutrition Programme. Future studies should include a larger sample with the inclusion of government officials and facilitators in all provinces of the country.

RELATED STUDIES

It is estimated that in 2019, 913 million tonnes of food were wasted, 61 per cent in households, 26 per cent from the foodservice industry and 13 per cent from the retail sector. This figure equates to 17 per cent of food being wasted globally, United Nations Environment programme (UNEP) (UNEP, 2021).

Around eight to ten per cent of all greenhouse gases (GHG) are associated with unconsumed food that is inevitably wasted and/or requires waste treatment methods (UNEP, 2021). These numbers are astounding and reveal how important it is to reduce waste in the hopes of improving the detrimental costs food waste has, with the consumer level presenting the highest burden.

The US's National School lunch program (NSLP) serves more than 31 million learners in over 100 000 schools daily. The NSLP provides an important opportunity for researchers to study how much and what types of nutrients learners consume and waste (Shanks, Banna, & Serrano, 2017). The lunchroom is experimental in nature because menus are designed by the local school food authorities per national nutrition standards, food portions are standardised, and many learners eat at school daily. This experimental nature allows for studies to be conducted on nutrient intake, dietary quality, menu performance, food acceptability, cost, and the effectiveness of nutrition education in the NSLP (Shanks *et al*., 2017).

In a study conducted in Portugal, of the 500 000 learners who attended primary education schools, 80 per cent of the learners had lunch at school. This shows a great dependence on the school lunch programme and the school meals would have to provide a balanced diet considering the school population needs and to follow recommendations from the Portuguese Ministry of Education (Dinis, Martins, & Rocha, 2013). However, it was found that there was regular wastage in these schools with some causes being noted as errors with menu planning, incorrect estimation of the number of meals, as well as with food selection and portion planning (Dinis *et al*., 2013).

Hiemstra (2018:15) noted that school top management plays a significant role in the generation or reduction of food waste in the school feeding program. Schools that viewed school feeding as an integral part of their school's mission experienced far less wastage than schools that considered the meal simply as a "fringe service offered to the children's parents." Schools whose top management officials placed importance on creating an awareness of sustainability

and in allocating resources to educating learners about consuming all their food, using diverse types of activities, experienced less wastage overall. One method used was the supervision of learners whilst they were eating. Hiemstra (2018:15) concluded that "staff awareness, and then especially awareness of the school's management is an important factor in the reduction of food waste." Having waste management as a topic to discuss during lessons could increase learner's awareness. One method is to show learners the weight of their food wasted on a plate or allowing learners to separate their leftover food into edible and inedible food items themselves before disposing of it into waste bins, (Hiemstra, 2018).

An increasingly popular method of educating learners on the importance of health and nutrition is through the use of apps and games. Putnam, Richmond, Brunick, Wright and Calvert (2018) conducted a study to assess learners' cognitive behaviour whereby a well-known children's media character was introduced into an app/game. This inherently made children more willing to learn about healthy food choices. Children would either be rewarded or punished based off their healthy or unhealthy food choices. The same concept could be applied in the NSNP, where learners have access to an app or gaming device, which educates learners on the consequences of food waste and the negative effects thereafter, this too would work on a reward system. In developing countries, a strange occurrence was documented by Aliyar, Gelli and Hamdani (2015) where SFPs led to learners being fed less at home as parents used the SFP as a replacement for feeding at home, which is contradictory to the aims of school feeding programmes. The families saw the SFP as a way of saving money and budgeting and spending the saved money on other household purchases. The successful implementation of a SFP requires that this substitution does not occur within households.

It is essential to examine the cause of food waste on a global scale, to find solutions that can be applied uniformly. Although there are differences between food waste in developing countries and developed countries, the aims of the feeding programmes differ between demographics as well. In a developing country such as South Africa, it is even more important to reduce food waste since the aims of these programmes are to alleviate hunger and malnutrition, increase school attendance, etc. (Parfitt, Barthel & Macnaughton, 2010). These basic physiological, safety and security needs are essential for growing children and future populations.

METHODOLOGY

The research made use of an exploratory design. An exploratory design is used when there are little to no previous studies on the problem at hand to refer to, i.e., to hypothesise an outcome. The aim here is to gain knowledge and information on the problem that may be undertaken in future similar research problems (Cuthill, 2002; Streb, 2010; Taylor, Catalano, & Walker, 2002). While researching the problem at hand, it became increasingly evident that there was extraordinarily little past research to consult. There are few studies on food waste conducted in South African schools as a whole, thus sourcing research on food wastage in schools based in Johannesburg and participating in the NSNP became a difficult undertaking.

Hence, the research design is exploratory to gain insight in and information on the problem of food wastage in Johannesburg NSNP schools.

Research Instrument

The research instrument was qualitative interviews, telephonic and face-to-face, with a few close-ended questions. This method was chosen because it was the best and most efficient method of extracting the necessary information from participants by letting them feel comfortable through the use of conversation instead of a rigid quantitative approach which may limit participants' feedback (Rahman, 2020). As language barrier presented a challenge, interviewing the participants allowed the researcher to explain certain concepts that may not have been understood otherwise better. The addition of the close-ended questions allowed for a greater understanding of the questions by the participants as this gave the participants a general idea of what the question required to present a conducive response.

The interview questions were divided into two sections, namely Section A and Section B. Section A comprised demographic characteristic questions and section B comprised questions relating to food waste management. Section B was further broken down into three parts in order to effectively answer the research questions. Part One proposed questions on the degree of food wastage, Part Two proposed questions on the menu composition and food type, lastly, Part Three proposed questions on waste management programmes.

Participants and sample

The participants/population "is all the individuals or units of interest, typically, there is not available data for almost all individuals in a population" (Hanlon & Larget, 2011:15). For this research, the population was principals, Volunteer Food Handlers (VFHs), NSNP coordinators at the schools and teachers in Johannesburg schools. To maintain the anonymity of the participants, the schools were not listed, neither any participant names. The study was conducted in Johannesburg North, South, East, West and Central. For this study, the participating institutions were referred to by code from A to S. Lastly, it should be noted that no learners took part in the interviews due to ethics concerns. The table below refers specifically to the geographic areas of the schools and the total number of schools in said geographic areas.

Gauteng suburb/town	Schools in Area	Code for schools	Participants in area
Diepsloot	1	A	1
Melrose	1	B	1
Lenasia	2	C, D	4
Mayfair	1	E	1
Riverlea	1	F	1
Diepkloof	1	G	1
Randburg	1	H	1
Doornfontein	1	I	1
Protea Glen	1	J	1
Yeoville	1	K	1
Klipspruit	1	L	1
Orlando East	1	M	1
Zola	1	N	1
Emdeni South	1	O	1
Tembisa	2	P, Q	4
Alexandra	1	R	2
Midrand	1	S	2
TOTALS	**19**	**19**	**25**

***Table 1**: Geographic location, codes and number of schools and participants (n=25) who took part in the study of food waste management in the NSNP, October 2019–March 2021.*

Data collection

Semi structured telephonic and face-to-face interviews

The data was collected by two methods, first through telephone interviews and next by face-to-face interviews.

"Interviews are methods of gathering information through oral quiz using a set of pre-planned core questions" (Thomas, 2010:314). Thomas (2010) continues to describe how interviews allow for specific issues of concern to be pursued by elaborating on proposed questions thus leading to "focused and constructive suggestions" on the interviewer's side.

Regarding conducting interviews, there are three methods, namely structured, unstructured or semi structured. In structured interviews, the interviewer uses predetermined questions that are generally concise and easily understandable close-ended questions. This form of interviewing is generally easy to conduct as the questions can be standardised by being repeated to all participants. (Thomas, 2010). Unstructured questions, allow the interviewer to pose open ended questions and the interviewee is open to express themselves freely. The direction of the interview is not predetermined and is dependent on both parties. These interviews are less easy to standardise as each interview will likely take on its own direction and pattern (Thomas, 2010). Thomas (2010) does however note that in such interviews, it is possible to produce a wealth of knowledge and information as the questions can be varied in difficulty and context. Lastly, there is a mix of both methods which is semi structured interviews. These interviews use both open- and close-ended questions as a resulting in an advantage of both interview styles. To maintain consistency, a set of pre-planned questions are posed to all interviewees so that the same questions are asked throughout all interviews. As the interview proceeds the interviewer may ask alternative questions if they so choose (Thomas, 2010).

This research made use of semi structured interviews, in the form of telephonic interviews, as well as face-to-face interviews. Before conducting the interviews, where telephonic interviews were used, participants were given a copy of the questionnaire together with a cover letter via email. It is important to note that since interviews were being conducted in South African public schools the researcher required the Department of Basic Education's (DBE) approval of the interview questions. This ultimately led to amendments of the questions, being made by the DBE that the researcher had to comply with.

Papargyropoulou, Wright, Lozano, Steinberger, Padfield & Ujang, (2016) developed a conceptual framework for food waste generation and prevention. Figure 1 is an adjusted version of said framework that was used in the study to identify the causes of food waste in NSNP primary schools.

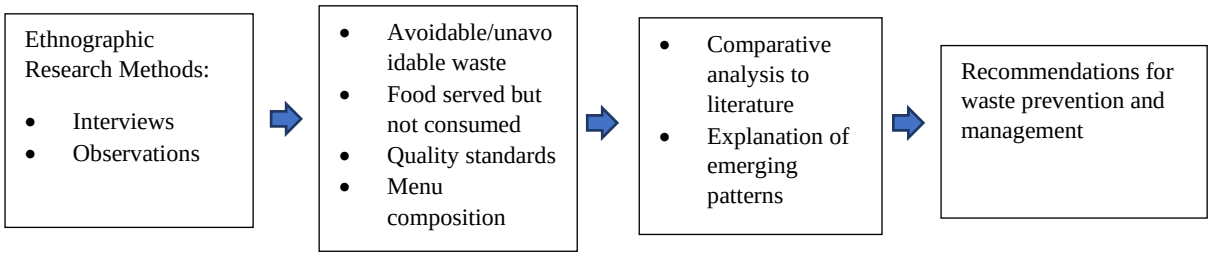

Figure 1: *Conceptual framework to understand the causes of food waste in the National School Nutrition Programme in primary schools (researcher's own adjusted framework) (Papargyropoulou et al., 2016).*

RESULTS AND DISCUSSION

The first part of this section will describe breakfast and lunchtime in South Africa based off research and conversations with the participants. The second part will only discuss the findings of the interviews conducted with the participants, and those specific questions. The closing section shall summarise the observations that were made during breakfast/lunch times and how waste can be prevented in these areas.

Breakfast and Lunchtime in the NSNP

In most, if not all South African government (public) schools (primary and secondary) there are two lunch breaks that take place throughout the school day. One is usually around 10.00 a.m. and the other around 12.00 p.m. depending on the time schools ends on each day. In contrast, in the US, learners have "recess" before lunch, which leads to learners rushing to finish their meals to go and play outside (Green, Mbogori, Stroud, & Friesen, 2019). However, South Africa does not make this distinction, lunch/recess are all at the same time and learners manage their own time to eat and play.

Interview findings and discussion

This section focuses on questions presented in Section B, Part 1

When presented with the question: *What do you understand about food waste?* The NSNP coordinator from school E stated, *"cooking too much food or learners not eating all the food that is dished up for them…"*. The hostel manager at school G said, *"food that doesn't get consumed either through wastage, expire or spoilt."* The principal and a teacher at school L added that *"excess food that is not eaten and end up in the dustbin or dumping area because it is rotten…"* and *"food meant for human consumption and still doesn't get consumed, which can lead to it to stay beyond expiry date or to spoil..."*.

When asked, *How much food, in your opinion, does your school waste in a day?* The participants had three (3) options to choose from "a small amount, an average amount, a large amount". None of the participants stated that their school wasted a large amount, therefore the figure below represents the results obtained from the remaining options of *a small amount* and *an average amount.* The majority of the participants (68%) stated that only a small amount of food was wasted daily. Upon further questioning during the interview, it was discovered that any leftover food on the day was usually given to the neediest learners, staff members such as the VFHs themselves or security guards to take home. Thus, eliminating the need for any food produced in excess to be discarded. In a report published by the DPE and Department of Planning Monitoring and Evaluation (DPME) it was noted that one reason for food wastage fluctuating daily, was that not all learners would consume the NSNP meal (DBE & DPME, 2016). Therefore, the food prepared as approved by the official figure would differ from the actual number of learners present to consume the food and the VFHs might either underprepare or over-prepare food, leading to wastage.

To ascertain the causes of food wastage, participants were presented with a list of possible reasons. From this list, participants had to choose which reasons most accurately described the reasons for food wastage at their school. The question "other" allowed for open-ended answers and discussions to be presented. Table 2 below shows the list of reasons that were presented to the participants.

Excess food is received which leads to spoilage
Food that is already on hand is delivered again
Food is received that is close to its sell-by date and ends up having to be thrown away
Excess food is prepared that goes uneaten/left on plates
Food is received that has exceeded its sell-by date
All learners did not consume the food.
Other, please specify:

Table 2: *Potential causes of food waste in the study of food waste management in the NSNP, October 2019–March 2021.*

The principal of school A stated that, *"food that is already on hand is delivered again…"* as a reason and added *"some learners not eating during break..."*. This was indicated when the researcher asked about other reasons. The deputy principal at school C plainly stated that, *"learners' attendance fluctuates, food is prepared for them, but they are absent and extra food is then left"*. Similarly, in a Portuguese study, *Dinis et al.* (2013) identified the incorrect estimation of the number of meals as a reason for food being wasted.

This section focuses on questions presented in Section B, Part 2.
Participants were asked "If you waste food, what types of food do you waste?" The table below represents those food items that the participants had to choose from.

Vegetables
Fruit
Bread/Grains
Protein
Tinned fish
Dairy products
Others, please specify

Table 3: *Possible wasted food types/groups in the study of food waste management in the NSNP, October 2019–March 2021.*

As aforementioned, the interview questions were amended by the DBE with which the researcher complied, hence the separation of "protein" from "tinned fish". The study revealed that of the 25 participants, 15 had stated "vegetables" as being the most commonly wasted food group with fruit second in line. The NSNP coordinator/teacher at school J mentioned *"vegetables, fruit and dairy products"* and went further by saying *"milk, as some learners end up vomiting"*. The deputy principal of School C noted that *"no one food in particular, depends on what is prepared for the day and the number of students in attendance"*. A few of the participants did state that no food groups at all were wasted and the least commonly wasted food types were grains/breads (such as pap, samp) and tinned fish.

This section focuses on questions presented in Section B, Part 3.
Figure 2 below answers the question of the presence of a waste management programme at the school. The question *Does your school currently have a program in place for food waste management* was posed to participants and the results are depicted below.

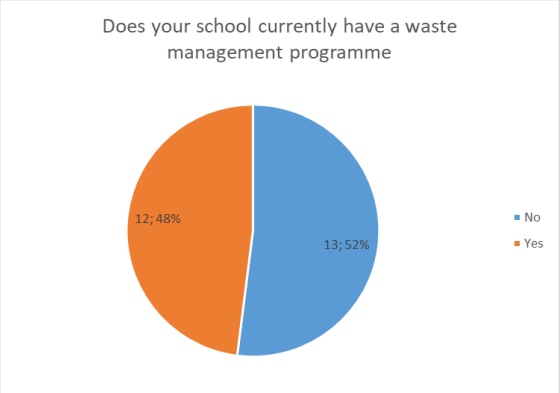

Figure 2: *Participants (n=25) response to the presence of a waste management programme in the study of food waste management in the NSNP, October 2019–March 2021.*

Figure 2 reveals that there was an almost even split between the schools that did and those that did not have a waste management programme in place. Should the participant have responded "yes" the follow-up question then asked, *"If yes, please describe the program."*

Two distinct answers were given: the first was that the food would be delivered to needy learners / community members, the other was that the food was placed in the garden as compost. School C said, *"groceries are controlled by the school's social worker who distributes food to needy families just before expiry date."* School P shared these sentiments and added *"every Friday, food is given to needy kids".* School S enacted a similar program and said it is a *"private school program, leftovers given to needy kids, security guards VFHs and there is a garden."* As the research for this study continued, the VFH at school N added that poor condition food would sometimes be *"put in garden, compost."* Like school N, school F was able to implement a waste management strategy and the principal stated that *"we normally shred it into the biogas digester."* School F was the only school to possess a biogas digester.

The findings revealed that majority of the schools did experience a certain degree of food waste and that this was largely caused by learners and not the VFHs. The VFHs followed the menu guidelines except in schools where food donations were received. Nonetheless, most of the schools indicated that the menu was always strictly followed. The study further revealed that the most wasted food items were vegetables, namely butternut as a great source of waste. This was largely due to the lack of seasoning (herbs or spices) present at the schools. Lastly, although all the schools had some sort of waste management programme in place, these were initiated privately by the schools and did not have government input.

RECOMMENDATIONS

Based upon the results of this study, the literature and participants' own recommendations, the researcher proposes the following recommendations to manage food waste in the NSNP.

1. Educate staff, management and learners on waste disposal methods and the consequences of food waste.
2. Promote the implementation and upkeep of gardens.
3. Approach sponsors who deal in waste management to implement waste management systems in the schools.

1. *Educate staff, management and learners on waste disposal methods and the consequences of food waste.*

Literature showed that education is a critical area that leads to food waste reduction. The NSNP mandate proposes educating learners in classes about nutrition, but participants did not indicate that this was indeed in place. Although learner preferences play a role in food acceptability, the NSNP still needs to provide learners with nutritionally dense meals. Therefore, by educating the relevant staff members, teachers, coordinators and VFHs on the importance of learners prescribed nutrient intake and on measures that can be implemented to reduce food waste, staff will more readily be motivated to implement these measures. The VFHs are also made up of community members and learners' parents, therefore by educating them, these practices could be taken up and possibly implemented in their homes. Additionally, educating learners on the importance of nutrients and why they need to eat certain food groups could assist in reducing food waste. If learners know and understand that they are eating e.g., soya mince because it is nutritionally dense in protein and the effects of protein in the human body, they may become less likely to waste the food item since they understand the benefits of it. Lastly, the additional of educational nutrition apps/games that appropriately educate learners on the consequences of wasting of food.

2. *Promote the implementation and upkeep of gardens.*

Several schools mentioned that they did have gardens, however, these gardens were maintained by the school and/or community members. Some gardens that were implemented by the government ended up dying off as there were no personnel to maintain the gardens. The gardens are a key area to manage food waste because left-over/discarded food items can be used as compost for the gardens instead of allowing it to eventually rest in landfills. Additionally, gardens present an additional food supply source. At the schools visited with gardens, participants noted that they use items from the garden like spinach and cabbage to supplement what was supplied. The garden also allows the freedom for schools to perhaps plant herbs that can be used as seasoning for menu items and in this way the burden to purchase is removed from NSNP itself and is cultivated by the schools.

3. *Approach sponsors who deal in waste management to implement waste management systems in the schools.*

A participating school mentioned that the school had been furnished with a biogas digester to handle food waste. Approaching bodies and corporations that are in the environmental sphere would greatly assist in food waste reduction. These institutions do not necessarily have to donate food waste processors and the like, but they can conduct educational presentations at the schools and promote waste management methods. In this way, those corporations may even create waste management guidelines for schools to follow, thus relieving NSP of this duty and allowing professionals in the environmental industry to create the guidelines.

To conclude, these are but a few recommendations that the researcher proposes for the NSNP to manage waste in schools. These are simply recommendations based on the literature and the participants' responses and should not be the final word of authority

CONCLUSION

There is limited research on the effects and causes of food wastage in the NSNP and other schools in South Africa, the literature is more constrained to the evaluation of the NSNP as a whole but on the topic of research on food waste management the research is limited. Although

globally there is a shift to become environmentally friendly and reduce overall waste and eliminate waste, the implication of waste within school feeding programmes is a relatively new endeavour. However, in countries such as the USA, and Brazil, to name a few, there has been up and coming research on the causes and effects of food wastage in school feeding programmes. South Africa is beginning to follow suit, but quantifiable research is still largely missing.

The implementation of nutrition-based education apps/games have proven to be largely successful in educating learners on healthy food choices especially on the increasingly technologically advanced generation. Therefore, the application of these technological functions to learners in the NSNP could prove to be an effective manner on educating learners on the importance of food waste reduction and effective waste management methods.

The present study was conducted to identify the causes of food wastage within the NSNP, specifically looking at Johannesburg schools. The study sheds light on the gaps in literature regarding food waste within the NSNP and similar school feeding programmes and other challenges that are found within the implementation of the NSNP and aims to fill these gaps. Experimental research needs to be conducted on the causes of food waste within the NSNP and how these causes may have lasting effects on the entirety of the NSNP.

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COVID-RESPONSIVE STUDIO MANAGEMENT SYSTEMS IN ARCHITECTURAL EDUCATION: THE CASE OF UNIVERSITY OF KHARTOUM

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Abstract
By the beginning of 2020, the world has changed dramatically as the COVID-19 virus entered the scene of our life. Now everyone believes that lifestyle won't get back to the point as it was. The pandemic triggers and inspires the search for innovative and responsive solutions that will shape tomorrow's architectural education and its pedagogical framework. This research aims at investigating the reflections of the pandemic on the management of the design studio, as well as its effects on the performance of students and staff. The research is based on the survey conducted to evaluate the system set for delivery of the design studio programs in the Faculty of Architecture, University of Khartoum. The survey investigates the perception of both staff and students about the online experience in managing design studios. The results of the research will help to adopt appropriate approaches in the pedagogy of architecture based on context-tailored solutions. Google-form questionnaires were sent to the students to measure and evaluate the possibility of conducting online teaching and learning program; 510 students from five levels participated in the survey. Another questionnaire was sent at the end of the first semester of the academic year 2019/2020 to examine the students' perception of the virtual studio experiment and the overall online experience. The findings showed that the adopted approach was more appropriate for senior year students. Also, it revealed that the combination between online learning and unit system can easily fit within the current system at the Faculty of Architecture, and can form the future of architectural design studio.

Keywords: Covid-19, Architectural Education, Design Studio, Online Teaching.

INTRODUCTION

COVID-19 pandemic started in December 2019 in many countries around the world, the first confirmed cases in Sudan were reported in March 2020. Sudan, like several other countries, was locked down and the schools and universities were shut down immediately. In June 2020, the ministry of higher education announced that universities and higher education institutions can resume their programs online; accordingly, some private universities and colleges started using online learning management systems and different social media platforms. Although many universities used online platforms and electronic learning management systems earlier, never before has it been adopted as the only educational method. By July 2020, the University of Khartoum administrator formed a committee consisting of 41 professors from the university's various faculties to study the possibility of using online distant learning to resume the academic year. In its recommendations, the committee mentioned the need to consider the uniqueness of colleges and levels within colleges to determine the readiness of colleges and departments to resume the educational process immediately. Before the pandemic, the use of E-learning platforms in the Faculty of Architecture at the University of Khartoum was occasional: few teachers were only using the basic functions of the existing online learning management system (LMS), such as uploading course material. The Pandemic forced educational institutions around the world into moving exclusively online, with no adequate infrastructure, and both teachers and students had not much experience in online learning

systems. This research focuses on identifying how the faculty of architecture at the University of Khartoum managed the educational process -especially the design studio- during the pandemic. It outlines the embraced procedure of exploring the online learning possibility, as well as its evaluation, how it affected the students and staff performance, and investigating the challenges and potential of this new management system.

Architectural education and the response to COVID-19

The architectural design studio is the core and heart of the architecture education process, and the faculty graduates' success is directly affected by its' success. The design process in the design studio is where the students primarily acquire knowledge and skills; they must find Solutions to open-ended complex problems as they discuss their ideas and solutions in frequent formal and informal face-to-face critique sessions. Schon named this process "reflection-in-action" (Kvan, 2001). Many researchers have discussed the importance of reviewing the current curriculum and teaching methods. For example, Kvan (2001); (Kvan, 2001), have explored the pedagogical issues of virtual designs Studio (VDS), he argued that the used methods of teaching are not the best, and better forms can emerge. More recently, (Ghaziani, et al., 2013) declared that architectural education is necessarily imperfect, and with the Contemporary massive Global changes that have never encountered before, architectural education needs a radical change (Tzonis, 2014). Although the pedagogical body of architecture is reluctant to implement any changes, especially in the design critique process, the pandemic and its health restrictions have forced the entire world to consider the change and adopt the appropriate approach and technology.

A considerable number of architectural schools around the world used the virtual design studio (VDS) in different forms since the 1990s; the usage developed and broadened with the improvement of the technology and the emergence of new digital platforms and architectural computer-aided design programs (Rodriguez, et al., 2016). Kvan in 2001, explored the potential of virtual design studio and raised several essential questions about using virtual Design Studio in architectural education. He discussed the pedagogical issues that ascend when the communication tool is changed from physical communication to digital communication. Moreover, he also asked the questions that the COVID-19 pandemic forced us to answer: 'What changes when we move the design studio into the medium of computer-mediated collaboration? What becomes of the role of the instructor and what changes in the participation of the students? (Kvan, 2001). In 2005, Tham and Werner addressed what they called 'the critical aspects of the online learning': the first aspect is the Institution, which its role includes technological, pedagogical, and social concern. The second aspect is the students, and the last aspect is the technology (Tham & Werner, 2005).

A study revealed that the success of the E-learning depends entirely on the instructors' skills to deal with technology, and how they adapt their courses to the online environment and conditions (Abou El-Seoud, et al., 2014). Other studies emphasize the importance of teachers' and tutors' skills in managing the virtual space, and both educators and students must have proper training in using the online learning management systems (Coman, et al., 2020; Asadpour, 2021; Iranmanesh & Onur, 2021). In fact, these studies find that most of the students describe instructors' skills as 'weak' and 'moderate' as best (Asadpour, 2021), and reported 'lack' of online teaching experience and technical skills (Coman, et al., 2020; Iranmanesh & Onur, 2021). The technical issues are not exclusively related to users' skills and experience, Internet accessibility and quality can be actual obstacles, as well as smart devices acquisition and affordability. (Kvan, 2001) mentioned these obstacles since 2001; although the recent investigations should focus more on the pedagogical methods for

implementing the change from physical education to virtual education, many studies still find the feasibility of conducting online teaching and learning is a real problem (Niculae, 2011), especially that the pandemic forced the educational institutions to move their programs entirely online without adequate training or preparation (Coman, et al., 2020; Asadpour, 2021). Communication and interaction are key differences between traditional face-to-face classes and screen-to-screen online classes; many studies indicate that communication is the prime missing part in the process (Niculae, 2011; Coman, et al., 2020; Asadpour, 2021). Another study revealed conflicting results; the majority of the students understood the critiques in the virtual design studio similar to the physical design studio (Iranmanesh & Onur, 2021). The same studies agree on the significant decline in informal peer-learning and interaction. While the online learning process saves traveling time and effort, students exert more time and effort into self-learning, especially when there is no physical communication with their peers nor teachers (Kvan, 2001; Tham & Werner, 2005). Niculae (2011) argued and claimed that conducting a virtual design studio (VDS) can create a highly interactive and collaborative studio environment. In the virtual design studio, the physical factor is absent, and the students feel isolated, which will directly affect their engagement and motivation (Rodriguez, et al., 2016). Accordingly, the teacher's job becomes more important and complicated; they must understand their students' motivations, and encourage interaction and collaboration among them by monitoring the online teaching process and giving them frequent feedback. (Coman, et al., 2020) stated that the traditional physical design studio is more teacher-oriented, and the virtual design studio has the privilege of being more student-oriented, (Kvan, 2001) and (Niculae, 2011) indicated that the effective VDS has to be more process-oriented but the recent experiments revealed that it is either teacher/tutor-centered as (Coman, et al., 2020; Iranmanesh & Onur, 2021) or student-centered as (Asadpour, 2021). This last one will most likely result in students feeling overwhelmed with the huge amount of coursework (Tham & Werner, 2005). On the other hand, VDS benefits in improving students' ability to carry out independent research and become self-directed learners (Abou El-Seoud, et al., 2014; Rodriguez, et al., 2016; Asadpour, 2021; Iranmanesh & Onur, 2021). Additionally, forcing the students to use VDS ended up developing their CAD modeling, drafting, sketching, and overall digital skills (Asadpour, 2021; Iranmanesh & Onur, 2021). Some studies have revealed other advantages of online learning, such as adapting courses to students' needs, flexibility, removing the barriers of space and time, and the design process becoming more attractive by socialization and communication with other cultures (Rodriguez, et al., 2016; Coman, et al., 2020).

THE CASE OF FACULTY OF ARCHITECTURE AT THE UNIVERSITY OF KHARTOUM

After the lockdown, University of Khartoum started studying the probability of using the online learning. The aforementioned assigned committee's mission was to investigate the following: 1. the university infrastructure: to see if the university is ready to exclusively implement online teaching and learning Program. 2. Students and staff readiness: the survey collected the necessary data from students and staff members about their regional distribution, access to the Internet, and its strength, as well as exploring any possible difficulties. 3. The curriculum: an investigation was held to identify the status of the academic process in each college and department in the University and to determine the percentage of theoretical and practical subjects for each one. 4. Any external factors: this team's mission was to study the existing conditions around Sudan in terms of electricity cuts, Internet coverage and accessibility, and study the possibility of using the existed distant learning systems (University of Khartoum, 2020).

Considering the committee findings and recommendations, faculty of architecture started preparing the application of the online learning. A survey was performed from June to August 2020, before the start of the academic year 2019/2020. Since that the e-learning matter has become mandatory, and a strategic factor with the new circumstances; a coordination with the College's Self-Evaluation and Quality Unit was made. To determine the feasibility of adopting online teaching and learning; the faculty administration started with collecting data about the courses, the way of the taught, and the evaluation methods, as well as gathering as much information as possible about the spatial distribution, access of Internet services and their quality for both students and professors, trying to identify problems that hinder the implementation of e-learning or negatively affect its quality in the university.

The total number of courses is 61 courses divided into four years –the fifth year is an only design studio with no supporting subjects-, 58% of those courses are entirely theoretical, 15% are practical, and 27% have theoretical and practical sections. An online questionnaire was sent by e-mail to the students from all levels to collect the necessary data. The number of responses was very encouraging as 92.8% of the students have responded. The questionnaire investigated the following aspects: the spatial distribution of students, the familiarity of the students with online teaching experience, the ability to conduct online learning, the acquisition of devices (smartphone or laptop), and the Internet accessibility and quality. Teachers and tutors were sent another questionnaire investigating nearly the same aspects and 97% of them have responded to it.

Results of Preparation survey

The faculty students in the bachelor's program are 550 students in five levels, the majority of them are females 81% (446 students).92.8%of students responded to the preparation survey questionnaire, the bulk lives in Khartoum state 90%, which makes the challenge of providing the essential services in rural areas limited to a high level. Additionally, 85% of students have never experienced any type of e-learning before; therefore, it was compulsory to train them to use the E-learning platforms especially LMS and VDS. Furthermore, students who thought it was improbable to establish online learning in the faculty are a minority 24%, which was very encouraging. As well as finding that the majority of them own smartphones or laptops 93%, and 67% have access to a good Internet connection. Teachers' and tutors' response was even more positive; 97% of them responded, almost all of them believed in the possibility of conducting online teaching and learning 95%, and 76% have access to a good Internet connection. Although a considerable percentage has never experienced online learning or teaching before 87%; a collaboration was made with The American-Sudanese Association of Professors in America (ASAPA) to organize a training course for teachers on e-learning.

In e-learning, teaching lectures can use the synchronous interactive teaching, which enables the student to attend the lecture directly; yet, lectures should always be recorded so that students can refer to them at any time (Hamid, et al., 2020). Nevertheless, the follow-up of studio work is different, as it requires a synchronized interactive teaching system so that the students can present their work for evaluation and get comments from the professors directly. To ensure the smoothness of the e-learning processes, it is best to divide the batch into groups according to the number of project professors, providing a master project and a supervisor for each group with 2-3 teaching assistants.

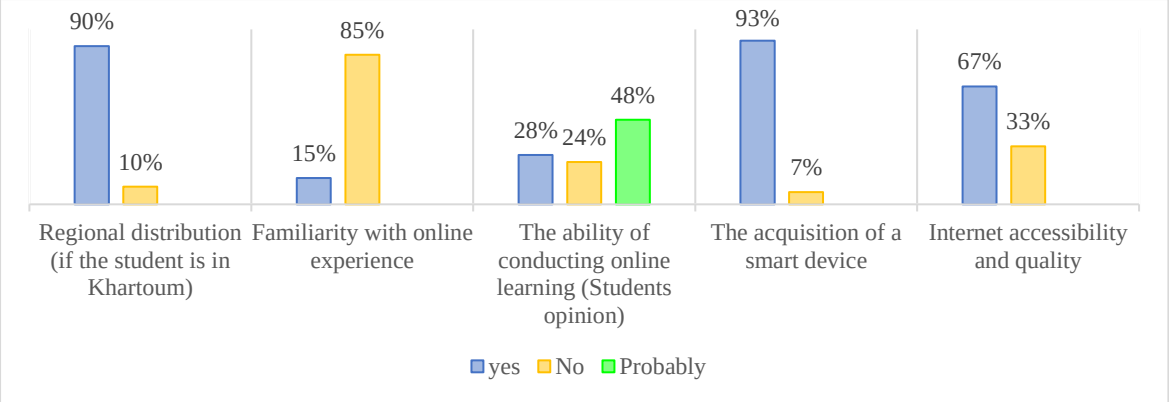

Figure 1: *Preparation survey results (Students response).*

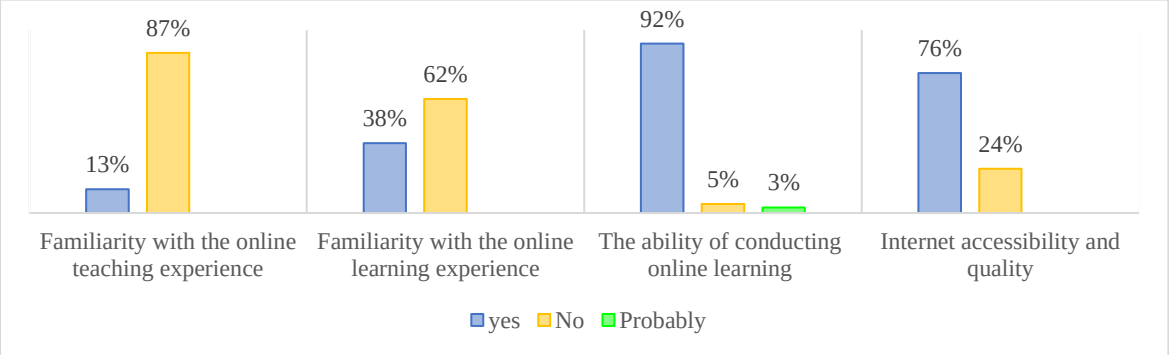

Figure 2: *Preparation survey results (Teachers response).*

Managing online studio through unit system

The traditional design studio is deeply rooted in one-to-one teaching activities; face-to-face formal and informal critique sessions, site visits and analysis, teamwork and collaboration. This would require a physical presence in the studio. However, these conventional teaching strategies must be changed; as it has been suffering from the following issues:

A) Lack of variety: the current studio program is designed to cover a wide range of building types rather than exploring issues, processes, phenomena, theories, themes, among others. This, in fact, does not reflect the nature of architecture as it combines social, cultural, technological, political, philosophical, and economic substances.
B) Students Staff ratio: generally, one to two senior studio leaders with few 3 to 4 TAs to manage a class of around 90 students. This leaves several students with little guidance on one side and burden staff on the other side. This issue is shared between several developing countries (Bunoti, 2011).
C) The inflexibility of the Programme: the current form of the studios' programme does not allow for current issues of the time to be explored in the design studio.
D) Quantity, not Quality: The focus is on the form of the final design not the process, the research, or the issues explored. E) Lack of connection with practice or real-world issues. (Faculty of Architecture, 2020).

A curriculum review committee was assigned earlier to review and improve the current curriculum. Studio management was at the heart of its attention due to the increased number of students per batch. Hence, the committee has conducted several workshops with the staff to discuss with them their proposed solutions, one of which was the proposed studio unit system. The unit system suggests dividing the batch into units of 25 – 30 students (the smaller the better) with a unit leader(s), assistant tutors, and visiting critics. Units are completely independent in terms of tutorial days and studio and marking. This system generates variety

and complexity in the projects, offers better tutoring for small groups, and provides flexibility to respond to emerging issues, methods, and ideas. (Faculty of Architecture, 2020)

Year 1		Year 2 & 3		Year 4		Year 5	
Studio 1.1	Studio 1.2	Studio 2.1 & Studio 3.1	Studio 2.2 & Studio 3.2	Studio 4.1	Studio 4.2	Studio 5.1 (Thesis 1)	Studio 5.2 (Thesis 2)
Unit 1		Unit A1	Unit A2	Unit 1	Unit 1	Theme 1	
Unit 2		Unit B1	Unit B2	Unit 2	Unit 2	Theme 2	
Unit 3		Unit C1	Unit C2	Unit 3	Unit 3	Theme 3	
		Unit D1	Unit D2			Theme 4	
		Unit E1	Unit E2			Theme 5	

***Table 1**: The proposed unit system. (Faculty of Architecture, 2020)*

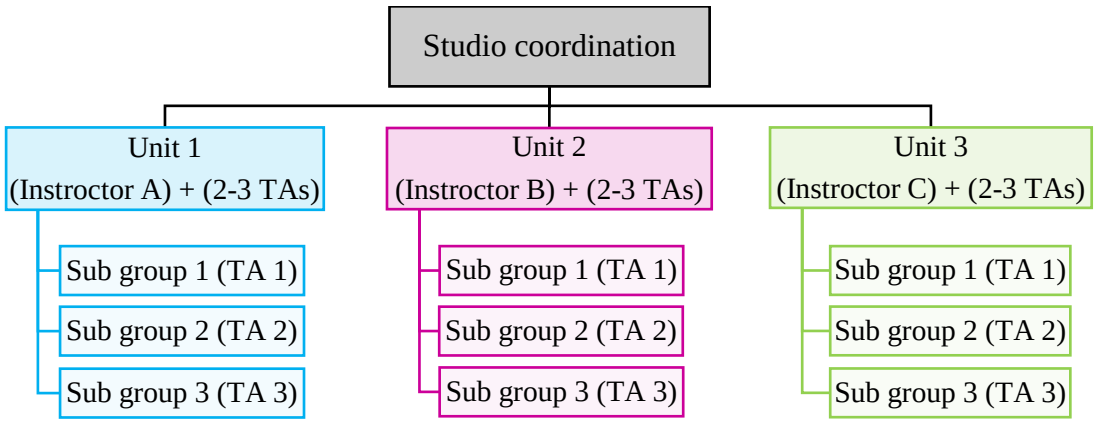

***Figure 3**: The proposed unit system "studio coordination". (Hamid, et al., 2020)*

Evaluation Survey

The second part of the study was conducted at the end of the first semester of the academic year 2019/2020. A google questionnaire was sent to the students for purpose of examining the students' perception, evaluating the used methods, and measuring its success; especially since the entire adopted pedagogical tools were new (unit system and online teaching). The survey covered all subjects and the studio, each in an individual form. In the studio google-form students were asked to rate their overall experience with online learning (5-point Likert scale, where 1 = very poor, 5 = Excellent), followed by the justification of the choice, if the answer was 4-5, what are the reason(s): (saves travelling time, less cost, provides better communication with the instructor and teaching assistants, getting feedback was easier than traditional studio, allows more innovation and learning new skills, other reasons), if the answer was 1-2, what are the reason(s): (more costly, less communication with the instructor and teaching assistants, getting feedback was harder than traditional studio, poor Internet connection, power cuts, harder to present the ideas, other reasons). The evaluation results are presented in Table 2.

	Number of students	Number of responses	Ratio
Year 2	186	156	83.9%
Year 3	97	88	90.7%
Year 4	85	85	100%
Year 5	86	71	82.6%
Total	454	400	89.30%

***Table 2**: Responses from the total number of students in each year.*

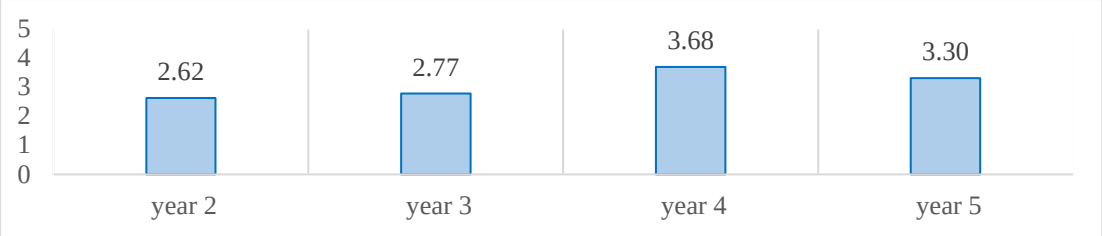

***Figure 4**: Students' perception towards online learning in each year. [Note: The graph shows the mean value from the responses in each year separately]*

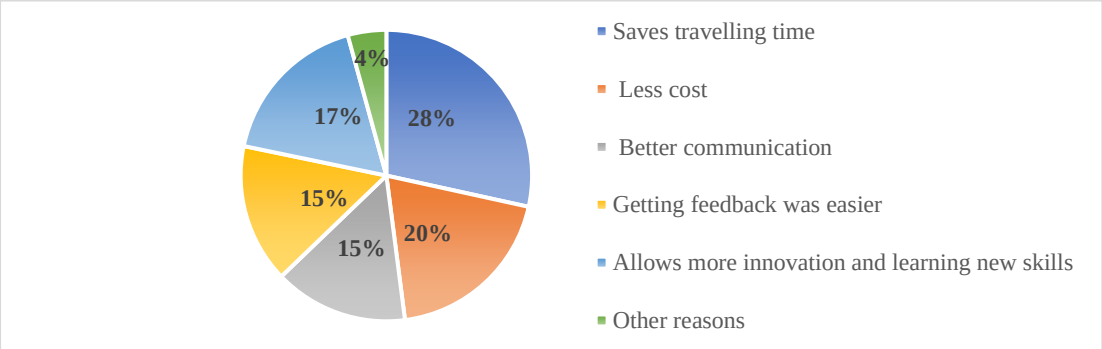

***Figure 5**: Advantages of online experience from students' perspective.*

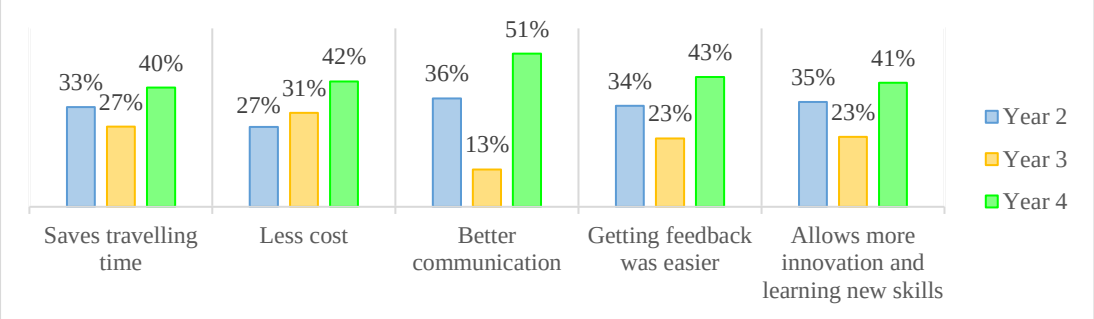

***Figure 6**: Advantages of online experience from students' perspective in each year.*

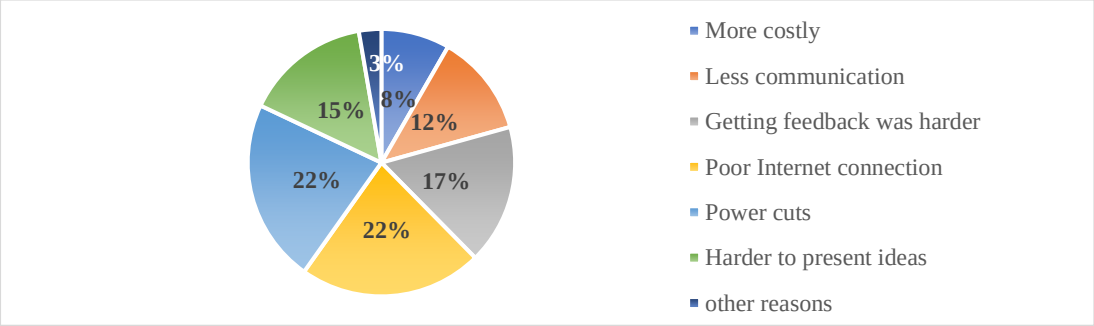

***Figure 7:** Disadvantages of online experience from students' perspective.*

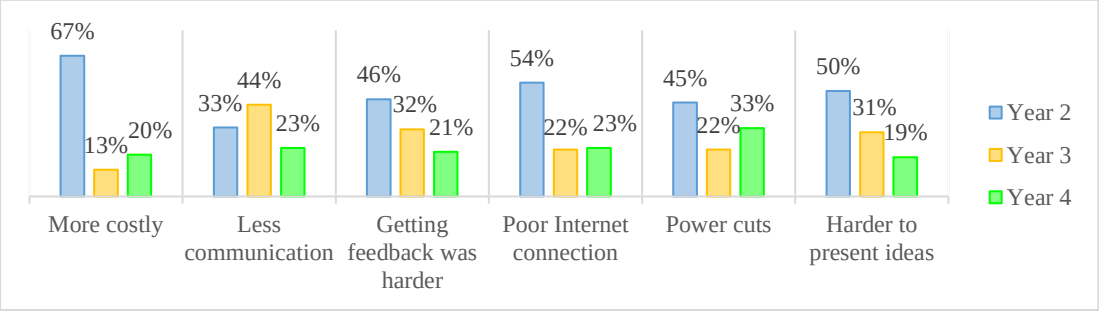

***Figure 8**: Disadvantages of online experience from students' perspective in each year.*

According to (**Table 2**), the students actively participated in the survey; almost 90% of the total number of students have responded. The overall mean of how students rated their online learning experiment is (3.09). Senior students (fourth and fifth-year students) had a better experience than the juniors (**Figure 4**). Also, fourth year students experienced the advantages of the online learning, as they gave them the higher rate among other years' students, as well as they rated the disadvantages the lower. Saving time and cost was the most important advantage of online learning in students' opinion, as they get approximately 50%. In contrast, power cuts and poor internet connection were the main disadvantages of the experience.

DISCUSSION

As many studies have previously investigated the possibility of VDS(Kvan, 2001; Tham & Werner, 2005; Niculae, 2011; Abou El-Seoud, et al., 2014; Rodriguez, et al., 2016; Coman, et al., 2020; Asadpour, 2021; Iranmanesh & Onur, 2021); COVID-19 provided on the one hand, an improved application of those previous applications where online teaching in architectural studios is already part of the education and on the other hand, a compulsory application where architectural education depended %100 on physical face-to-face teaching. Regardless of how much the architecture pedagogical body might be reluctant to change in the latter case, many of the studies that were conducted during the pandemic proved that there is some flexibility in the architecture pedagogy. The Faculty of Architecture at the University of Khartoum found this enforced change as a good chance to adopt a completely new system to run and manage the studio (unit system combined with online learning). The responses of both the students and teachers to the survey were very encouraging in terms of respondents' number, their optimistic expectation of applying online teaching, and their readiness to use it.

Students of today are native speakers of the digital language, and it was easier for them to communicate in virtual settings; although the majority of them did not experience online learning before; the findings of this study illuminate the usefulness of online learning for senior students (fourth and fifth-year students).

According to **Figure 4**, their experience with online learning was more successful among all levels; this might refer to the fact that they have more tendency for self-learning, are more familiar with architectural terms and vocabulary, and have more advanced skills in drafting, modeling, and presentation programs (CAD). Additionally, junior students need closer monitoring and one-to-one critique session. This result comes in line with the findings of Iranmanesh & Onur (2021), who investigated the potential advantages and shortcomings of VDS during the COVID-19 quarantine from the perspective of students in a department of architecture. Moreover, from **Figure 6** and **Figure 8** fourth-year students had the highest input in rating the benefits of online learning; and vice versa, they had the lowest in the weaknesses rating. [Note: The fifth year has a different nature from other years; since the evaluation of their thesis projects occurs at the end of the academic year. Consequently, students were only asked to evaluate their online experience but the rest of the questionnaire was different.

The results of the current study showed that the main benefit of online learning is saving time and cost traveling to the university; this can be crucial in Sudan, especially with the current economic and political circumstances. Yet, Tham & Werner (2005) argue that online learning

requires more time and effort in research, and students might easily feel overwhelmed with the large amount of coursework. Furthermore, students agreed on the effectiveness of online learning in allowing more innovation and self-learning; this aligns with the findings of (Rodriguez, et al., 2016; Asadpour, 2021; Iranmanesh & Onur, 2021). On the other hand, consenting with results of (Bunoti, 2011; Asadpour, 2021; Iranmanesh & Onur, 2021), obstacles of implementing online teaching and learning were highlighted by the students. Evidently, poor internet quality and the regular power cuts were the most critical obstacles in students' experience, and unfortunately, they will probably obstruct future attempts unless the efficiency of the internet quality at the faculty increases and an electric generator is provided. Moreover, the results showed that students felt isolated and faced communication problems in terms of connecting with the instructor and tutors and the easiness of presenting their work and delivering their ideas; this supports Kvan (2001) concerns, agree with the results of (Coman, et al., 2020; Asadpour, 2021) but conflict with (Niculae, 2011; Iranmanesh & Onur, 2021). Finally, Using LMS was convenient to a large extent for courses teaching; as they do not need synchronized discussions, but it was not appropriate for studio work. Many students reported its crush during submission time.

Apparently, the unit system facilitated the management of the studio during the online experience; dividing the batch into groups made the follow-up and the interaction much easier. However, teaching architecture design means different things to different people, each educator teaches design in their own set of ideologies, and there is a tremendous diversity of contents and methods of teaching (Ghaziani, et al., 2013); therefore, the independence in leading the design process, and evaluating students' work appeared to be challenging.

CONCLUSION

COVID-19 lockdown and restrictions forced the entire world to adopt new approaches; like online learning. For the Faculty of Architecture at the University of Khartoum it was the first time to apply online learning. Given the faculty infrastructure, limited finance, and technical resources; the education process was not completely online, yet, the entire experience was new and needs to be evaluated, especially the management of the design studio, as well as its effects on the performance of students and staff. The preparation survey indicated the importance of teachers' and tutors' training to use the online learning system more professionally as well as the necessity of rehabilitation and increasing the efficiency of the internet quality at the faculty and providing electric generator. These steps will minimize the technical issues that occurred during the academic year to both students and teachers.

The evaluation results revealed that the online teaching is more applicable via LMS for subjects, but the studio critique sessions and follow-up need a synchronized platform, for example: (Zoom, Microsoft teams, Google classrooms). Also, online teaching appeared to be more appropriate for senior students. As part of developing and reviewing the curriculum, the formed committee was proposing the unit system as a new approach to managing the studio. The emergence of COVID-19 has accelerated the implementation of this proposed solution; hence, the findings of this study can be reflected and used by the curriculum review committee to improve the unit system. The application of the unit system showed shortages in the studio coordination; therefore, they have to be clear objectives and expected outcomes confirmed at the beginning of each project, as well as the evaluation criteria.

It will not only be problematic to go back to traditional methods; but also, impossible. After investigating the benefits and downsides of exclusive online learning, the suggestion of the 'hybrid system' can be the best choice to combine both systems' advantages.

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CLOUDS OF LIES OBSCURE SUDAN'S SKY: POLITICS OF MISINFORMATION, DISINFORMATION, AND HATE IN TIMES OF TRANSITION

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Abstract
Sudan's December (2018) Revolution demonstrated the potential of social media in resisting dictatorships and building up revolutionary social capital toward democratic transitions. Elbashir regime and its successor, the Transitional Military Council (TMC), recognized this critical role and confronted it by blocking internet access at one extreme, and by mastering the tactics of misinformation and disinformation campaigns as the more subtle standard practice. After the regime fell, coordinated covert influence campaigns were launched by shady companies from foreign countries praising the military, undermining the civilian political organisations, and casting doubts on the democratic transition. The campaigns continued after reaching the power-sharing agreement between the TMC and the political parties, with concerted efforts to discredit the civilian government, spread hate speech, and create divisions amongst the political forces. The spread of fake news, disinformation, misinformation, and hate speech represents serious risks to the peace and democratic transition in Sudan, such as rising ethnic tensions and conflicts, an increase in insecurity, and the gradual erosion of public trust in the democratic transition and the political process and parties. In this research, we develop a crowdsourcing citizen-based fact-checking system based on a comprehensive analysis of fake news, disinformation, and hate speech. We consider writing styles, lexical and semantic structures, corpus, sources, networking topologies, propagation patterns, credibility, and false knowledge. The technical solutions studied represent appropriate technologies as they aim to empower ordinary citizens and meet their basic needs for access to information. We utilise Natural Language Processing (NLP), sentiment analysis, and crowdsourcing fact-checking to recommend strategies and policies for prevention and intervention mechanisms and to promote citizen and alternative media, taking Sudan Bukra TV Channel as a model. The findings of the analysis will be used to recommend a legal framework that empowers access to information and data, and combats hate speech without jeopardising freedoms of expression.

Keywords: Misinformation, Disinformation, Citizen Media, Natural Language Processing (NLP).

INTRODUCTION

Coordinated misinformation, disinformation, fake news and hate speech are among the biggest threats to peace and democracy in Sudan. This paper looks at the technically appropriate approaches to combat them, especially in times of transition. We present a literature review of the topic and lessons learned from the more-studied and more-technically advanced cases of the US 2016 elections, Brexit, and COVID-19. We review the traditional and social media Sudanese landscapes. We examine the legal framework of information access and dissemination in Sudan.

The paper presents examples of misinformation, disinformation, fake news, and hate speech in Sudan and introduces some of the players who are trying to confront them. We present fact-checkers and new media outlets and examine how they can work together utilising what we learned from past experiences, current trends, and research in Sudan and around the world in the fields of AI, ML, information theory, media, and psychology. We also discuss some of the challenges and areas where more research can be done. The paper draws from the experience of operating Sudan Bukra TV Channel as well as uses its resulting outcomes to further the efficiency of the channel in playing its role in promoting peace and democracy. The technologies considered in the paper are designed with ordinary people in mind, both as beneficiaries and contributors, and hence, are inherently appropriate.

BACKGROUND

Omer Elbashir's regime banned independent newspapers and controlled TV and radio stations from the day it overthrew the democratic government in 1989. In the subsequent years, the regime took control of the media and information spheres via legislative, security and scientifically manipulative policies. These measures eventually undermined the traditional media and diminished the people's trust in it. Newspapers' publication figures declined, yellow journalism increased, and real independent television channels were non-existent.

The Sudanese youth adopted social media platforms as they started to spread in the mid-2000s. This resulted in a generational shift from traditional media to social media. In the aftermath of the Arab Spring (ca. 2011), political opponents, especially the youth, started using social media outlets such as Facebook, Twitter, and WhatsApp to communicate, organise, and inform. However, the use of social media across Sudan remained limited by the geographic coverage of mobile broadband networks, penetration of smartphones, digital literacy, and affordability.

The regime scaled up its efforts to understand the mechanisms of social media use and the tools to thwart them. It generated and spread disinformation and fake news to disrupt resistance activities before and during the first major mass protests after the Arab Spring in September 2013 (September Revolt), and partially blocked access to social media outlets.

A specialized unit in the National Intelligence and Security Service (NISS) called Cyber Jihadist Unit, was established in 2011 (Abubkr, 2014) (Reporters Without Borders, 2020) to oversee spying on the opposition and organising the government's manipulation of people's perceptions via fake news and disinformation campaigns. Intending to defend the regime and weaken the opposition, the regime apparatus denied news about protests and conducted smear campaigns, distractions, and trial balloons, among other tactics.

At the onset of the December Revolution, the mass popular protests that began in Sudan in December 2018, the government blocked access to social media platforms and regained full control of the messaging of local newspapers, and radio and television stations. Sudan Bukra TV Channel was established to counter the regime's narrative and inform the Sudanese people. It was broadcasted from outside Sudan beyond the control of the regime, and people could watch it using satellite dish receivers, common all over Sudan. It operated from the cloud and made use of everyday technologies and tools, like mobile phones and agile methodology. The goals and means of Sudan Bukra demonstrate appropriate technology concepts.

Targeted campaigns of disinformation and fake news intensified during the later phases of the revolution and after the formation of a transitional government. Covert coordinated operations were reported to have targeted Sudan from countries such as Russia, Egypt, and United Arab Emirates. At the same time, websites and social media accounts disguised as news websites mushroomed in Sudan.

LITERATURE REVIEW

We take Wardle's definition for **disinformation**, "false information that is deliberately created or disseminated with the express purpose to cause harm. Producers of disinformation typically have political, financial, psychological or social motivations", and **misinformation**, "information that is false, but not intended to cause harm. For example, individuals who don't know a piece of information is false may spread it on social media in an attempt to be helpful" (Wardle, 2018). There is no universally agreed definition of **hate speech**, but we take it to be speech that incites violence, discrimination, hostility, or genocide against a defined group. **Fake news** was defined as "fabricated information that mimics news media content in form but not in organizational process or intent" (Lazer et al, 2018).

Social media enabled tremendous changes in the political arena during the Arab Spring, which promised to become a game-changer in global politics, enhancing political debate via social media, enacting social consensus, and improving governance. But the UK Brexit Referendum, the 2016 US Presidential Election, Internet shutdowns, and heightened censorships showed the other face of 'digital dictatorship'. Gopaldas investigated the "Digital dictatorship in Africa" and highlighted the questions of freedom of expression, censorship, and how digital technologies went from empowering citizens and toppling dictators to being used as tools of oppression and discord (Gopaldas, 2019). He discussed the measures and responsibilities of governments, civil society, Internet providers, and regulators in evolving realities that sit at the intersection of technology, politics, and governance.

In addition to the establishment of the "Cyber Jihadist Unit" in 2011, the Sudanese regime imported remote control systems (RCS), and sophisticated computer spyware to manipulate information and spy on government opponents, journalists, human rights activists, and various youth groups (Abubkr, 2014). Later, after the September 2013 Revolt, where around 200 protesters were killed, Citizen Lab published February 2014 a report that documented the use of this software to censor journalists, activists, and politicians (Marczak; Guarnieri; Marquis-Boire; Scott-Railton, 2014).

Facebook (Meta, 2019) announced on the first of August 2019, the removal of multiple Pages, Groups, and accounts that were involved in coordinated inauthentic behaviour on Facebook and Instagram, belonging to two separate operations: one originated in the United Arab Emirates and Egypt, and the other in Saudi Arabia. The operation originating in UAE and Egypt had Sudan as one of its target countries and had links to two allegedly marketing firms; New Waves in Egypt and Newave in UAE. Facebook deleted 259 accounts, 102 Pages, 5 Groups, 4 Events, and 17 Instagram accounts.

The New York Times (Walsh & Rashwan, 2019) reported that a Facebook spokesperson said they had no evidence the Emirati and Egyptian marketing firms were related to their respective governments. However, the NYT found out that there were many hints for such links. The two

companies used money, deception, and fake accounts to support the Sudanese military and to promote regional political elements of significance to the Emirati and Egyptian leaders.

Facebook (Meta, 2019) then announced on the 30th of October 2019, the removal of three pro-Russia networks of Facebook accounts, Pages, and Groups, as well as Instagram accounts that engaged in foreign interference which was classified as coordinated inauthentic behaviour targeting some African countries. The targeted countries identified in the report were Mozambique, Madagascar, Libya, Central Africa, and Sudan. Facebook removed 17 Facebook accounts, 18 Pages, and 6 Instagram accounts that originated in Russia and focussed primarily on Sudan. The people behind the accounts were a combination of authentic Sudanese nationals, fake accounts, and compromised accounts. They frequently shared stories from Sudan News Agency (SUNA) as well as Russian state-controlled media Sputnik and RT. In May 2021 Facebook (Meta, 2021) also reported the removal of 83 Facebook accounts, 30 Pages, 6 Groups, and 49 Instagram accounts operated by local nationals in Sudan on behalf of individuals in Russia. The removed accounts were reported to be related to the 2019 disabled accounts.

Organised trolling is another form of manipulating social media intentionally to pollute the political theatre. Systematic trolling is examined in the research that takes Russian organised troll accounts retweets in the context of the #BlackLivesMatter movement (Stewart, Arif & Starbird, 2018). The research found the co-existence of troll accounts in two political divided banks without crossing the borderline. The study does not discuss the content and behaviour of accounts that interact with the troll, but it quantifies the troll tweets that reach the 10 most frequent and allocates their spread across the political cluster.

Zhou and Zafarani conducted an extensive and comprehensive fake news survey (Zhou & Zafarani, 2018). They identified and specified the fundamental theories across vast disciplines e.g., psychology and social sciences, to facilitate and enhance multidisciplinary research of fake news. The survey review evaluates and summarises the current research on fake news according to four perspectives: (1) the false knowledge it carries, (2) it's writing style, (3) its propagation patterns, and (4) the credibility of its creators and spreaders. The researchers first disambiguate between fake news, misinformation, and disinformation concepts, and then provide a list of the open research area in the field of fake news, which includes fake news early detection, identifying check-worthy content, cross-domain fake news studies, deep learning for fake news studies, and fake news intervention. The research is worth setting up the direction in both advanced research and application.

The question of how social media users consume misinformation was the subject of Greeng, Yee & Roesner's research (Greeng; Yee; Roesner, 2020). It is crucial to understand how people assess and interact with low-credibility posts. They found various reasons why people do not investigate low-credibility posts, including taking trusted posters' content at face value, as well as not wanting to spend the extra time. People use support platforms for investigating low credibility content in addition to their ad-hoc strategies. Users' support includes media literacy and education professionals, and research fact-checking services and platforms. User strategies used to investigate suspicious posts include investigating the source or poster and looking at comments, though they had little attention to the content for a variety of reasons.

Lazer *et al* reported many studies that showed that false information spreads more rapidly and by more people than true information, especially when the topic is politics. However, although there is no literature on the medium-to-long-run impact on the political behaviour of exposure

to fake news, they stated that evidence suggested the impact might be limited. They pointed out the role social bots (automated accounts impersonating humans) play in spreading fake news and manipulating platforms' algorithms. Successes at detecting bot methods will likely inspire future countermeasures by bot producers (Lazer. *et al*, 2018).

Pennycook and Rand (Pennycook and Rand, 2021) highlighted the dissociation between believing and sharing fake news. They showed that many people will share content that they will not necessarily identify as accurate, and as such, social media sharing judgments can be quite divergent from judgments about accuracy. This can be understood from in attention as well as the social media context, which in many cases encourages sharing, liking, and similar interactions regardless of any other considerations.

One suggested strategy to fight fake news, misinformation, and disinformation is to raise citizen awareness and news literacy. Farmer (Farmer, 2019) argues that it needs to start early, in K-12 students. Children's media competency must be raised through a formal curriculum. They need to know how to access, interpret, evaluate, and respond to news in its various forms. They need to understand how news and other mass media are produced and the critical features of each medium. They should also be encouraged to participate in generating news to grow as active citizens. The educators themselves need to have these literacies and gain competency to integrate them into the curriculum.

Another comprehensive discussion of Artificial Intelligence (AI) as a tool for both creation and fighting fake news and misinformation was provided by Giansiracusa (2021). The book explores different deception and recommendation algorithms, which include deepfake photo, video, auto play, and GPT-3. These algorithms play a critical role in the economy of distraction and spreading fake news and misinformation. Google's YouTube recommendations, its auto-complete search, and advertisement were investigated in detail, and the book showed how they could accelerate misinformation and disinformation spread. The last chapter of the book showed several fact-checking tools that use algorithms to detect and aid human fact-checkers in their job. Lazer *et al* showed that the science supporting fact-checking efficacy is mixed, as people are affected by things like selective exposure, confirmation bias, and desirability bias. Pennycook and Rand showed that corrections and warnings resulting from fact-checking have a positive impact despite earlier literature cautioning from fact-checking unintentionally spreading the fake news it attempts to rebuke. They concluded their discussion of interventions and new approaches to fight fake news by suggesting that crowd-sourced fact-checking approaches can be combined with ways that encourage people to be more attentive and analytical.

SUDANESE LEGAL FRAMEWORK

It befits the recent history of regulating and legislating journalism in Sudan, as the medium to publish information, that its first responsible body, the Press and Publishing Section, was established by the intelligence service of the British colonisation in the 1920s. The responsibilities and names changed many times but remained under the command of the state's security or police services even after independence, until the 1970s when it was brought under the Ministry of Culture and Information and the independent Council of Press and Publication (Ministry of Information, 2014).

By the time the December Revolution succeeded in toppling Elbashir's regime, gaining access to information and sharing it was governed by many laws and regulations, including the 2009 Press and Publications Law, the 2015 Access to Information Law, the 2018 Cybercrime Law, the 2018 Telecommunications and Postal Regulation Law, and the 1991 Sudanese Criminal Law. The government and its security apparatus operated beyond the limits of any law or regulation, placing Sudan at the bottom of the World Press Freedom Index (Reporters Sans Frontières, 2019) and similar lists tracking freedoms of expression and speech.

Activists, experts, and citizens embarked on the efforts to draft new laws to protect the fundamental rights of accessing and sharing information and opinions after the establishment of the Transitional Government resulting from a power-sharing agreement between the military and civilian leaders. However, the 2020 Cybersecurity Crimes Law was a step in the wrong direction, changing nothing in the 2018 Law but increasing some penalty periods. While the government states that the law aims at protecting individuals' privacy and combats the spread of rumours and "harmful publishing", the worst of the 2018 Law was kept intact with the language of many articles remaining clearly vague. The 2020 Law has been used against activists and civilian politicians for the most part on behalf of the military generals using the rumours, privacy, and defamation articles. Evidence shows that the government still breaks the articles prohibiting telecommunications network shutdown, spreading rumours and fake news, and faking identities on social media platforms.

The Access to Information Law, similarly, suffers from vague language, and restrictions and procedures that nullify its declared purpose. Mohamed Suliman shows that there are 12 types of classified information that are restricted from citizens and that the fees charged to obtain information can be another obstacle. He points out the lack of any mention of protection for whistle blowers (Suliman, 2019).

Efforts to reform these laws and to ensure that the government and its institutions are held accountable for breaking them should be at the forefront of the battle to confront misinformation, disinformation, fake news, and hate speech. These efforts must be coupled with assurances to protect and enhance freedoms of opinion and expression.

Examples of Misinformation, Disinformation, Fake News, and Hate Speech Campaigns

The Sudanese people were subjected to coordinated well-researched campaigns of disinformation, fake news, misinformation, and hate speech during the three decades of Elbashir's regime. The official media outlets: newspapers, TV, and radio channels were used extensively in controlling the media in its first few years. People remember a daily speech by a military officer on the waves of Omdurman Radio, spreading lies about the opposition parties and their leaders, and about regional and international politics. Sudan TV had its fair share of such programs, with a special focus on demonising the rebels in South Sudan and glorifying jihad and jihadists.

With the explosion of satellite TV channels, FM radio stations, and non-political newspapers, the regime and its supporters developed new means to further their control of the public spheres in Sudan. The regime cadres mastered the art of distraction by promoting tabloid journalism and sensationalist topics over all the traditional media outlets. Topics such as rare crimes, weird events, implausible phenomena, and gossip about famous people were shared via many platforms and caught the attention and interest of significant numbers of ordinary people.

With the influx of social media platforms, the regime was swift in switching gears and infesting them with its malicious campaigns and fake accounts and stories. Some of the remarkable examples were the infamous "I was there and there was no protest" response by many individuals affiliated with the regime when they tried to rebuff the occurrence of mass protests against the government. Other recurrent piece of fake news propagated by the regime, whenever its forces kill peaceful protesters, is accusing unidentified third parties and minimizing the number of killed protestors. Additional recurrent themes spread by the regime's institutions and supporters are stories and gossip about socially unacceptable behaviours, especially by females, or about homosexuality.

There are well-documented instances of hate speech by leaders of the regime, some of them were combined with misinformation or fake news to justify violent attacks against civilians, especially in the areas of Darfur and South Kordofan.

Right for Peace, the NGO that works on the prevention of mass violations of human rights conducted a contextualised report about Sudan. It looked for historical violence incidents and traced their causes and consequences in contemporary conflicts. The report found that Sudan is seeing an escalation of violence characterised by clashes between ethnic groups, and often ignited by instances of hate speech. The report calls for the need for the government to take responsibility to de-escalate attacks, protect citizens and hold those responsible for the community's inter-ethnic dispute and conflict to account. Many people argue that justice needs reforms and enforcement, and they point to Sudan's weak and discriminatory justice system (Rights for Peace, 2021).

In addition to the fake news created by the regime, the last few years witnessed many incidents of misinformation propagated within the civilian powers that led to painting a negative picture of other factions or parties within the civilian front. Among the chief incidents is the rumour that some political parties had advanced knowledge about the intention of the Transitional Military Council to break the Sit-In in front of the military HQ, which led to a massacre on the 3rd of June 2019.

Some indicators that certain news or speech in Sudanese social media can be fake news, disinformation, misinformation, or hate speech (mostly in Arabic) are:

- Presence of the word "urgent - عاجل" highlighted and repeated
- Presence of the word "copied - منقول"
- Suspicious news sources and links
- Excessive use of emojis, symbols, colours, and bold text
- Spelling and grammatical mistakes
- Forwarder/spreader

These indicators will be expanded and analysed to inform the fact-checking system.

FACT CHECKERS

Efforts to combat misinformation, disinformation, fake news, and hate speech have been sporadic and lacking persistence for various reasons. Many journalists, activists, and social media influencers either created platforms or used their social media platforms, individually or as groups, to publish true news and, at times, rebuke fake news and misinformation. Most of

the platforms created by groups of journalists were actually closer to electronic newspapers than fact-checking platforms.

Sudan Bukra TV Channel is one such platform. Strict fact-checking was not its main mission; however, the objective of the channel inherently includes spreading true news and exposing misinformation, disinformation, fake news, and hate speech in the process. By early 2020, it became clear that there was an organised effort, most likely by the security apparatus, military, and militias, to create and circulate fake news and misinformation by tens of news websites and platforms. Sudan Bukra started to plan to combat this using its broadcast and its social media presence. The idea was to dedicate a small team of journalists, under the leadership of an experienced one, to monitor the social media for misinformation and disinformation, and then correct them immediately on the channel's social media accounts (Facebook, Twitter, and website) and its TV screen news ticker. The plan included creating a daily short video report with the misinformation, disinformation, and corrections of the day. However, the plan had not materialised because of financial and administrative challenges that affected the operation of the channel in Sudan. The channel continues to strengthen its network of citizen journalists and to encourage Sudanese people all over the country to report news and stories using common mobile phones. This approach makes ordinary citizen content producers and consumers using appropriate technology means in both roles; means that are affordable and accessible.

Karrib was a fact-checking platform relying on crowd sourcing created by an individual activist. It was short-lived because of financial issues. Currently, Beam Reports is Sudan's only high-standard fact-checking platform. The team examines some of the stories that get wide distribution and assigns one of four classifications: fabricated, misleading, selective, and correct. The team presents analysis and evidence for the classification of each story, and sometimes produces comprehensive reports with detailed analysis and references. Some social media platforms designated Sudanese individuals or groups to volunteer as partners to report and advise on matters related to Sudan, giving the platforms more local insights and context.

NLP AND AI IN THE DETECTION OF FAKE NEWS, MISINFORMATION, AND DISINFORMATION

The field of news fact-checking, misinformation and disinformation detection and hate content classification is relatively new. The surveyed model and studies showed shortcomings of the automatic interventions (ML, AI, and NLP). Although it is quick and powerful in the identification of content of interest and its class, the cognition of citizens and their response toward fake news, misinformation, and disinformation lacks behind. Strategies based on news correction announcements do not work, due to being locked-in physiologically in negation news, hard to recognize misinformation, and delayed detection of fake news.

More effective strategies are based on building citizen competency, consciousness, and sensitivity toward fake news and disinformation. It is better to act actively to stop the route of propagation. But, again, the speed of NLP and Machine Learning is required in hybrid with the slow smart insights of humans to overcome the mass propagation of fake news, by building crowd mass aided consciousness. The study of these intentional campaigns needs many contextual datasets and fact-checker infrastructure.

This research aims to build, in the future, a Sudanese-oriented dataset that facilitates the research on the topics, which the current datasets missed (Paper with Code). Most of the fake

news datasets are Western, COVID-19 dominant, and English based. The following steps are key to our plan:

a. Build the dataset using current news and content schema with emphasis on the content structure (title, body, etc), source profile, location identification, and propagation model.
b. Build the crawler that extracts information from main sources in social media, Facebook, Twitter, YouTube, and WhatsApp, and saves it in a database according to the content schema.
c. Automate fact extraction that emphasises features that enable further analysis based on Entity Resolution, Recording Time, Knowledge Fusion, Credibility Evaluation, and Link Prediction.
d. Use social network analysis, knowledge graphs, and NLP extensively in content analytics.
e. Combine the fact-checkers insights currently active in the Sudanese landscape to be embedded into the dataset.
f. Use the analysis results in updating mitigation strategies.

Implementing this plan relies on the contribution of common Sudanese citizens in building the dataset, analysing content, and training the models. The end result of having access to accurate information translates to more empowerment for the people, which is an expression of appropriate technology in use.

CONCLUSIONS AND CHALLENGES

A combination of fact-checking (human and AI/ML/NLP) and raising critical and analytical thinking seems to be the way to go. We recommend the cooperation of Sudan Bukra with Beam Reports to produce programs and build a dataset that tackles the two facets of this issue; correcting misinformation, disinformation, and fake news, and educating audiences to improve their attention and critical and analytical thinking for the news they encounter. We plan to conduct surveys among journalists, media personnel, information experts, and others about their views on these issues. The results of the surveys and the discussions which will follow will improve the paper, especially in the Sudanese context, and the recommendations.

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AN ASSESSMENT OF THE EFFECTS OF SOCIAL MEDIA ON LEARNERS AT NUST IN BULAWAYO, ZIMBABWE.

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Abstract
Social media refers to web-based technologies for building virtual networks and communities which engage in sharing of content such as personal information, text documents, videos and photos. They are becoming so popular and are ever growing technologies in Zimbabwe. Recently, they penetrated academic areas in all learning institutions due to the new normal as a result of the covid-19 pandemic. Several studies have been done to envisage the use of social media sites, however very few discuss the impacts and effects that they have on learners' learning activities, especially during lockdown situations. Therefore, this paper assesses the effects of social media in the learning processes at the National University of Science and Technology (NUST), a Higher Learning Institution in Zimbabwe with the notion of informing policy makers vis-a-vi a pandemic situation. This paper discovers the negative and positive effects that social media have in the learning processes, focusing on learners in particular. A quantitative and qualitative research methods were designed with a post-positivist approach. Questionnaires were used as data collection tool. Data was collected from learners and analysed using SPSS. Results revealed that social media play a fundamental role in the learning process, especially in academic collaboration. However, most learners spend time glued to social media at any given time, even during planned times. This brings about positive and negative effects in their learning such as constant access to varied velocity, validity, volume of information and subsequently, information overload, oversight and overhead respectively.

Keywords*:* Social Media, Facebook, YouTube, WhatsApp, Learning Process.

INTRODUCTION

Media is defined as one of the instruments for communication (Oxford Dictionary and Thesaurus, 2009). Social media are primarily web-based technologies for building virtual networks and communities which engage in sharing of content such as personal information, all sorts of documents, videos and photos. It is the most adopted means of communication by institutions, groups and individuals, especially youths. Social media facilitate interaction amongst humans where they create, share and exchange ideas and information in virtual societies and networks. The social media platforms that have been made available on the web all require internet access and computing devices mostly in the form of smart phones, iPads, minicomputers, laptops and so on. This research focused on the utilisation of Facebook, YouTube, and WhatsApp by learners at NUST. NUST is a Higher Learning Institution located in the City of Bulawayo in Zimbabwe, approximately catering for ten thousand learners taking science, technology, engineering and mathematics programmes in its ten faculties. Cost of education and Covid-19 pandemic changed the way the institution does its business with social media at the centre stage impacting both positively and negatively.

There are many who believe that there are both negative and positive aspects when it comes to social media in regards to learners (Wang, et al, 2011, p.6). Despite this, many Zimbabwean Universities still use social media even though there are great concerns surrounding it. Very

little research has been done in developing countries like Zimbabwe regarding the subject matter at hand. In this paper, we break the ground and reveal that the positives and negatives of social media are constant access to varied velocity, validity and large volumes of information. Furthermore, to the contrary we take cognisance of negatives of social media as information overload, oversight and overhead that would also affect time management in the learning process.

RELATED STUDIES

The Internet is an attractive medium throughout the world that has impacted people in different ways (Alabdulkareem, 2015). Learners are amongst the Internet user population that have been impacted one way or the other, in particular on their learning process. The Internet enables communication and activeness in education especially with the use of social media. Social media allow for creation of relationships between users and provide functionality for sharing content (Boyd and Ellison, 2008). As social media continues to grow in popularity, the authors concur with the school of thought that the use of technology through social media is vital in learners' academic succession. In the last decade, the online world changed radically. It is quite evident that the use of technology has brought with it a tremendous change in people's lives, from personal to professional lives as well as from the way people store, exchange and access information with the option of sharing or retrieving information sparingly or completely.

To date statistics on social media usage in America have revealed that 90% of young adults of ages between 18 to 29 use social media fully as compared to 35% -75% of the older generation (Perrin et al, 2015). This is to show that young people, particularly tertiary learners, are more into social media as compared to any other age group. This is a concern especially in developed countries like the United States of America and European countries (Wade and Forste, 2013). Inquisitively, the fact that the trends in the usage of social media and its effects is not well documented in literature amongst African countries including Zimbabwe does not mean that this is not an issue of concern. The study of this phenomenon has not yet penetrated the field of research as it has in the western countries.

Learning can be defined as the collaboration between learners and educators as they discuss ideas and possible solutions to problems (Klopfer, et al, 2009). Social media is known to enhance learning by encouraging students to engage in collaborations. In this regard, there is a need to know how social media enhances the learning experiences amongst learners in Zimbabwe. However, reasons for using social media are varied. Elsaif (2018) postulated that the dominant reason for the use of social media is to socialise and make new friends. This was also confirmed by another research conducted by Zhong (2020) who sought to assess the implication study of social media literacy in schools. The main reasons billions of learners use social media networking platforms are to make friends and satisfy their social needs. Some learners want to make friends, stay updated with trending issues, collaborate and study with other friends and as a source of recreation and relaxation.

Social media has now been embedded within Higher Learning Institutions and many learners spend about 10 hours on social media (Al-Sharqi, et al, 2015, p.4). Social media do not just help learners acquire knowledge but establish relationships with people, help battle with isolation by providing announcements and information that would be otherwise hard to gain face-to-face (Raut and Patil, 2016, p.282). Advantages that arise due to the use of social media is access to large volumes of information of different formats. It is now easy to acquire huge

amounts of information as social media improved the way we absorb new information. With increased uses of technologies in both academic and business sectors the use of social media helps in the development of skills that are beneficial to learners and throughout their lives.

However, many believe social media have more negative effects than positive effects. Many have great concern over the overheads of lack of privacy that social media provide as users of these social media can share personal and private information (Raut and Patil, 2016, p.283). There is fear that this information may be misused or cause harm to learners. Also, social media presents information overloads that can cause distractions especially if it is used during school hours (Jacobsen and Forste, 2011, p. 279). It is in this regard the researchers sought to contribute significantly to the already existing literature by clearly zooming in on the effects of social media on learners. Research done by (Zanamwe et al, 2013, p. 1-11) explored the positive effects of social media on learners, especially on performance, revealed that social media cannot be separated from teaching and learning processes.

METHODOLOGY

A quantitative and qualitative research designs were carried out to inform the data collection and analysis process in this research. However, the research is largely quantitative. The data collection technique was in the form of questionnaires. These questionnaires were handed to the respondents (n=60) to fill. The respondents were selected from the graduating class in the department of Computer Science at NUST. Firstly, the demographic questions such as; what is your Gender? What is your age? Which year are you in? These were meant to define and elicit the non-confidential profiles of the respondents. Subsequently, the main research questions were posed such as; Do you use social media? How many hours do you spend on social media in a day? What is your most preferred social media? What do you use social media for? What effects does social media have on you? The acceptance of social media for learning theoretical framework was derived from and adapted from the technology acceptance model with the view port designed to assess how the usage and acceptance of social networks were affecting the learning process.

Closed ended questions were used and distributed amongst the learners. The response rate was adequate of which 10 were not returned and 50 were returned and answered correctly as instructed. The data collected from the respondents was then analysed using SPSS and the findings were presented in summary descriptions by tables and diagrams. The results derived from the analysis are discussed in the subsequent section.

RESULTS AND DISCUSSION

This section makes an analysis of results. These results are discussed pointing to the effects of social media in learning processes.

Gender		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Male	24	40.0	48.0	48.0
	Female	26	43.3	52.0	100.0
	Total	50	83.3	100.0	
Missing	System	10	16.7		
Total		60	100.0		

Table 1: *Respondents gender distribution.*

Table 1 shows the statistics of the gender of the respondents. There was gender balance within the respondents with 52% being females and 48% being males. Of the 60 questionnaires sent, a good number that is, 50 students replied and 16.7% questionnaires were not completed. In relation to the results, it is worth noting that the use of social media is not gender sensitive. Both male and females engage on social media platforms and equally use the platforms for the same reasons as revealed by this study: to share information, acquire knowledge, to keep track of contacts, friends and trends. The age of the learners is depicted in Table 2.

Age		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	18-22 years	20	33.3	40.0	40.0
	23-26 years	12	20.0	24.0	64.0
	27-30 years	7	11.7	14.0	78.0
	31- 35 years	5	8.3	10.0	88.0
	36 years and above	6	10.0	12.0	100.0
	Total	50	83.3	100.0	
Missing	System	10	16.7		
Total		60	100.0		

Table 2: *Age distribution.*

Table 2 shows the distribution frequency table of age groups. An interesting result is revealed here, that most of the learners close to ninety percent (88%) are digital natives aged between 18-35 years and only a few (12%) above 35 years of age are digital immigrants. This age difference is reflected in the number of learners who claim not to use social media and this reveals their immigrant residence in digital skills. Coincidentally, the age of today's university learners is expected to be in the range of digital natives. The ages reflected in Table 2 are corresponding to the distribution on the year of study shown in Table 3.

Level		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	year 1	25	41.7	50.0	50.0
	year 2	16	26.7	32.0	82.0
	year 3	5	8.3	10.0	92.0
	year 4	1	1.7	2.0	94.0
	year 5	3	5.0	6.0	100.0
	Total	50	83.3	100.0	
Missing	System	10	16.7		
Total		60	100.0		

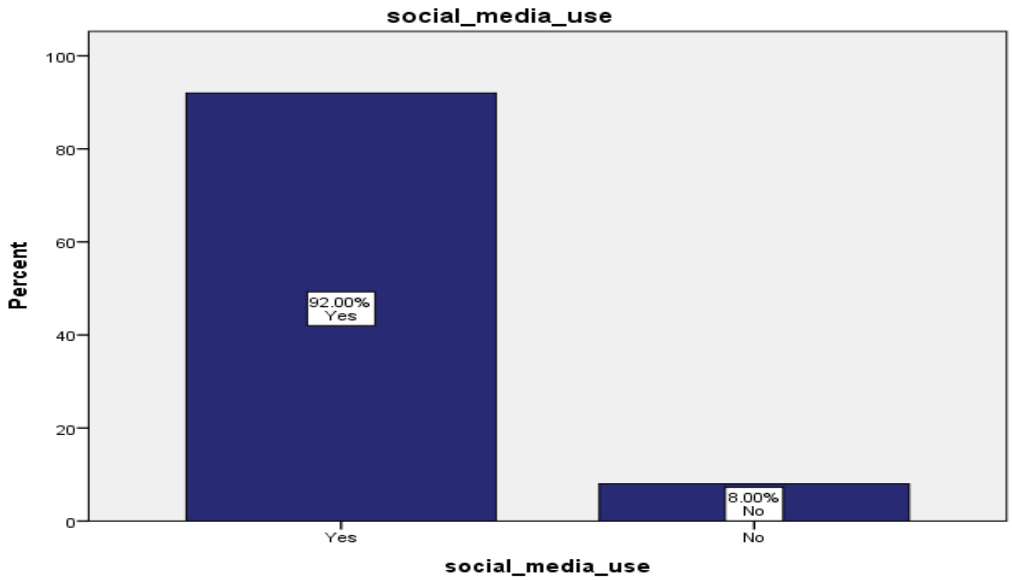
Table 3: *Frequency distribution on the year of study.*

Fifty percent of the students who participated in this study are first year students and in the age groups between 18 – 26 years. The distribution of the year of study shows that most of the respondents were in the first, second and third levels of university studies. Those in the final level of study, that is year four and five are only four, (8%) which also corresponds to the digital immigrants who are those who indicated that they do not use social media as shown in Table 4. This result is important in distinguishing the types of learners that find social media useful in education and those that do not.

Social Media Use		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Yes	46	76.7	92.0	92.0
	No	4	6.7	8.0	100.0
	Total	50	83.3	100.0	
Missing	System	10	16.7		
Total		60	100.0		

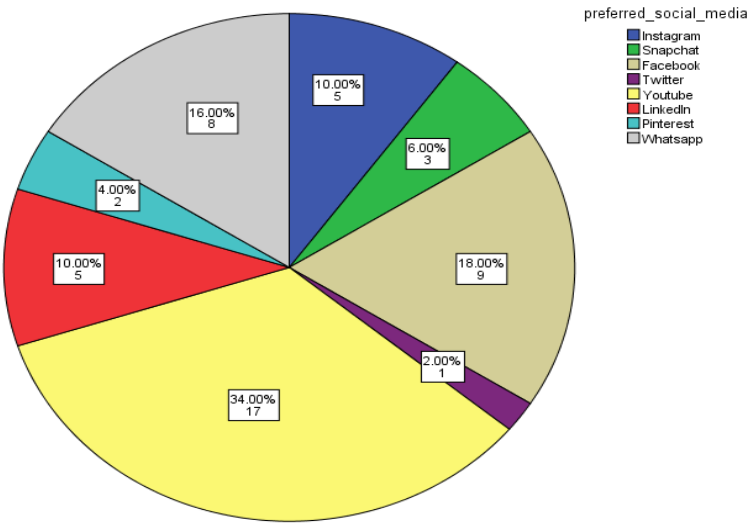
Table 4: *Frequency distribution on social media use.*

Table 4 shows the frequency distribution of people who use and those who do not use social media. Only eight percent (8%) of the respondents answered indicating that they do use social media. They are also identified as final level learners, who are above 35 years and identified as digital immigrants. These are at the end of the spectrum of those who use social media for other things rather than school work. It is worth mentioning at this point that those who use social media have been revealed by this study to be digital natives and mostly in the early levels of their education. This group found social media relevant to their learning due to the new normal induced by the covid-19 pandemic which stimulated working and collaborating online. Graph 1 visually emphasizes the users of social media for education versus the non-users.



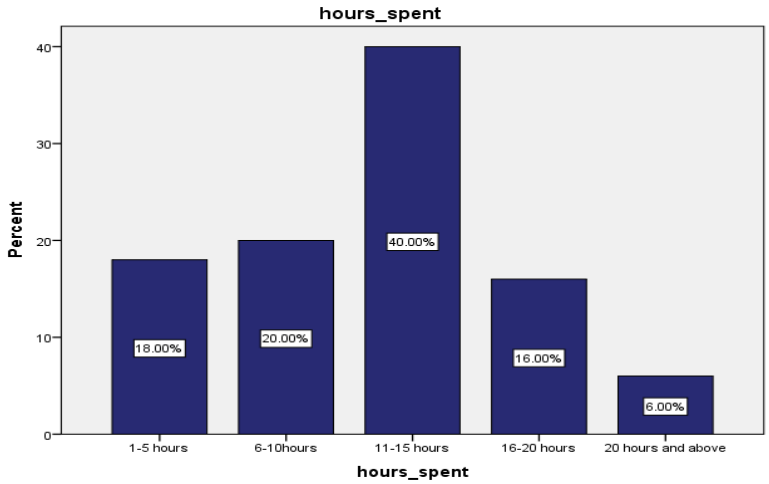
Graph 1: *Use of social media.*

As shown in Graph 1, 92% of the respondents use social media. The other 8% hold the belief that social media causes distraction from school work and misuse of private information as shown in Graph 5. We rule out the notion that this could be that the 8% do not have internet access because on campus internet is free. Of the majority that uses social media, the platform distribution is shown in Graph 2. YouTube is the highest with 34%, followed by Facebook with 18%, while WhatsApp has 16% and the rest of the platforms share the 30% market share of the university learners.



Graph 2: *Preferred social media.*

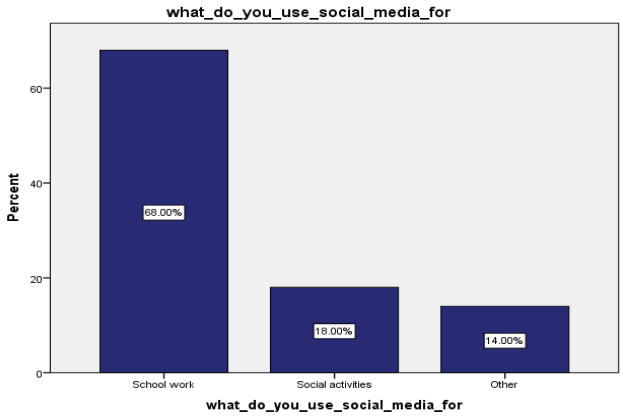
Graph 2 shows the distribution of preferred social media platforms by the university learners. The functionality of the platforms seems to correspond with the main purpose for use by learners. YouTube is well known for the educational content and videos and has the highest market share of the learners. Twitter has the least market share and correspondingly, the amount of educational information that one may tweet is limited, rather it is good for live notifications and keeping with the trend. Similarly, the second largest market share goes to Facebook which is good for collaboration and sharing content while keeping in touch with friends. The second last market share is held by Pinterest which limits access to most material to subscribers. It is definitely noteworthy that the preferred social media platforms correspond to the needs of the learners that is to access educational information and collaborate.



Graph 3: *Hours spent on social media.*

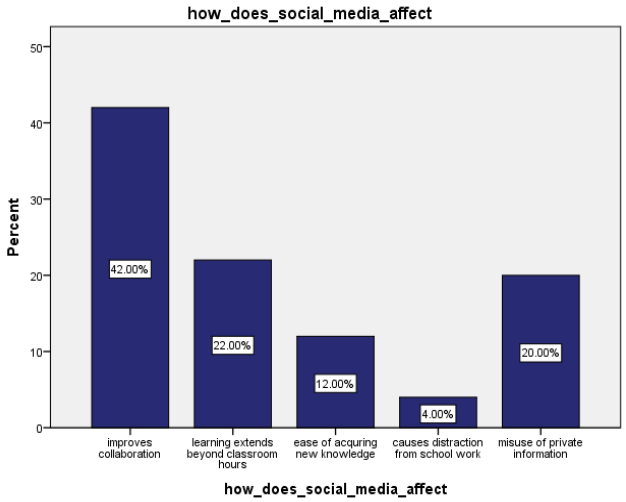
The frequency distribution of hours spent on social media is shown on Graph 3 to be almost a normal distribution with mean of 12 hours and standard deviation of 4 hours. 40% of the learners spend 11-15 hours online. This may reflect that the learners are on social media during and after lecture times. This is made possible by the ability to access social media platforms on the phone in addition to access on the computer. This makes social media a very accessible application than any of the conventional software applications. The time spent by and

accessibility of social media to learners is congruent to the responses shown in Graph 4 on usage.



Graph 4: *Social media use.*

Graph 4 shows the frequency distribution for what learners use social media for. More than half, that is 68% use social media for school work, with only 18% using it purely for social reason such as connecting to family and friends, and 14% for other reasons like business, entertainment, sports and the like. The high usage of social media for school work shows the impact of the new normal of blended education and working online that was recently induced by the global pandemic. Social media was traditionally known to be for connecting friends and family, but this study has revealed from the survey data that education is increasingly benefiting from its use. Graph 5 also depicts positive effects of social media to the learners' education.



Graph 5: *Effects of social media on learners.*

Graph 5 shows the frequency distribution for how social media affects university learners. It is worth highlighting the respondents' positive recommendations of social media by informing readers that social media improves collaboration, it extends learning beyond classroom hours and offers the ease of acquiring new knowledge. A few respondents, that is, only 24%, think negatively of social media as causing distraction from school work and it has latent misuse of private information.

CONCLUSIONS

The research reveals that learners at NUST spend a lot of time on social media and usually spend most of their time on YouTube. This is due to the fact that learners use YouTube to acquire knowledge for their course content and assignments. WhatsApp and Facebook follow YouTube in that order. This is attributed to the fact that some of the social media applications are usually for business purposes and as such, learners do not use them quite often. The research also revealed that most learners at NUST usually use social media for school purposes, especially for information, communication and collaboration as put forward by Zanamwe, et al (2013). Most of the respondents believe that social media improves collaboration amongst learners. This may be because of the use of Facebook and WhatsApp ability to connect people and allow for content to be sent from one person to the other.

The positive effects of social media on learners are better and improved communication, timely information gathering and dissemination, socialising, teaching and enhanced learning, improved academic performance, technology skills development and career making. The use of social media also is beneficial for keeping online contact in the case of a pandemic which requires people to isolate or quarantine themselves. We recommend social media for use in blended learning whereby learners keep in contact in addition to the conventional physical contact during learning hours.

Some negative effects of social media on learners are theft, cyber bullying and isolation. Thus, learners' behaviour does change as well. Social media contributes to poor academic performance, lower self-image and less interest in school-oriented issues (Maya, 2015). Moving forward, other studies posit that social media tends to affect the ability of learners to express themselves in English, either in writing or speaking; the use of short-handwriting to chat with friends and families subsequently becomes a habit thereby reproducing the same mistakes in learning process. Most language errors were noticed in assignments and examinations. An appropriate recommendation to the owners of the social media platforms is the activation of the use of a dictionary for auto correction of spellings and language syntax.

Social media has a bad effect on learners, as it causes learners to indulge in terrible slang language and causes them to disregard folk educators and the laws in the general public. A study was also conducted by Mahas (2014) who contended that the usage of social media has an effect on learner's privacy, as these social media networks consist of hackers ready to hack the personal information of learners. They can damage the privacy contacts of learners in addition to social media addiction. We therefore recommend the use of social media with strict adherence to the use of proper language and spellings.

An analysis of the results suggests that most NUST learners use YouTube, WhatsApp and Facebook as their preferred social media. Most learners use social media for school purposes. Furthermore, we conclude that social media improves learners' collaboration. Recommendations to these findings are that more universities should endeavour to embrace more of social media as a learning tool. The learners are already engaging on social media and are aware of the various benefits and negatives associated with the usage (Ansari and Khan, 2020). Social media platforms are very useful in the case of the new normal for blended learning and online meetings and or work imposed by the covid-19 pandemic. The effects of social media in the learning processes at NUST are more of positive than negative. It is confirmed that benefits of social media in education far outweigh the negatives and has proven to be practical as revealed by the respondents of this study.

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PREDICTION AND ANALYSIS MODEL FOR ACADEMIC SCHOOL PERFORMANCE (SUDANESE PRIMARY SCHOOLS AS CASE STUDY)

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Abstract
One of the most serious barriers currently facing educational institutions today is the lack of standards for measuring school academic performance. As a result, the enormous amount and rapid growth of data, as well as the ability to use it to improve the quality of administrative decisions to provide quality education, are not fully realized. There is a challenge in Sudan in effectively assessing school performance due to a lack of clear factors and quality standards. This paper examines the environmental factors that influence academic school performance and then develops and evaluates a prediction model that can notify decision-makers and planners of various hazards associated with those factors. In data analysis, data mining techniques are quite useful. A decision tree technique was utilized to identify several factors that can impact academic performance, and the WEKA (Waikato Environment for Knowledge Analysis) tool was used for analysis and prediction to develop a classification model. Six different decision tree algorithms: J48, Decision Stump, Naive Bayes, Random Tree, Rep Tree, and Hoeffding tree were compared. From the findings of this paper, it can be concluded that J48 is the best-performing algorithm for classified accuracy because it achieved maximum accuracy of 64.27% using 10-fold cross-validation. It shows that the instances of 2213 are correctly classified from the 3443 instances, and it took the minimum amount of time to build this model through Explorer.

Keywords: School Academic Performance, Educational Data Mining, Factors, Prediction, Accuracy, School Performance.

INTRODUCTION

One of the most essential aspects of human resource development is education, so schools are one of the most influential institutions in modern societies for socialization and personality development. Educational institutions are rapidly expanding, resulting in a significant increase in educational data and the need to analyze it using educational techniques. Educational Data Mining (EDM) is one of these technologies, which is concerned with discovering knowledge by using data mining tools on educational data.

All educational system components (teachers, students, academic planners, and administrators) can benefit from using EDM to analyze and visualize educational data. It can assist academics and educators in developing, planning, and making decisions in their educational programs and the conceptual map that follows. It can, on the other hand, aid in the prediction and analysis of a student's performance, behavior, and social network.

School performance is one of the quality indicators that can determine not only the quality and quantity of learning for students but also the entire teaching situation and context (Miguel,2002). It can be predicted in a variety of ways, including data mining techniques that provide an approximate result on performance by mining all of the factors that influence it.

The purpose of this paper is to comprehend the performance, develop and assess a school performance prediction model, and introduce a prediction model that incorporates education to aid decision-makers and those who care. to improve the quality of managerial decisions and to provide high-quality education. One way to achieve the highest level of quality in the education system is to develop a useful prediction of student success in a primary learning institution.

RELATED STUDIES

In the education field, researchers relied on prediction processes and prediction models. For example, (Deshpande, Pimpare, Bhujbal, Kommwar, & Wagh, 2016) used data mining techniques to analyze, visualize, and predict student performance. a system that aims to apply various data mining techniques to student performance on tests and exams A Decision Tree algorithm is used in this research to predict student performance and identify the strongest and weakest subjects. However, relying solely on examination/test performance predictions ignores other indicators that go into educational evaluation.

(Al-Radaideh & Al-Shawakfa,2006) and his colleagues wanted to use a decision tree model to predict students' final grades in the C++ course at Yarmouk University in Jordan in 2005. Three different classification methods were used, including ID3, C4.5, and Naive Bayes. Their findings revealed that the Decision Tree model outperformed other models in terms of prediction. Other researchers presented a new model which uses decision tree algorithms such as (CART, ID3, and C4.5) to predict a student's exam performance (Yadav & Pal, 2012). Their research provides a strong indication of which students will (Pass and be promoted) or will (Fail) in their final exams. Furthermore, their research aided the weak students in their efforts to improve. The researchers used a rapid-miner tool to conduct their experiment. According to their findings, both the ID3 and C4.5 algorithms were successful in identifying students who were likely to fail by having a high true positive rate of their model (78 percent), while the CART had a true positive rate of (64 percent).

As described by(el-Halees,2009), data mining can be used in the educational field to improve our understanding of the learning process by focusing on identifying, extracting, and evaluating variables related to students' learning processes. Educational Data Mining is the term for mining in an educational setting. (Ramesh, Parkavi & Ramar, 2013) Predicting student performance: a statistical and data mining approach." International journal of computer applications, a study was conducted on data collected from a questionnaire that contains several factors that are expected to affect student performance.

The goal of this related work by (Kaur & Singh,2016) was to develop a model that could predict student performance using the Weka Tool. The goal of this study is to use the Weka tool to predict student performance using the Naive Bayes algorithm, which describes student performance. However, this research is limited to extra educational data as well as psychological, personal, and student-environmental factors.

METHODOLOGY

The method used for identifying factors that influence school performance and developing an effective data analysis model by using data mining techniques to provide an approximate performance prediction.

As a result, the figure below illustrates the general design process and demonstrates the techniques and methodology based on the scientific approach to solving the problem.

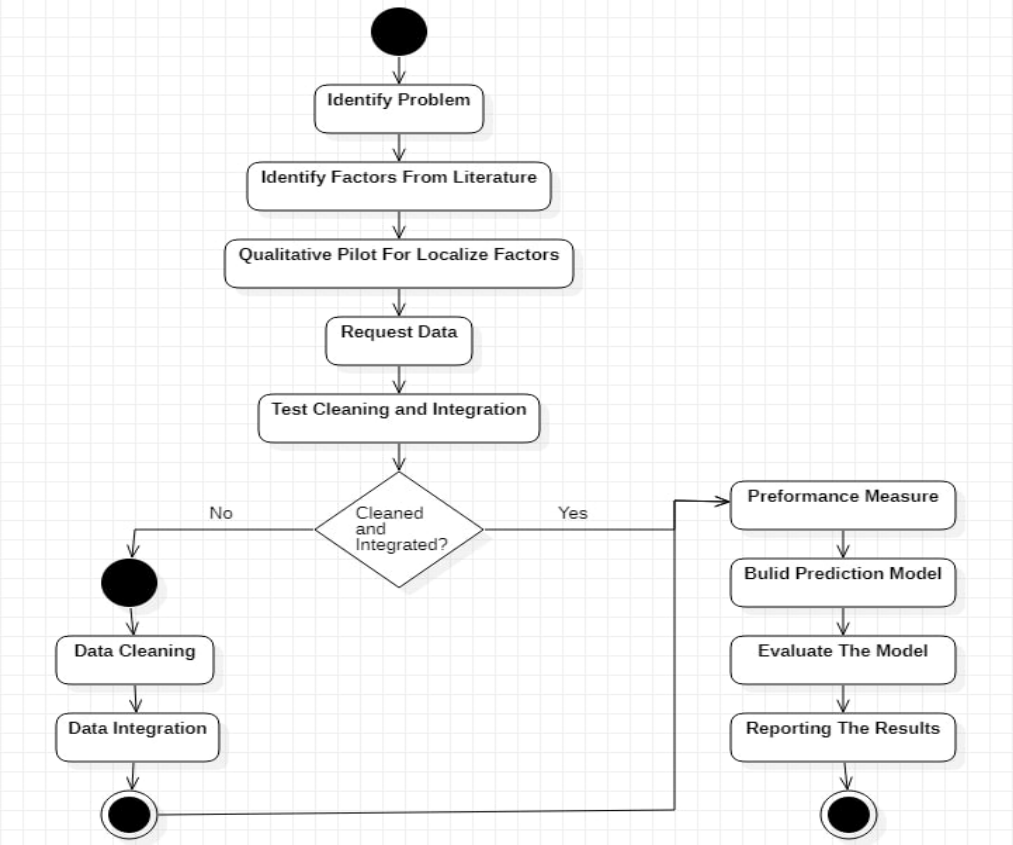

Figure 1: *The Methodology.*

Identify Factors:

After analyzing the list of factors that have been conducted from related work, stated that the following factors are the most influential in measuring performance: locality_name, location, Status, Type, Student-to-Teacher Ratio, Latrines, Electricity, and Potable Water Source.

Data Constructing:

Based on the paper scope the data from Khartoum state has been obtained after requesting, It contained the following data (School ID, school_name_arabic, school_name_english, locality_name, location, School Status, School Type, teachers, students_total, Total_Classrooms, Electricity, Potable_Water_source, Latrines, Latrine_male, Latrine_female, Latrine_common) which numbered 3,797 records and 16 columns, and after conducted a cleaning test on it becomes 3443 records with 9 columns.

Implementation Using Weka Tool

Weka (Waikato Environment for Knowledge Analysis), is a Java-based data mining application developed at Waikato University. WEKA is a robust data mining application that allows users to categorize and analyze the correctness of datasets using various algorithmic approaches. Weka's workbench includes methods for the main data mining problems: regression, classification, clustering, and association rule mining, and its algorithms are suitable for generating a predictive model accurately. The interfaces accessible in WEKA that we have utilized include Explorer, Experimenter, and Knowledge Flow. In this paper, we employed data mining techniques to predict academic performance for schools using accuracy

classification. Weka was used as the data mining software tool to carry out all the experiments and implementations.

The model uses the (J48) decision tree approach, which is the implementation of algorithm ID3 (Iterative Dichotomiser 3) developed by the WEKA project team. Which is a simple decision tree learning algorithm developed by (Quinlan,2007), the basic idea of the ID3 algorithm is to construct the decision tree by employing a top-down, greedy search through the presented sets to test each attribute at every tree node to Select the attribute that is most useful for classifying the provided sets.

RESULTS AND DISCUSSION

Decision tree, rules, prediction, accuracy, and selected attributes are the five aspects of the model results.

Decision tree

A decision tree is a decision-making aid that employs a tree-like model of decisions and their potential results, The model was built using the (J48) decision tree approach, which uses gain ratio as an attribute selection measure. was utilized to build the model. For dividing the node, the attribute with the highest value is selected. Hence, the attribute "Locality name" has the highest value in this research, hence it is selected as the decision tree's root node. This node was selected for further splitting because the attribute "Type" has the next higher value. This process is repeated until the entire tree has been built. The decision tree is depicted in Figure 2. A rectangle represents each leaf node, while an oval represents the root node or splitting node. (see Appendix B, to clarify the figure).

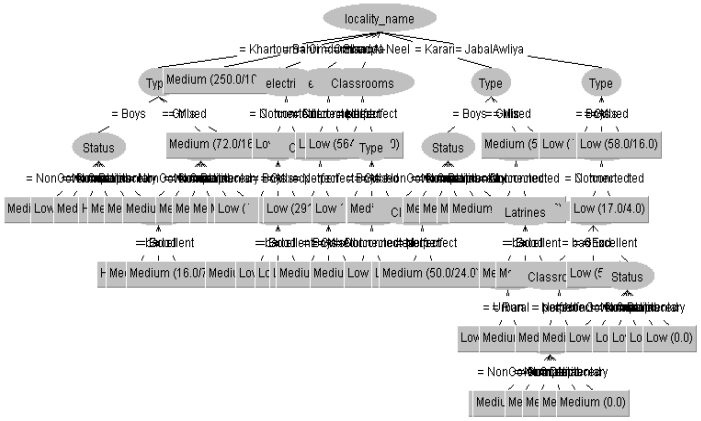

Figure 2: *The Tree View.*

Rules

The classification rules can be derived from a decision tree by tracing the path from the root node to each leaf node in the tree. Each leaf node provides the class value for the prediction, and each splitting node is logically ANDed to construct the rule antecedent. Any attribute, or any combination of attributes, can be predicted using rules. (instance # means the number of schools that achieved the entire rule), see appendix.

Rule #	Rules	Predicted Class	Instances #
1.	locality_name = JabalAwliya AND Type = Mixed AND Classrooms = perfect	Low	(47.0/11.0)
2.	locality_name = Ombadda AND electricity = Connected AND Classrooms = Not Perfect AND Type = Girls	Medium	(89.0/39.0)
3.	locality_name = Ombadda AND PTR = Good	Low	(443.0/172.0)
4.	locality_name = Bahri AND Classrooms = Not Perfect AND Type = Girls	Medium	(11.0/4.0)
5.	locality_name = Bahri AND Type = Grils AND location = Urban AND PTR = Good AND Latrines = bad	Medium	(32.0/12.0)
6.	locality_name = Bahri AND Classrooms = perfect AND Type = Mixed	Medium	(31.0/8.0)

Table 1: *Classification Rules.*

Accuracy

The accuracy is calculated by dividing the total number of correct instances by the total number of instances. The accuracy of a model is measured in the percent of correctly identified examples in Weka. To evaluate the classification model 10 fold cross-validation methods have been used. In 10-fold cross-validation, all the data has been divided into 10 disjoint sets of approximately equal size. This is an iterative process. Each time 9 disjoint sets act as training data and one set is used as testing data. Six different decision tree algorithms J48, Decision stump, Naive Bayes, Random tree, Rep tree, and Hoeffding tree have been compared. The results are depicted in Table 5.3 for the percentage cross-validation method respectively.

Decision Tree	Accuracy %	Time Taken to build the tree	No. of correctly classified instances	No. of Incorrectly classified instances
Decision Stump	47%	0 sec	1623	1820
J48	64%	.03 sec	2213	1230
Naive Bayes	53%	.02 sec	1832	1611
Random Tree	52%	.02 sec	1821	1622
Rep Tree	55%	.08 sec	1914	1529
Hoeffding Tree	53%	.09 sec	1832	1611

Table 2*: Comparisons of Algorithms Using Cross-Validation.*

From the table above the highest accuracy has been achieved by the J48 decision tree algorithm. The overall accuracy of this model is 64.27% using 10-fold cross-validation. It shows that the instances of 2213 are correctly classified from the 3443 instances.

Selected Attributes

The attribute selection task essentially consists of choosing influential factors from the highest to the least influential. The mined decision tree technique revealed various factors that had a significant impact, due to the research questions, it was discovered that the dataset consisted of 3,443 schools. The academic performance was strongly influenced by the locality_name, type, electricity, and location in the results of school data, despite the fact that the condition, PTR, and latrines, had an average impact and the classrooms, the portable water source, had the least impact.

Model Evaluation and Interpretation

To evaluate the classification model 10-fold cross-validation the confusion matrix was used, it shows the accuracy of the predicted classes. Table 4 shows the confusion matrix for cross-validation.

		Predicted class			
	Class	**A = High**	**B = Medium**	**C = Low**	**D = Failed**
Actual class	**A = High**	55	196	69	1
	B = Medium	20	982	350	4
	C = Low	9	316	1149	3
	D = Failed	4	71	187	27

Table 3: *Confusion Matrix for J48 Algorithm Using Cross-Validation.*

Detailed Accuracy by Class:

Accuracy by class contains a precision, recall, and f-measures according to different kinds of classes (High, Medium, Low, and Failed).

Algorithm J48	**Accuracy %**	**Precision**	**Recall**	**F-Measures**
High	64%	.625	.171	.269
Medium	64%	.627	.724	.672
Low	64%	.655	.778	.711
Failed	64%	.771	.093	.167

Table 4: *Accuracy by Class.*

CONCLUSION

A case study of educational data mining in Sudanese primary schools was presented in this paper. It was largely used to improve school performance by predicting school performance using classification techniques and decision trees. After a comparison of four decision tree algorithms, the J48 decision tree technique was chosen for building the model. The model had a 64.27 percent accuracy in both the 10-fold cross-validation approach and the percentage method, and the total time to develop the model was 0.03 seconds, From the 3443 instances, the 2213 instances are appropriately classified, we discovered that after prediction the highest performing schools are in the Khartoum - Bahri - Karari areas and that girls' schools surpass boys' schools in terms of academic achievement, and also found that schools with electricity outperform schools without electricity and that schools in urban areas perform better than schools in rural areas. And that non-governmental schools do better than others schools, and that when the PTR is good, the school performs well academically.

According to the findings, this paper recommends that officials in the ministry of education provide a greater emphasis on functional factors to improve student and school performance and the quality of administrative decisions to deliver high-quality education.

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Appendix:

The following files are for download	
Gzipped file	**Description**
https://docs.google.com/uc?export=download&id=18S0GBySxlVAj-qN4HnLwE0iWxsCh_hfB	Whole Appendices and described Weka Configurations of paper algorithms.

AN ANALYSIS OF IMPACT OF SEO FOR SUDANESE UNIVERSITIES WEBMETRICS RANKING, CASESTUDY: UNIVERSITY OF KHARTOUM WEBSITES

Nada Ali
Sudanese Knowledge Society, Sudan

Abstract
The ranking of universities published on the web by Webometrics Foundation is considered an international measure in increasing the transfer of scientific and cultural knowledge though promoting web presence for the Sudanese universities that would like to increase their existence and visibilities on the web. Therefore, this research aims to implement an effective process for education web ranking evaluation through developing and test a method to identify the website metrics. Because they are the most valuable for site developers and webmasters to follow moreover, this research has examined ten subdomains from university of Khartoum. The methods of research are observation, questionnaire, and web meterics analysis as well, Google master tool and data collection. Such methods are used to track performance and key metrics were developed to monitor user behaviour and areas for usability improvements.

Keywords: Web Ranking, Web Analysis, Webometrics, Web-Metrics Tools, SEO.
.

INTRODUCTION

The current situation of Sudanese educational websites development and high competency on the webometrics universities ranking (Spanish web educational ranking) lead to study of the reasons and factors of ranking, the problem underlying this research is that most developers focused on the design and attractiveness factors to attract visitors while the appearance of websites is important, there other factors with an impact on number visitors such as search engine optimization and website usability.

The main purpose of this research is to explore the visibility factor of the university of Khartoum (the main factor of webometrics account for 50%) between the selected web metric, we will analyze the overall websites, and this study examines ten websites (that use U of K subdomain) that vary in their performance in the usability metric. The Objective of the Research:

- To understand the current practice and identify key criteria for web performance methods, metrics, and techniques.
- To explore functionalities of different analytics tools and learn about the scope of these tools and the types of methods they support.
- To implement an effective process for education Web Ranking evaluation.

The overarching research question draws closely from the proposed importance of adopting key metrics.

RQ: Which web metrics are most closely connected with website total clicks (number of visitors) that help in web educational ranking?

This research considers the search engine optimization approach as an important resource for monitoring web traffic, and gives a practical review of web search metrics from a user satisfaction point of view.

AN OVERVIEW OF WEBOMETRICS CASE STUDIES

One of the studies aimed to analyze the website ranking for Iranian Medical Sciences Universities for 41 websites on webometrics, some metrics have a significant role, such as: removing indexed pages, indexed scientific resources, input links, and rich files indexed in search engines. Indexed pages and indexed links in Google Search and Google Scholar search engines showed a limited number of universities possess a high-quality website and others have weak effects. (Dastani, Panahi, Sattari, 2016)

Another study has developed a system to guide website development based on SEO by testing with samples of Rajamangala University of Technology (9 websites) in Thailand. The study applied to 75 university websites (extracted randomly from the Webometric website) which showed some of the SEO metrics, such as the number of backlinks, Alexa Rank, and Page Rank, which has direct and significant impact on universities' rankings. (Chotiktipat1, Nilsook2, &Sodsee3, 2018)

Also, Thailand universities' websites were ranked by Webometrics in January 2017 for overall 180 websites, it has found the relationship between the impact ranking of the website in webometrics and the result from the SimilarWeb tool the top universities in webometrics websites have many referral visits and the number of total page views. (Suksida, L. Santiworarak, 2017).

In conclusion, previous studies showed how far SEO metrics can affect the website rank of the university. But also, other economic, political, and social conditions can affect web metric ranking, but they are not considered in the webometric ranking.

UNIVERSITY OF KHARTOUM WEBSITES' RANKING (WEBOMETRICS) IN PRACTICE

Sudanese universities have strategic plans to seek the target of open access and place their presence on the Web, as internal and external communication pillars that support the academic environment which must be visible and useful to the academic community. Therefore, visibility requires measurement through indicators that allow it to be evaluated and comparisons between Sudanese, African, and Arab universities. Web Analytics is part of the digital content unit at the university of Khartoum which makes it works toward wards web analytics not only for the quality of the information that is used but also for its impact. This has made universities competitively seek to establish strategies and policies for users to increase the use of materials published there. Among digital repositories of open access, and integrated with social media networks like Facebook, Instagram, Twitter, Google Plus, and the big competition to encourage its researchers through developing technological competencies so that their findings are published formally on the web, also encourage the student and teacher using E-learning system. The Ranking Web (webometrics) is published two times (January and July) per year, and currently, it is part of a series of similar rankings covering Hospitals, Research Centers, Business schools, and Repositories. Table 1 describes the web metrics, Ranking:

World Ranking	Continental Ranking	Country Rank	Presence	Impact	Openness	Excellence
2795	68	1	99999	4647	1619	2448

Table 1: *The Webometrics Ranking in July 2017 University of Khartoum.*

The Challenges of the Ranking for Sudanese Universities Based on Webometrics

- The evaluation of university quality is raised by its production and documentary use. Such as bibliographic citations, university repositories, Learning Management systems, and E-journals, U of K's ranking is not raised according to visibility factors, but according to presence, openness, and scholar factors.
- Backlinks are off SEO; it occurs when other websites link back to yours, so the control factors are in the hands of other organizations. Not like On SEO factors.
- Web metrics model doesn't report about the state of ranking; it just gives guidelines and best practice information.
- The Significance of this research is adding valuable insights into the area of Web Analytics and the role of education's website ranking, especially in Sudanese universities. It needs to be highlighted:
- Web education analysis and the importance of the role of search engines in optimizing websites.
- Website metrics as a strong point for web analysis and SEO.
- Analyzing users' behavior may lead to getting ideas
  for qualifying and standardizing the website to meet the interest of users and give high ranks to universities.

RESEARCH METHODOLOGY

The study follows a mixed method approach that provides a more complete and comprehensive understanding of the research problem than either quantitative or qualitative approaches alone**.** This integration involves using multiple stages of data collection and data analysis as shown in (Figure 1).

This study uses multistage Random sampling, there is no bias involved in the selection of the sample, the websites are selected from the different campuses of the University of Khartoum that include services websites (e.g. Administration), department and faculty websites, and research institutes websites. This means that university websites have different weights, ages, and objectives, which reflect traffic behavior. They also serve different audiences where some websites are just informative while others involve interaction with visitors.

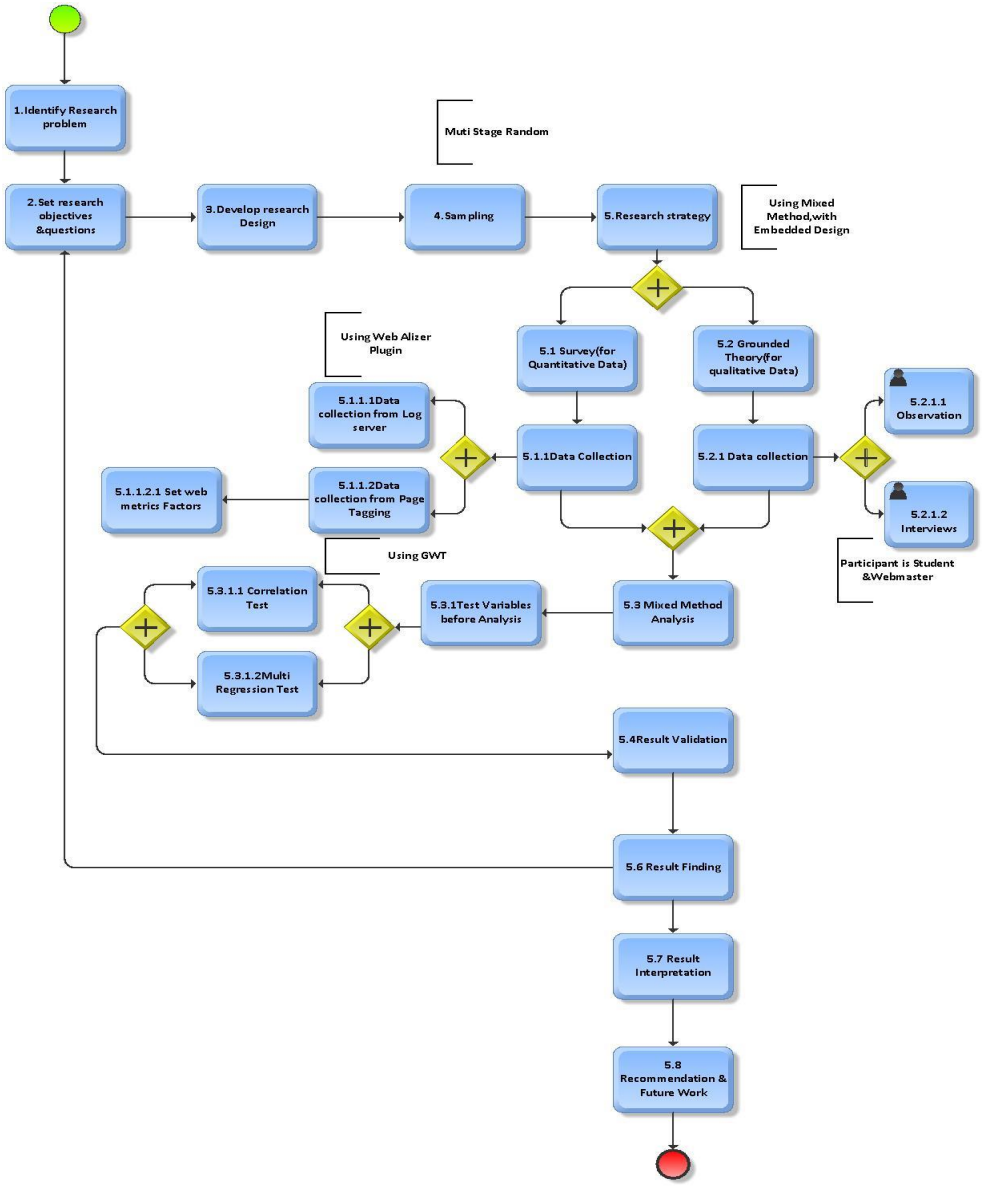

Figure 1: *The Research Design.*

The quantitative tools collected data by two-way log server analysis, in this case, the researcher used Webalizer plugin and page tagging here the researcher used Google webmaster tools (GWT) and other helped tools like SEO quake to take some information not clear in GWT, like age of websites and back links.

Metrics/Factors	**Definition**	**Categories**	**Type of factors**
Search analytics by queries	The total number of search queries by individual page on your property that were returned by search results	Search Traffic/ analysis	-
Search analytics by pages	The total number of search queries by query strings that users searched for on Google.	Search Traffic/ analysis	-

Metrics/Factors	Definition	Categories	Type of factors
Total click	Count of clicks from a Google search results page that landed the user on your property	Search Traffic/ analysis	count
Impression	The number of times pages from your site appeared in search results.	Search Traffic/ analysis	count
Average position	The average top position of your site on the search results page for a given query.	Search Traffic/ analysis	ratio
Click on rate	The percentage of impressions that resulted in a click to your site.	Search Traffic/ analysis	ratio
Link to your site	It displays the backlinks	Search Traffic	count
Index Status	The total number of pages from your XML sitemap is indexed.	Google Index	count

Table 2: *The Webmeterics of Google Master Tools.*

- For qualitative data collection, Grounded Theory research was used in this study to investigate the important questions that were set in this study, the proposed interview questions undertaken in UofK, set of informal interview questions were directed to students, webmasters, and one network engineer in UofK.
- Gathering information from participants (webmasters) through interviews involving unstructured and generally open-ended questions, the research participant consists of the five webmasters, one network engineer, and discussion groups consist 27 students from the school of mathematical sciences (4th year) beside the researcher also to get certain information about what the reasons of increasing or decreasing the visit or click on the selected website certain time between 29 October to 3 December 2017). the questions were
- What are the reasons behind visiting UofK websites?
- How did you find out about UofK websites?
- Do you find what you want for the first time in a search engine?

The information gathered from interviews can be summarized as follows:

- The students agreed on the low visits and interaction with websites, but there are some reasons to visit such as registration, Calendar, publication, and advertising the result.
- The network engineer thought that affects the network connection is one of the reasons that affect the website traffic.
- The students always used the keyword to find the wanted website, so they used to search by query instead of the following URL and mentioned difficulties to find the website URL on other external websites.
- The student criticized the content of the website, as not useful for them and it is not easy to find what they want on university websites.

IMPLEMENTATION AND RESULT

The researcher used GWT as a quantitative instrument, participant observation, and a questionnaire as a qualitative tool, this method strengthened the research study. The findings from the Web Analytics investigation, and qualitative interviews from respondents at the University of Khartoum, faculty of mathematical sciences.

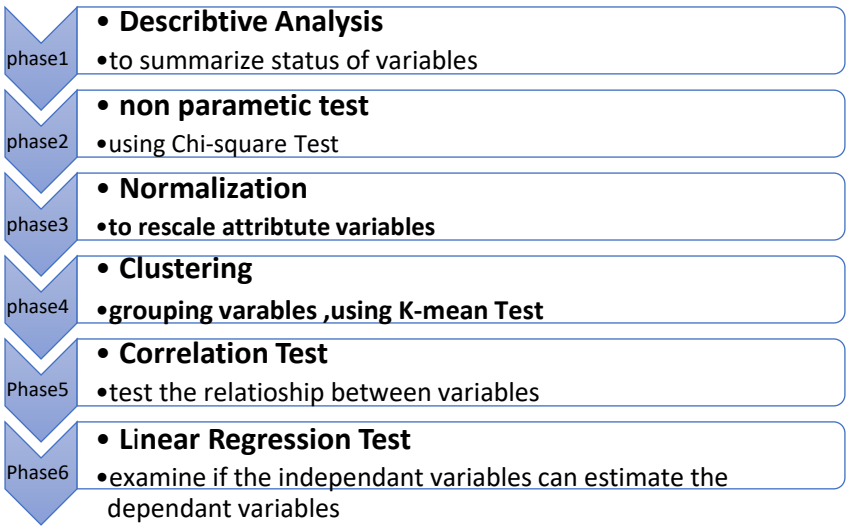

Figure 2: *Steps of Analysis Webmeterics.*

The result of the web metrics Analysis showed significant relationships between total click and Web metrics factors (total index factors, AVG -page crawl, AVG-time spend) those factors are strongly correlated with total links.

Phase 1: The researcher summarized the status of websites from descriptive Statistics generated by SPSS, the result showed not a normal distribution for all variables in websites.

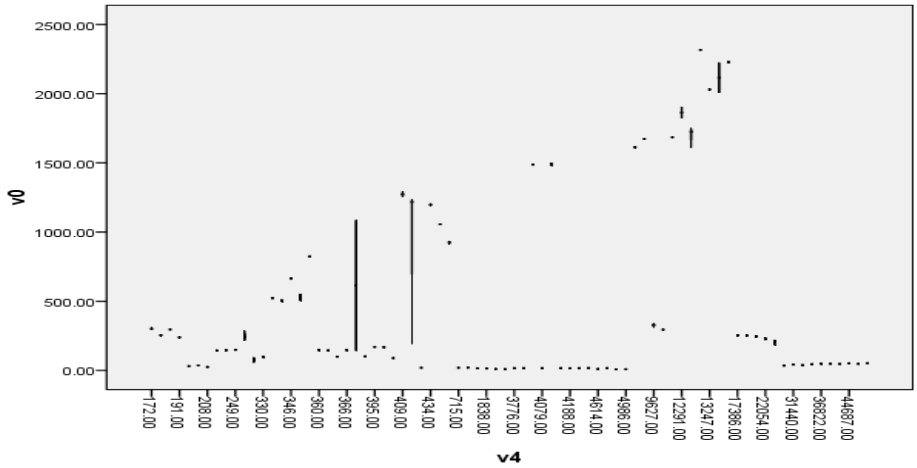

Figure 3: *Illustrates the status of total click (v0) with links to its variable (v1).*

It is clear the dispersion between variables. The next figure (4) showed the distribution of total links for all selected websites.

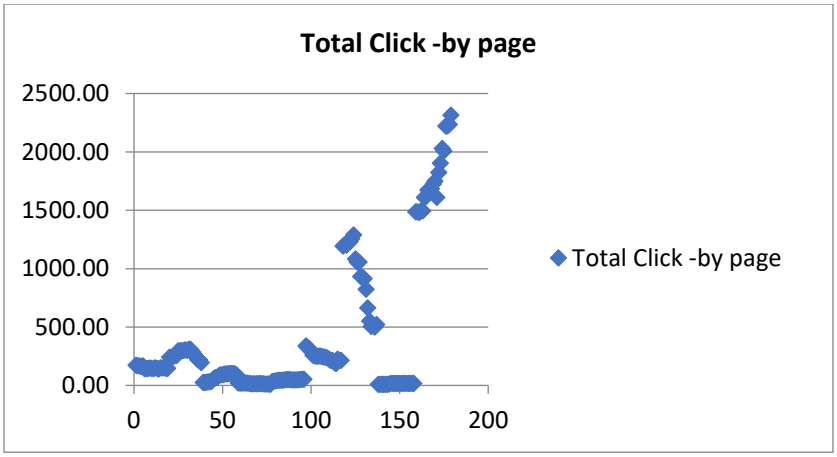

Figure 4: *Total Clicks for all selected websites.*

Phase 2: The researcher did a nonparametric test to involve estimation of the key parameters of that distribution (e.g., the mean or difference in means) from the sample data. Table 3 showed the result of the chi-square test for variables

Test Statistics

	v0	v1	v2	v3	v4	v5	v6	v7	v8
Chi-Square	82.804[a]	1.140E3[b]	63.753[c]	55.022[d]	56.743[e]	74.810[f]	92.911[g]	87.955[h]	47.525[i]
df	122	62	11	117	77	71	31	94	123
Asymp. Sig.	.997	.000	.000	1.000	.960	.356	.000	.656	1.000

Table 3: *Chi square test.*

Phase 3: The researcher needed to rescale attribute values to fit in a specific range by using Normalization, this step is very important when dealing with attributes of different units and scales since all attributes should have the same scale for a fair comparison between them. In other words, normalization is a technique used to level the playing field when looking at attributes that widely vary in size as a result of the units selected for representation, Rapidminer is the software tool that is used for normalization.

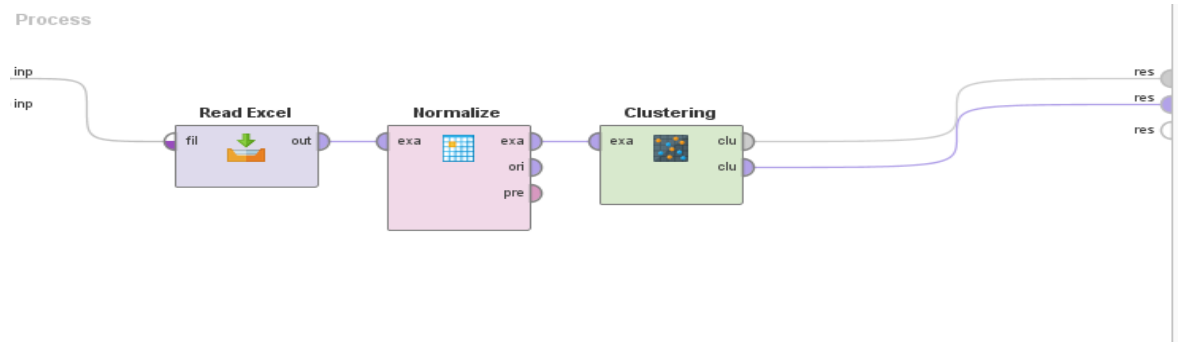

Figure 5: *Normalization steps, using RapidMiner.*

Phase 4: Clustering is concerned with grouping variables together that are similar to each other and dissimilar to the objects belonging to other clusters. Clustering using the k-means test was conducted using Rapidminer (a data science software platform).

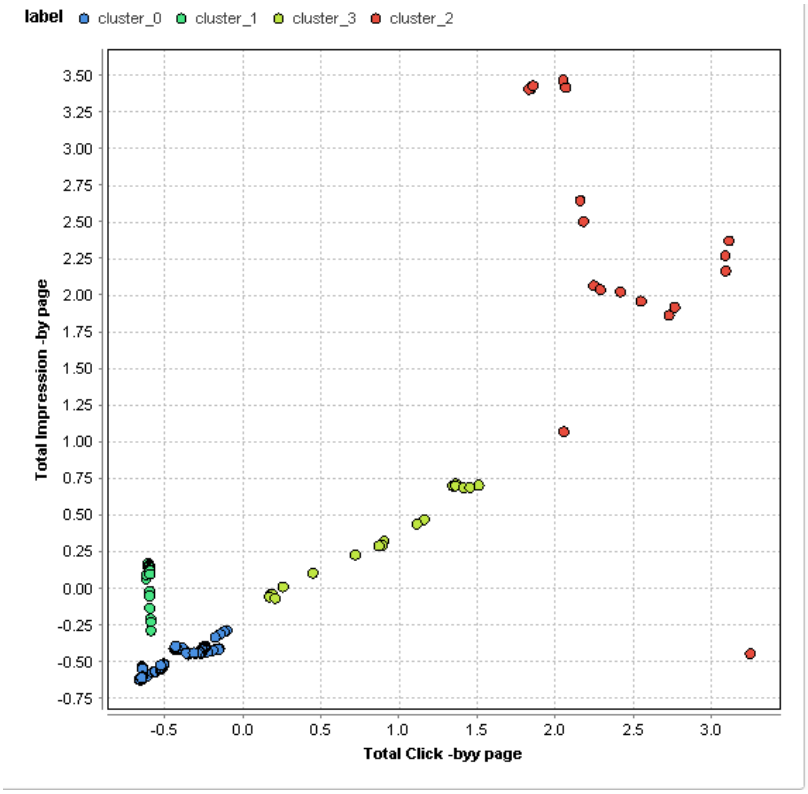

Figure 6: *using K-mean test to clustering variables by RapidMiner Tool.*

Phase 5: Correlation test: Table 4 presents the Pearson correlations between the total clicks and Links to site variables here are the significant correlations between total clicks and links to the site.

		v0	v4
v0	Pearson Correlation	1	-.056
	Sig. (2-tailed)		.454
	N	179	179
v4	Pearson Correlation	-.056	1
	Sig. (2-tailed)	.454	
	N	179	179

Table 4: *Correlation between total link and links to sites for all websites.*

The result of the correlation from the table is not significant.

		v0	v5
v0	Pearson Correlation	1	.787**
	Sig. (2-tailed)		.000
	N	179	179
v5	Pearson Correlation	.787**	1
	Sig. (2-tailed)	.000	
	N	179	179

**. Correlation is significant at the 0.01 level (2-tailed).

Table 5: *Correlation between total links and Google index for all websites.*

		v0	v6
v0	Pearson Correlation	1	.823**
	Sig. (2-tailed)		.000
	N	179	179
v6	Pearson Correlation	.823**	1
	Sig. (2-tailed)	.000	
	N	179	179

**. Correlation is significant at the 0.01 level (2-tailed).

Table 6: *Correlation between total links and crawl page for all websites.*

Phase 6: Linear Regression analysis is used to see if any additional information can be achieved. Table7shows the results of multiple regression analysis when links to the site, total index, and page crawl are analyzed towards the total click. The number of links to a site is excluded from the analysis because the metric is strongly correlated with both AVG page crawl and total index.

Model	R	R Square	Adjusted R Square	Std. The error in the Estimate
1	.787[a]	.619	.617	364.93848

a. Predictors: (Constant), v5

Table 7: *Liner regression Model Summary.*

These main research findings can be summarized as follows:

- Firstly, the answer to qualitative questions pointed out non-technical factors that affect the number of visits to websites more than other factors. Having an event (in the department for example) is considered non-technical.
- Secondly, the links to the site /backlinks do not exhibit a strong relationship with total clicks for the website.
- Thirdly, total index, AVG page crawl and AVG time spend is significant metric in this study.

CONCLUSION

The study aims to implement an effective process for education Web Ranking evaluation. The main research question for the thesis was to examine which web metrics are most closely connected with the total clicks of a website. The supporting research question was what the other factors that affect website visitors are. The research questions formed the basis for the research strategy followed in this thesis. The objectives of the case study were to identify a set of key web metrics that contain the most valuable information about site visitors and about the website itself.

The researcher decided to follow a mixed research strategy and collected data from primary resources (interviews) and secondary resources (page tagging and log server). The researcher examined nine web metrics Factors collected from ten websites during a period of three weeks. The study evaluated the relationships of the web metrics towards websites' Total clicks by using correlation and regression analyses. The results of the analysis showed a strong

correlation between total clicks for a website and the web metrics factors (total index factors, AVG -page crawl, AVG-time spend). Also showed a weak relationship with links to sites (backlinks). That means the factors related to the performance of websites and internal infrastructure have a great influence on website traffic as well as increasing website visitors. Another non-technical factor derived from Interviews such as events and activities in the university.

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ENERGY AND MATERIALS

PAPERS

SOLAR POWER FUTURES: BOTTOM-UP POWER

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Abstract
Puerto Rico is one of the most vulnerable places to natural hazards and every hurricane season the electrical infrastructure is threatened by a potential disaster. When Hurricane María crossed Puerto Rico in 2017 the devastation resulted in a power blackout that lasted 329 days and accumulated an estimate of Customer Hours of Lost Electricity Service (CHoLES) that exceeded three billion, causing an approximate of 3000 deaths. The last 200,000 customers reconnected to the electric grid spent between 156 and 329 days without power, accumulating almost one billion of the total three billion of CHoLES. While this vulnerability could be overcome with small photovoltaic (PV) systems deployed at a massive scale, various government-sponsored reconstruction plans do not include such an approach and favor transition to natural gas, utility scale solar and mini-grids instead at an estimated cost of USD 20 billion. This study provides the basis for an alternative way to invest focusing on alleviating the unequal access to electricity for the most vulnerable communities. The proposed bottom-up approach is the only one so far based on estimated consumption level data representative of the residential customers of Puerto Rico. It has the potential for short term action based on individual solar household systems that could include medium and long term planning to incorporate virtual power plants, nanogrids, and microgrids to decrease energy cost and improve electric energy reliability.

Keywords: Bottom-up Power, Census, CHoLES, Energy Justice.

ONLY THE ABSTRACT IS PUBLISHED IN 10TH ICAT PROCEEDINGS FOR THIS PAPER BECAUSE IT HAS BEEN SELECTED FOR PUBLICATION IN A SPECIAL ISSUE OF THE AFRICAN JOURNAL ON SCIENCE, TECHNOLOGY, INNOVATION AND DEVELOPMENT (AJSTID).

MICROALGAL BIOMASS AS BIOFACTORIES FOR THE PRODUCTION OF BIOENERGY AND BIOFUNCTIONAL COMPOUNDS FOR PHARMACEUTICAL APPLICATIONS

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Abstract
The synthesis of neutral lipids and unique bioactive compounds from microalgae is key to the successful commercialization of microalgal-based value-added products and biofuels. The low yield of microalgal bioproducts is exacerbated by the selection of unsuitable microalgal strains and suboptimal growth conditions. A robust indigenous Chlorella vulgaris strain was isolated from a wastewater treatment plant in Durban, KwaZulu-Natal, South Africa, and purified to monoculture. The purified isolate was propagated in a laboratory-scale bioreactor. Optimal growth conditions were manipulated for maximal microalgal growth and synthesis of neutral lipids. This study aimed to optimize C. vulgaris growth conditions for the production of long-chain neutral lipids (14 to 22 carbons). A one-factor-at-a-time approach was adopted for the optimization of key growth variables. The optimized growth conditions were light intensity (111 µmol m^{-2} s^{-1}), $NaNO_3$ (1.5 g/L), and photoperiod (24h:0h/light:dark), which produced the highest biomass (225 mg/L), presence of neutral lipids, and desirable growth kinetics. Proteins were quantified by the Bradford assay, yielding 1.39 mg/mL of total proteins and qualitatively detected by SDS-PAGE. Carbohydrates and reducing sugars were quantified by the Anthrone and the 3,5-dinitrosalicylic acid (DNS) methods, yielding 1.87 mg/mL and 0.57 mg/mL respectively. Biochemical analysis of microalgal biomass revealed 27% (w/w), 23% (w/w), and 38% (w/w) of proteins, carbohydrates, and lipids respectively. The detection and preponderance of neutral lipids were confirmed by Nile red staining and qualitatively by thin-layer chromatography (TLC). The neutral lipids were also detected by gas chromatography-mass spectrophotometry (GC-MS) and quantified gravimetrically. Transmission electron microscopy showed dramatic accumulation of lipid globules due to nutrient starvation of the cells. The study established optimal growth conditions for C. vulgaris and also evaluated the suitability of the neutral lipids for biodiesel production. The dominance of PUFAs demonstrates the suitability of these oils for biodiesel production and as value-added products for pharmaceutical applications.

Keywords: Bioenergy, Biofunctional, Microalgae, Neutral lipids, Polyunsaturated Fatty Acids.

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RENEWABLE ENERGY ALGORITHM TOOL FOR RURAL ELECTRIFICATION AND APPROPRIATE TECHNOLOGY

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Abstract
Estimating an appropriate cost-effective sizing of photovoltaic (PV) and battery energy storage system (BESS) for a residence, business or microgrid without a proper thorough analysis of the energy dynamics involved, can lead to the expensive risk of installing an oversized or undersized system. Lack of understanding of detailed performance expectations can lead communities to be dissatisfied with the Solar PV+BESS. Furthermore, generation versus end-load dynamics can pose a challenge for utilities to predict, as PV and BESS systems increase their presence within the electric power grid. This paper proposes a modeling tool, the Renewable Energy ALgorithm Tool for Rural Electrification and Appropriate Technology (REAL-TREAT), that explores the most cost-effective options for both single renewable energy systems (RES) and microgrids. The proposed methodology provides projected hourly performance for a PV+BESS in a year, considering estimated hourly load and solar data. The year-long hourly energy dynamic model provides an approximate range of cost-based PV and BESS component sizing, centered on the local utility rate per kilowatt-hour cost ($/kWh) and a nominal interest rate for monthly annuity financing. The proposed methodology has been used in a co-design project with a rural community exploring energy alternatives with a special interest in microgrids. Its applicability in communities of Eastern Africa is explored. Results yield detailed year-long hourly energy dynamics data that can be of use to both electric utilities and end-load consumers. It allows utilities to approximate magnitude and time periods of energy exchanges between the electric grid and RES serviced end-load customers or microgrids, whilst providing enough energy and financial data for communities to explore energy consumption management strategies and make the most cost-effective investment. The data that REAL-TREAT makes available can help users to better estimate RES sizing, provide utilities with reliable data for power-flow exchange, and allow for energy resilient community empowerment.

Keywords: Hybrid power sources, renewable energy system sizing, energy dynamics, renewable energy system financing, energy resiliency empowerment.

INTRODUCTION

Affordable access to electric power has been paramount in the integration of societies and communities. For many it has become a life-sustaining commodity that should be recognized as a human right. Yet not all have access to electric utility power, and many have access but do not have a reliable nor affordable source. As utilities around the world shift their attention towards producing energy from renewable sources to meet their electric demand (IEA, 2021), US government agencies predict a reduction in fossil fuel reliant energy with an increase from renewable sources (U.S. Energy Information Administration, 2021). Although renewable sourced electric power generation may mitigate the impact that fossil fuel volatility may have over electric utility prices on the long run, having said generation remain centralized may not improve reliability for vulnerable electric power grids where many susceptible communities

depend on the degree or lack of maintenance and restoration efforts utilities give to their infrastructures, keeping said communities vulnerable against extraordinary social, atmospheric, or telluric eventualities.

For example, lack of maintenance left Puerto Rico's centralized electric power grid susceptible to atmospheric and telluric phenomena, contributing to the longest power blackout in the island's history following hurricanes Irma and María in 2017, (Castro-Sitiriche, Cintrón-Sotomayor, Gómez-Torres, 2018). The catastrophic damage dealt to the island's electric transmission and distribution systems inhibited the recovery of nearly all the island's water and sanitation, telecommunications, and healthcare infrastructures, amongst others (Kwasinski, Andrade, Castro-Sitiriche, O'Neill-Carrillo, 2019). Inadequate federal and local government response, sluggish supply chain and recovery personnel logistics, and government-imposed budget cuts also slowed restoration efforts (Lopez-Cardalda, et al., 2018). Ensuring energetic resiliency for all of the island's inhabitants became a paramount objective, with multi-sectorial studies leaning towards decentralizing the electric power grid into various microgrids fed by roof-top and/or utility scale renewable energy systems (Sandia National Laboratories, 2018).

As communities or individual consumers seek to supply their electric power demand outside centralized utility infrastructures, through renewable energy systems (RES), oftentimes they are met with prices that can be financed by the most affluent members of our societies yet remain prohibitive for low-to-moderate income communities. To this we can include different technical factors that may cause improper and/or uneconomic RES component sizing, aggravated by current industry practices that ignore key economic factors when leveling out costs when determining the net value of said proposed systems.

To facilitate RES design and reduce the chance of component sizing estimation errors, various solutions that undertake hourly assessments of generated energy and end-load power consumption have been implemented. The U.S. National Renewable Energy Laboratories (NREL) currently offers two open access models for said purpose: the System Advisory Model (SAM), designed for residential/commercial RES and power purchase agreement (PPA) modeling (NREL, 2018) and the Engage Energy Modeling Tool that allows for multi-sector energy generation and transmission, along with economic dispatch planning (NREL, s.a.). A solution available in the market is the Hybrid Optimization of Multiple Energy Resources (HOMER) software (HOMER Energy, s.a.), originally developed by NREL to assist in the design of micropower systems and compare different power generation technologies (Lambert, et al., 2006). From solar/grid laboratory scale microgrid life-cycle cost analysis (Gandhi, et al.,2016) to optimization and sensitivity analysis (Makwana, et al.,2019), solar/biomass optimization (Gautam, et al.,2018), solar/grid/diesel generator optimization (Nikhilesh, et al.,2020), including solar/wind/battery/fuel cell economic analysis (Rohani, et al.,2010), HOMER software has been used for many hybrid energy source case studies. The problem behind these highly instrumental multiple scale RES design solutions is that they require their users to possess extensive specialized technical training, making them inaccessible to lay people and communities without trained technical professionals.

This paper offers an algorithmic framework to help users determine the cost-based sizing of RES components needed to supply end-load demand within predefined scenarios, estimating $/kWh equivalency at any scale, providing valuable economic approximations for communities and would-be prosumers, with useful technical information for utilities and industry professionals.

METHODOLOGY

The proposed algorithmic model, the *Renewable Energy ALgorithm Tool for Rural Electrification and Appropriate Technology* (*REAL-TREAT*), is designed to provide any user with the necessary information for the most cost-effective RES component sizing, in a straightforward manner (See Figure 1). Predicting year-long hourly estimations of energy or power flow dynamics, between single source or hybrid combinations of PV, wind, auxiliary generator, and/or utility generated AC power tied with BESS supplied power, against a measured or estimated end-load, it allows for economic forecasts that can point towards any desired level of cost-efficiency, requiring a minimum number of inputs and assumptions within a constrained window of iterations.

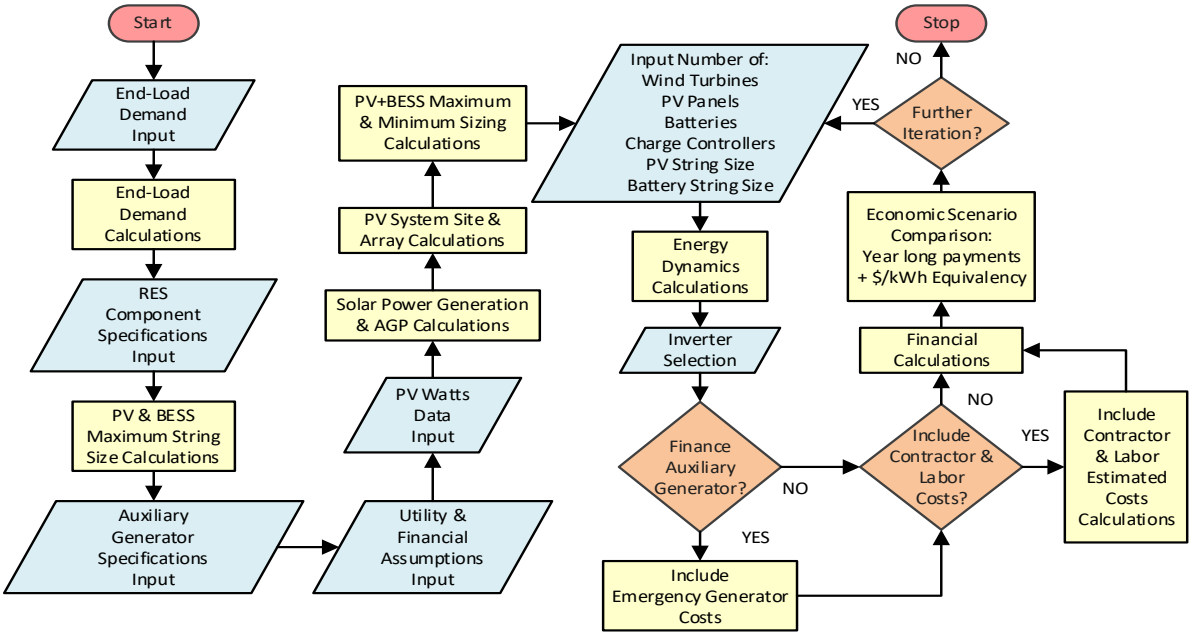

Figure 1: *REAL-TREAT Operational Flowchart.*

Input Requirements

The model does not require in-depth electrical training but requires the user to have some degree of electrical knowledge, such as where to find equipment specifications, provide measured or estimated end-load consumption, and input potential or measured solar and wind power generation data for the chosen site. The European Union's open-access PVGIS application (EU Science Hub, 2022) or NREL's PVWatts Calculator web-based application (NREL, 2021) can provide such data. The user must also make certain assumptions or assume the defaulted values, such as the local electric utility rates and price of fuel for auxiliary generator supply comparisons. The model allows expert technical users to change default values such as the point of common coupling (PCC) voltage, power factor (PF) and annual interest rates for financial calculations.

The model is designed with default preset scenarios composed of different power sources schemes or a hybrid combination of those (e.g., grid tied, stand alone, bi-modal) that will ultimately supply the end-load demand. Each scenario is financially compared against total demand supplied by an electric utility or an emergency generator scenario for long-term power blackouts.

- *Scenario 1* - End-load demand supplied by utility generated power.
- *Scenario 2* - End-load demand supplied through an emergency generator.

- *Scenario 3* - End-load demand supplied by grid-tied RES without BESS, no net-metering.
- *Scenario 4* - End-load demand supplied by grid-tied RES without BESS, with net-metering.
- *Scenario 5* - End-load demand supplied by stand-alone RES system, until BESS's state of charge (SOC) falls below the selected depth-of-discharge (DOD), and the utility supplies end-load demand while the RES generation recharges the BESS above the DOD.
- *Scenario 6* - End-load demand is supplied by a stand-alone RES, until BESS SOC falls below DOD, emergency generator supplies load demand and recharges BESS above DOD.
- *Scenario 7* - End-load demand is supplied by a stand-alone RES, until BESS SOC falls below DOD, and utility supplies both end-load demand and recharges BESS above DOD.
- *Scenario 8* - End-load demand is supplied by a bi-modal RES with a net-metering contract.
- *Scenario 9* - End-load demand is supplied by a stand-alone RES, until the BESS SOC falls below the selected DOD, and an emergency generator supplies the end-load demand while RES generation recharges the BESS above the DOD.

Model operation

REAL-TREAT can calculate to meet demand in the most cost-efficient manner, by estimating the power flow dynamics between input hybrid combinations of renewable power sources and their components with the end load, under specific considerations.

End-Load Demand

Complex power sizing – Although PV systems and BESS's are rated and expressed in active power magnitudes (e.g., W, kW, kWh) and utilities generally charge customers for kilowatt-hour consumption, most loads consume complex power (VA, kVA, kVAh). In other words, they require active, reactive, and sometimes distortion power to operate. RES's convert the active power supplied by a PV+BESS into complex power through inverters to supply complex loads. All measured or estimated power consumption must be expressed as complex power. If complex power measurements are not available, a power factor (PF) must be assumed and applied. The default (PF) in REAL-TREAT is 0.9 and 0.85 for residential and commercial/industrial loads respectively. All operations in this model, particularly the Energy Dynamics calculations, are performed with complex power values (kVA) to reduce improper sizing error.

Averaged daily consumption –This is averaged for a 24-hour period with the measured or calculated complex power. For example, in 7 days of measured hourly consumption, every single hour within the daily 24-hour period should be averaged, to better estimate daily real and complex power consumption. This is useful when normalizing a demand curve for consumption estimation.

Impedance Calculations – Impedance can be calculated with complex power values and PCC voltage, whose default is 120 VAC. Most users will not use this feature, although this is particularly useful for specialized technical studies and impedance-based solution comparisons.

Maximum Demand – The hour in which maximum energy consumption, and approximate maximum current with a 1.25 continuous current factor. (García-Cooper, Castro-Sitiriche, 2022)

RES component string size

Component specifications are necessary to calculate system size, energy generation, storage, and power flow calculations for the model to identify the maximum BESS string size and calculate maximum PV string sizes, providing both the maximum number of PV and BESS units that can be connected in series and the maximum number of series strings that can be connected in parallel, to lessen the risk of malfunction. (García-Cooper, Castro-Sitiriche, 2022)

Solar Generation Data

Solar power generation – When entering potential or measured solar irradiance and AC generation input data, the magnitudes must correspond to a 1 kW peak (kWp) PV system design and cover the 8760 hours of the year. If the desired system is larger than 1kWp, the magnitudes are multiplied by the system's size. For example, if a 1 kWp PV system in a particular site can generate up to 4.35 kWh in an average day, then in that same site a 5 kWp PV system should generate up to 21.78 kWh under the same conditions. With the hourly irradiance and AC generation data, daily generated power can be calculated throughout the year, allowing the user to identify the days where both the least and most amount of energy is estimated to be generated per month and year, allowing to categorize each day for the PV and BESS recommended sizing algorithms. The daily generation mean must be calculated at this point.

Accumulated Generation Probability (AGP) Table – Our paper proposes an Accumulated Generation Probability (AGP) algorithm to reduce the number of iterations necessary to attain the desired sizing. Daily measured AC generation for a 1 kWp PV system is divided in 25 categories or ranges *(Table 14*, García-Cooper, Castro-Sitiriche, 2022*).* Once established, the number of days that generated an amount of energy equal to or within the high and low limits of each category are counted. With daily PV generation sorted into categories, the number of days per category are accumulated to calculate the AGP up to that category. *(*García-Cooper, Castro-Sitiriche, 2022*).*

PV System Site & Array Calculations – The area in which the system is to be installed should be surveyed, measured, and adjusted to national or international electrical codes. Row separation calculations must be performed, depending on the module tilt whose default angle is 20° (Dunlop, 2012), and the maximum number of PV modules within the measured area should be determined (García-Cooper, Castro-Sitiriche, 2022). The user can apply a shading analysis method, provided by Solar Pathfinder or other solutions (Solar Pathfinder, 2022). Some sites lack adjacent structures or flora that can cast shadows on the PV modules, not requiring a shading analysis. Should any shading falling on part of the PV array will cause generation reduction. The model provides a simple site shading analysis method, where the affected area is entered for the months that will yield less generation during the year. (García-Cooper, Castro-Sitiriche, 2022).

Maximum and minimum PV sizing recommendations – For maximum and minimum PV modules, a preliminary starting point is calculated by dividing the average daily consumption with the daily year-long PV generation mean (García-Cooper, Castro-Sitiriche, 2022). The high and low values of the AGP Table are adjusted to the preliminary sizing by multiplying said high and low values to the starting point. Once the AGP table limits have been adjusted, the recommended PV sizing is determined. The recommended AGP starting point requires the z-

values for each daily generated kWh and number the days that fall within one standard deviation from the mean (-σ > z > σ), representing the targeted percentage of days per year (García-Cooper, Castro-Sitiriche, 2022). Once the PV system sizing has been established, said value will be the recommended maximum and the minimum can now be calculated (García-Cooper, Castro-Sitiriche, 2022).

Maximum and minimum BESS sizing recommendations –BESS sizing can be established by determining the hourly RES generation of a particular day and the difference between the average daily end-load. The maximum recommended storage needs must be equal to the value corresponding to the recommended AGP (García-Cooper, Castro-Sitiriche, 2022).

Energy dynamics – As the user inputs the desired number of RES components, the selection will output specific year-long hourly power flow estimations (see Figure 2). The first intrinsic parameter is the RES generated AC complex power estimate that can be composed of wind turbine generated power and/or PV generated power (García-Cooper, Castro-Sitiriche, 2022). The generated AC power calculations can be estimated if the user has access to any year-long solar and wind estimates of the site area, as provided by PV GIS, PV Watts, or other software. The complex end-load demand must either be measured or estimated throughout the whole year. If the measured end-load demand consists of one day, the same must be repeated 365 times. If the measured end-load demand is of 7 days, the same must be repeated 52 times, and so forth. Through this, the net complex power flow can be calculated. In essence, AC generation and end-load consumption are the cornerstones that will allow the calculation of all year-long power flow parameters that will ultimately facilitate proper RES sizing and comparative cost-effectiveness analysis, such as:

- RES Generation Supplied Load
- Available DC Energy for BESS Charging
- Load not supplied by the RES Generation
- Unused RES Generated AC Energy
- BESS Power Flow Dynamics
- BESS Supplied Load
- Load not Supplied by RES to be supplied by alternate power source

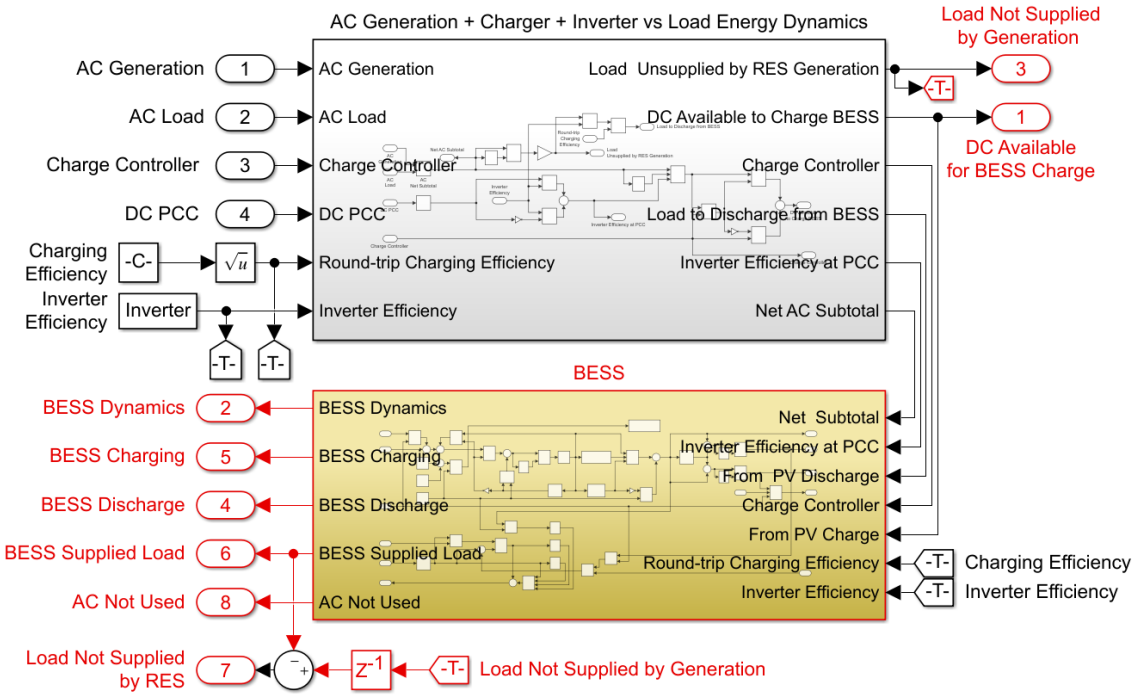

Figure 2: *REAL-TREAT Energy Dynamics I/O Simulink Schematic.*

Inverter selection – Inverter sizing should meet both the maximum hourly estimated AC power generation throughout the year and the maximum end-load demand, applying a 1.25 continuous current safety factor.

Financial Calculations –RES component costs must be financed at a user defined interest rate via a ***present worth of annuity*** calculation **(*P/A, i%, n*)**. The construction material costs are also estimated and added to the principal estimates, in proportion to the RES component sizing. The user can define the number of years that each component or category is to be financed. The default value for batteries, MPPT's, inverters and auxiliary generators (optional) financing is 10 years, while the PV modules and construction financing has a default of 20 years. The model also has the option to include contractor and labor costs in the construction financing. The economic analysis for each scenario will be defined as follows:

- *Scenario 1* – Average consumption $/kWh per utility rate is projected for month, and year.
- *Scenario 2* – Average consumption and $/liter of fuel or $/lb. of gas consumed by a generator to supply said demand is projected for month and year.
- *Scenario 3* – A monthly annuity payment provided for the selected RES sizing plus any monthly $/kWh payments made for utility energy consumption that the RES could not supply.
- *Scenario 4* – A monthly annuity payment is provided for the selected RES sizing plus added monthly $/kWh payments and/or credits made to/by the utility for net AC energy.
- *Scenario 5* – A monthly annuity payment is provided for the selected RES sizing, added to monthly $/kWh payments made for utility energy consumption needed for unsupplied load.
- *Scenario 6* – A monthly annuity payment is provided for the selected RES sizing, added to monthly payments for $/liter of fuel or $/lb. of gas consumed by emergency generator that provides for both unsupplied load and BESS recharging.
- *Scenario 7* – A monthly annuity payment is provided for the selected RES sizing, added to monthly $/kWh payments made for utility energy consumption needed for unsupplied load and BESS recharging.
- *Scenario 8* – A monthly annuity payment is provided for the selected RES sizing, added to monthly $/kWh payments and/or credits made to/by the utility for the amount net AC energy.
- *Scenario 9* – A monthly annuity payment is provided for the selected RES sizing, added to monthly payments for $/liter of fuel or $/lb. of gas consumed by an emergency generator that provides for unsupplied load.

RESULTS AND DISCUSSION

REAL-TREAT was originally designed to estimate the RES component sizing and associated costs for microgrids in the remote community of Castañer, Puerto Rico. Validated in Excel and Simulink, the model was applied for several case studies in different geographical areas.

Case study: Single-Family Residence in Kassala, Sudan

Estimated end-load data of day-long hourly measurements with an average monthly consumption of 276.4 kWh compared to year-long hourly solar data, along with RES equipment specifications, yielded an AGP table in accordance with the typical meteorological year (TMY) data provided by PV GIS for Kassala. For example, if a 1 kWp PV system is estimated to generate between 2.57 and 2.44 kWh in one day during a 365-day period. That same system is estimated to generate between 5.15 and 5.28 kWh per day for 50 days throughout the year. That means said system should generate a daily amount of AC energy equal to or between 5.28 to 1.02 kWh for 318 days throughout the whole year or an AGP of

86.30%, with a 74.48% probability of generating between that window for two days in a row, up to seven days in a row. Table 1 yields sample days taken throughout the year, within AGP categories. It is important to stress that the values may drastically change if a shading analysis is applied (García-Cooper, Castro-Sitiriche, 2022).

PV Generation for 1 kWp PV System	kWh/day	PSH	PV GIS TMY Date
Maximum	5.638	7.70	2/19/2019
< = 90% AGP	5.291	7.51	4/24/2013
< = 80% AGP	5.026	7.32	4/2/2013
< = 70% AGP	4.969	7.13	5/6/2015
< = 60% AGP	4.874	7.04	11/1/2015
< = 50% AGP	4.841	6.83	9/1/2013
< = 40% AGP	4.686	6.60	9/4/2013
< = 30% AGP	4.391	6.41	9/22/2013
< = 20% AGP	4.123	5.85	8/28/2012
< = 10% AGP	3.614	5.03	8/22/2012
Minimum	2.442	3.40	7/11/2007
Mean	4.806	5.74	Calculated

***Table 1**: Sample Days of AC Generation and Peak Solar Hours (PSH) per AGP Category.*

After applying the preliminary PV sizing starting point to the AGP table, the first step towards the recommended PV sizing is determined with the percentage of days that generated AC power within a standard deviation of the mean, being 79.5% rounded to the nearest tenth. This 80% will be used for the BESS sizing, while the PV sizing is determined by $(1 - AGP)$, or 20% (see Table 2). Maximum and minimum RES component starting points with maximum string sizes are yielded in Table 3, whilst Table 4 displays the final user-defined component sizing, within AGP recommended limits. (García-Cooper, Castro-Sitiriche, 2022)

	AGP	PV System kWp	BESS kWh
Preliminary PV Sizing Starting Point		**2.01**	
Recommended PV Sizing for AGP <= 10%	10%	2.38	10%
Recommended PV Sizing for AGP < = 20% of Year	**20%**	**2.18**	20%
Recommended PV Sizing for AGP of < = 30% of Year	30%	2.12	30%
Recommended PV Sizing for AGP of < = 40% of Year	40%	2.06	40%
Recommended PV Sizing for AGP of < = 50% of Year	50%	2.01	50%
Recommended PV Sizing for AGP of < = 60% of Year	60%	1.95	60%
Recommended PV Sizing for AGP of < = 70% of Year	70%	1.95	70%
Recommended PV Sizing for AGP of < = 80% of Year	80%	1.91	**80%**
Recommended PV Sizing for AGP of < = 90% of Year	90%	1.86	90%

***Table 2:** Recommended PV and Storage Sizing per AGP Value.*

Recommendations	Maximum	Minimum	Max Series String Size	Max Parallel String Size	Max PV Modules for Site
PV Modules Starting Point	6	3	3	5	31
BESS Units Starting Point	4	2	4	4	

***Table 3**: Recommendations and limits for sample family residence in Kassala, Sudan.*

User Defined Number of Components		Per Residence	Calculated User Defined RES Size		
Number of Wind Turbines	**0**	0	Wind Turbine	0	kW
Number of PV Modules	**6**	6	PV	2.58	kW
Number of Batteries	**2**	2	BESS	7.68	kWh
Battery Bank Chargers	**1**	1	PV Strings	2	
Chosen PV Series String Size	3	-	Battery Parallel Strings	1	
Chosen Battery Series String Size	2	-	Batteries per MPPT	2	
Number of Emergency Generators	**1**	1	Emergency Generator	2	kW
Component & Construction Principal Costs (without Emergency Generator)				**$8,900.00**	

***Table 4**: User defined component selections for sample family residence in Kassala, Sudan.*

The model will calculate the approximate principal costs of the chosen RES component sizing, including an estimate of construction materials needed to install them (García-Cooper, Castro-Sitiriche, 2022), to illustrate how much a consumer would have to pay to supply end-load demand under the different scenarios, compared to how much would be paid to a utility for the full supply of end-load demand. Each component sizing iteration will change annuities in proportion to changes in the present principal costs. For this study, the most cost-efficient scenario would be the 5th scenario for an RES composed of 6 PV modules, 2 LiFePO batteries, 1 MPPT charge controller, 1 3 kW inverter and construction materials estimate. Since some utility power grids have a higher degree of uncertainty and/or lack of reliability than others, a financial comparison alone may not yield enough information for the user to weigh in said uncertainty (See Table 5). Power flow data can further facilitate decision making (See Table 6).

Scenario	Annual Costs	Monthly Costs	Differential to Utility	$/kWh
1 – Utility Connected (Assumed $/kWh Rate)	$665.20	$54.67	$0.00	$0.21
2 – Emergency Generator	$10,400.00	$900.00	$846.00	$3.28
3 – PV+W grid tied to Utility - No Net Metering	$700.00	$60.00	$6.00	$0.22
4 – PV+W grid tied to Utility - Net Metering	$300.00	$30.00	($25.00)	$0.09
5 – PV+W+ BESS with Utility Back-Up for Load	$1,100.00	$84.00	$30.00	$0.35
6 – PV+W+ BESS with Aux. Gen. Back-Up Load + BESS Recharge	$1,100.00	$87.00	$33.00	$0.35
7 – PV + Wind + BESS Stand Alone + Utility Back-Up for Load + BESS Recharge	$1,100.00	$84.00	$30.00	$0.35
8 – PV + Wind + BESS Bi-Modal Net Metering	$1,000.00	$84.00	$30.00	$0.32
9 – PV + Wind + BESS Stand Alone + Auxiliary Generator for Load	$1,300.00	$102.00	$48.00	$0.41

***Table 5**: Economic Comparison Under Different Scenarios.*

Scenario	Excess PV AC Not Used (kWh)	Excess PV AC Not Used (Hours)	Average AC Not Used (kWh)	Aux Gen. supplied Load (kWh)	BESS SOC<(1-DOD) (Hours)
5 – PV+W+BESS with Utility Back-Up for Load	1,051	0.80	1,310	27.09	**129**
6 – PV+W+BESS Stand Alone + Aux. Gen. Back-Up for Load + BESS Recharge	1,057	0.80	1,322	5.82	**18**
7 – PV+W+BESS Stand Alone + Utility Back-Up for Load + BESS Recharge	1,059	0.80	1,323	36.86	**12**
9 – PV+W+BESS Stand Alone + Auxiliary Generator for Load	1,051	0.80	1,310	23.18	**105**

***Table 6**: Power Flow Comparison Under Different Scenarios.*

Unused energy can be sold to utilities or Peer-to-Peer contractual agreements, while auxiliary supplied load can be purchased from a third party or supplied by the user from back-up scenarios. The hours where the BESS's SOC is under the DOD can indicate the time that auxiliary generated energy would be needed and help determine the probability of a blackout. In our case study, the most cost-effective scenario seems to be a stand-alone PV+BESS that uses the electric utility as a back-up when the BESS SOC would reach the user-defined depth of discharge or DOD. But if the user has no access to electric power through a utility, a small 2kW emergency generator can supply load in times where the BESS reaches the DOD. The approach is still more cost-effective than supplying year-long demand with either an RES or an emergency generator alone.

The following table (See Table 7) represents the energy that a utility does not have to produce, to later transmit, either because the user is supplying the end-load or because the user is providing energy to neighboring parties in the utility electric power grid. The avoided generation costs can be calculated with average utility electric power generation, average fuel consumption, and fuel costs. In the example shown, we have calculated the utility's cost of $0.116 per kWh generated. With transmission and distribution impedances, the avoided costs to transmit the energy could also be ascertained but said power losses are beyond the scope of the present model.

Utility Avoided Costs	Hourly Average kWh	Hourly Avoided Costs	Hours Supplying (FOR / TO) Utility	Annual Avoided kWh	Yearly Avoided Cost	Avoided $/h
Load Not Having to be Supplied by Utility	0.18	$0.02	8,631	1,582	$182.88	$0.02
Generation Received by PV+BESS	0.72	$0.08	1,310	946	$109.35	$0.01
Totals			**9,941**	**2,528**	**$292.23**	**$0.03**

***Table 7:** Utility Avoided Generation Costs.*

Year-long AC Generation Estimates

Through the model, year-long energy generation estimates can be projected with PVGIS, PVWatts or data provided by analogous solar energy production software, yielding detailed energy generation figures that can be of great aid to industry professionals. (See Figure 3)

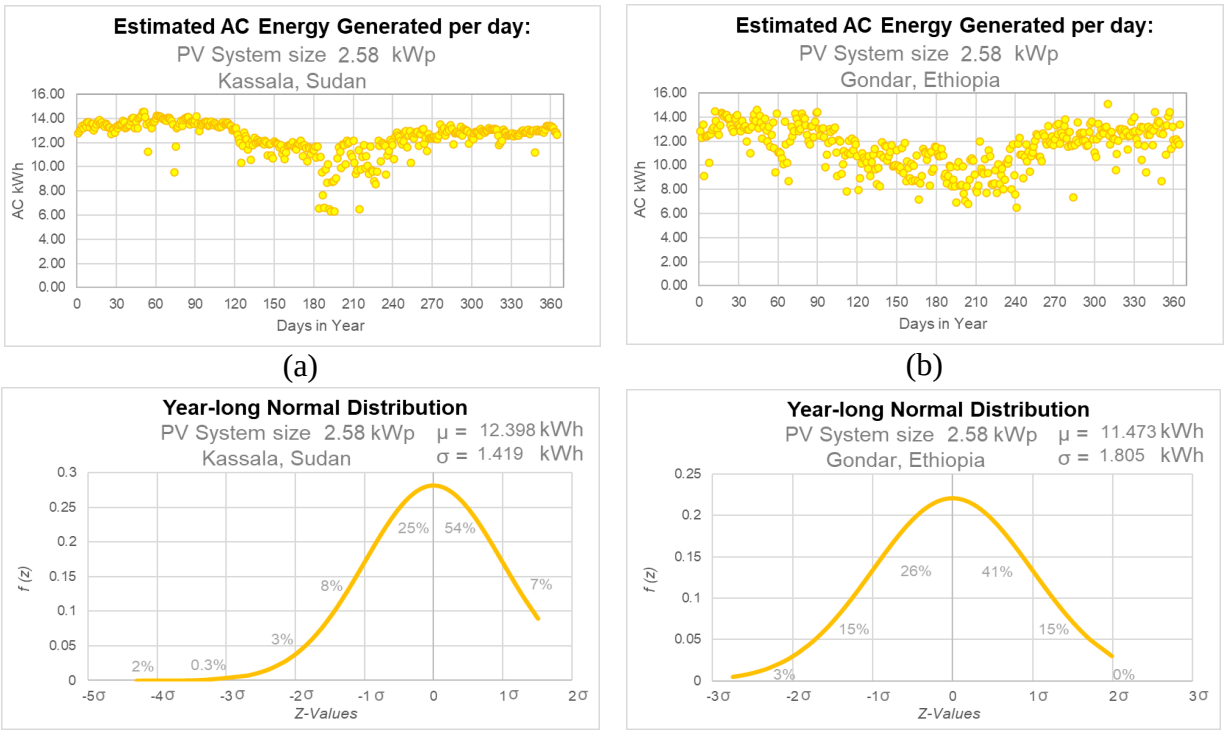

Figure 3: *Solar Generation potential between (a, c) Kassala, Sudan & (b, d) Gondar, Ethiopia.*

Energy Dynamics Estimates

Based on BESS AGP equations, the model provides detailed hourly illustrations of the BESS charge/discharge dynamics, hourly BESS SOC and provide estimates of when the user will need to consume third-party energy or when the user can provide energy to the auxiliary energy supplier (See Figure 4). These projections can be of great value to utilities, as they can predict the time window where additional generation should be supplied and/or reduced minimizing the need for peakers or unnecessary stand-by generation. (García-Cooper, Castro-Sitiriche, 2022).

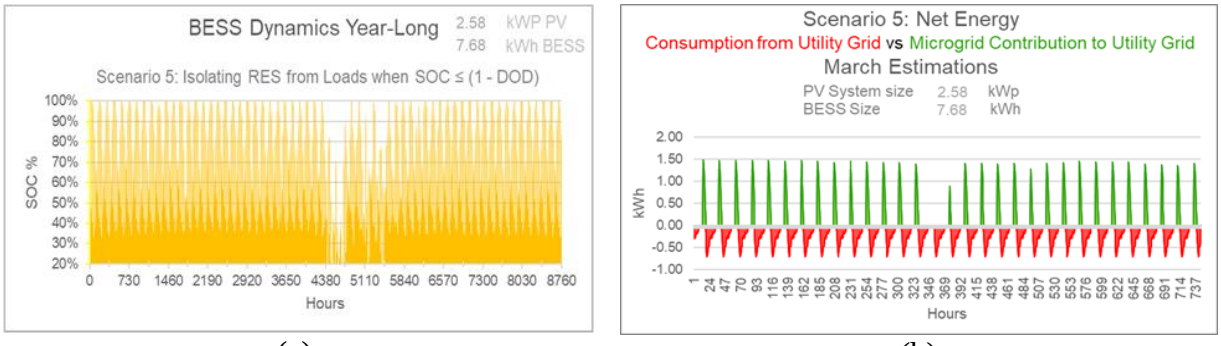

Figure 4: *(a) Year-long BESS SOC & (b) Net Grid Consumption vs Contribution Dynamics Case Study: Kassala, Sudan.*

CONCLUSION

This paper proposed an algorithmic model that helps users determine the cost-effectiveness of a renewable energy system (RES) with a minimum number of iterations regardless of any background technical preparation and sizing, reducing the amount of time needed for detailed site analysis, while comparing different scenarios of single or hybrid power sources supplying end-load, providing useful hourly information for utilities and industry experts. A case-study detailed the number of RES components that represented the least amount of investment and monthly annuity payments, compared to sole utility electric power supply amongst other scenarios. The study displayed the effect a shading analysis can have on RES component sizing, proportionally affecting any financial analysis. Wind turbine generation was not cost-effective and was discarded.

The REAL-TREAT model has been employed in single-residence, multi-residential, microgrid and statewide demand studies. The model can enable communities to access life-sustaining electric power, by better estimating the size of the renewable energy system that most cost-effectively meets their electric consumption needs. Future work involves automated inverter selection, experimental field application and on-site metering.

ACKNOWLEDGEMENTS

This work was funded, in part, by the Economic Development Administration project award #:01-79-14864 and a grant by the Environmental Defense Fund. The authors thank UPRM professors Agustin Irizarry and Fabio Andrade for their feedback on the early versions of the REAL-TREAT model.

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REAL ENVIRONMENTAL PROBLEMS REQUIRING REAL SOLUTIONS: THE DEVELOPMENT AND APPLICATION OF INNOVATIVE BIOMATERIALS IN NEW PRODUCT DEVELOPMENT WITHIN INDUSTRIAL DESIGN EDUCATION

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Abstract
Industrial Designers develop physical manufactural products intended for production, and the purpose of these products is to satisfy a need or solve a problem. Ironically these products end up creating more problems than the single problem they may have intended to solve, and their end-of-life is not considered in their inception. In order to empower Industrial Design students and equip them with sustainability tools as part of their skillset, annually the student group are tasked with a project where they undertake material experimentation and development as a first step of their product design process. As opposed to utilising readily available materials, they are tasked with creating their own, with a focus on the sustainability of their material and its ability to break down effectively or suit re-use once the product has reached the end of its life. This is then followed by problem identification, where students find evident environmental problems caused most often by decisions regarding material specification. They then undertake a product development process where a final proposed design outcome is prototyped as much as possible from their own developed material. This paper will present a selection of these projects, where the outcomes were able to be presented to the South African Plastics Pact which is a collaborative pre-competitive initiative that brings together key stakeholders from the local plastics value chain. This has allowed for links and partnerships to be created directly between students, and large industry. One of the presented projects has sparked interest with one of the largest retailers across Southern Africa servicing over 850 stores nationwide and will be taken further as an industry-university collaboration. This groundwork has allowed for future projects to align directly with industry from the start, and students can engage with industry key players in developing appropriate solutions.

Keywords: Sustainability, Industrial Design, Product Design, Biomaterial, Product Life Cycle.

INTRODUCTION

Industrial Designers develop physical manufactural products intended for production, and the purpose of these products is to satisfy a need or solve a problem. The definition of Industrial Design, from the World Design Organisation is as "… a strategic problem-solving process that drives innovation, builds business success, and leads to a better quality of life through innovative products, systems, services, and experiences." (WDO, 2022). At the Department of Industrial Design (Specifics ommitted for peer review) students learn how to develop solutions to problems through the effective application of design thinking, and the Industrial design process. These solutions are intended for various scales of manufacturing, relying on available and applicable manufucturing process and materials. The goal is to satisfy a need or solve a problem, more often than to satisfy a need or solve a problem, more often than not with the thinking that the solution is designing more products to stimulate more manufacture (Figure 1.)

***Figure 1**: Industrial Design student setting up an exhibit of products. Photo by author.*

Ironically these products end up creating more problems than the single problem they may have intended to solve, and their end-of-life is often not considered in their inception as illustrated in Figure 2.

***Figure 2**: Plastic pollution in 2019 cost South Africa staggering R885bn (Mail & Guardian, 2021).*

At the Department of Industrial Design, University of Johannesburg, students are annually undertaking a project entailing not only the designing of a product intended for manufacture, but they are also tasked with developing the materials used within the product composition. This allows them to understand the inputs required in generating required material for manufacturing their product, as well as understand the amount of waste generated through this process. There is a considerable number of new advancements in sustainable materials, and this paper illustrates the attempts to integrate it effectively into the design education curriculum. The purpose of this paper is to present an ongoing student project undertaken with the Industrial Design students and the relevance of teaching sustainable material considerations to design students.

LITERATURE REVIEW

When it comes to products and the production thereof, there are material inputs, and processing inputs. The lifespan of the products is also a consideration, as outlined in an article titled *Green Raw Material & Product Preservation*, the extended lifespan of products needs to be considered to allow them to be shipped, stored, purchased by consumers, and used in their

entirety before concern of product spoilage, or its end of life (Yarnell, A., S. Foster, J. Rabiei, and J. Blankenship. 2021). There are methods and tools of assessing the life cycle of products, an effective application of this being undertaken in my home city being *the Life cycle assessment of single-use and reusable plastic bottles in the city of Johannesburg* (Olatayo, Mativenga, & Marnewick: 2021). The outcome was that the for both bottle types, the production phase had the highest impact, followed by the use phase and then the disposal phase. It was recommended that manufacturers of reusable bottles should focus on reducing the environmental impact of manufacture and extended producer responsibility for, particularly, end-of-life waste management. How are industrial design students prepared to assist in solving these problems? In an article regarding the current state and trends of processing secondary raw materials of winemaking in Ukraine, it illustrates that waste materials from one system have much opportunity as material inputs into other systems. It was concluded that in terms of volume and chemical composition, secondary raw materials of winemaking are of great value in the manufacture of food, animal feed, and technical products (Osipova, Radionova, Khodakov: 2021). Students need to engage with this, whilst they are learning how to design products. It should be inherent in design process methodology.

It is too easy to look at a material collection and simply specify a material that seems to be the most appropriate for the intended application due to aesthetic or functional requirements. What are the origins of that material? How much energy was utilized in the harvesting and processing of raw materials to create that sheet of metal, plastic or wood? The supply chain starts with a product design that is needing to be manufactured. The materials utilized in the manufacturing of this product are needing to be extracted and processed into material 'stock', be it wood, steel, or plastic. These semi-finished products are then further processed into final product outcomes, for example machinery, furniture, homeware or vehicles. All of these stages lead to environmental impacts, in material and energy inputs required, and the resulting emissions and waste streams. (RMIS, 2022). How can students effectively grasp this when they rely on going to their nearest hardware supply store, or virtual material library and specify the 'nicest' material they think may best showcase their design?

THEORETICAL FRAMEWORK

Students need to experience hands-on the steps taken in generating the material specified in their designs. The complexities of the material justifications span much further than what is initially foreseen. As seen in the product lifecycle presented by the EU Science Hub's Raw Material Information System, these decisions have incredibly severe impacts (figure 3). The method in which students engage with this project follow that of a Product Life Cycle approach, with an overarching central focus on environmental sustainability. A Life Cycle of a product needs to look at every stage going all the way back to the acquisition of the raw materials utilized in each and every component, and the processes required to process it along to final produced product. That is the half-way mark. Students then need to also consider what happens to the product throughout it's life and what is to happen to the product once it ceases to 'live'.

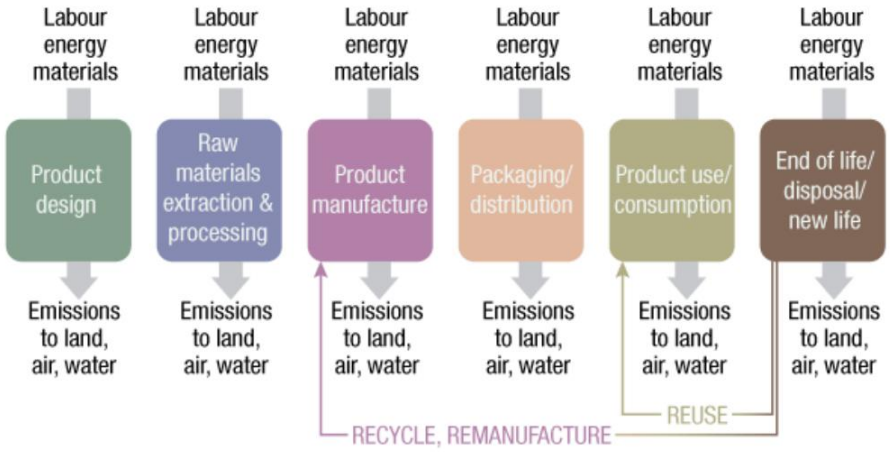

***Figure 3**: Product Life Cycle and associated impacts (RMIS, 2022).*

In 2017, a project was undertaken with the 3rd year Industrial Design student body, in attempt to challenge the previous practices of simply 'specifying materials', and rather task students with developing their own materials. The goal was to process their own materials, from biological sources and thereafter utilize their developed material in a product design process. This granted them the opportunity to engage with raw materials, material processing, and material production, in the space of biological based materials. The project was a great success, which was judged through student assessments and personal reflections, and was carefully structured in a manner to allow for students to experiment freely without the fear of failure: encouraging them to experiment and try many different approaches within the frame of the project. This approach is explained effectively in a *Learning from Failed Experiments: The messy aspects of doing science*, where students were provided guidance in several key places during activities, in others I moved to a more open-ended inquiry-based model of instruction. Students had the freedom to make their own decisions about their investigations and, importantly, were free to make mistakes (Pleasants J., 2018).

Since then, it was decided to incorporate the project annually within the 3rd year group, allowing for different approaches to be undertaken each year, within the boundaries of sustainably and bio-based materials. In 2017 and 2018 students developed a furniture or homeware item, and integrated weaving, in 2019 the class focused on a food industry item, 2020 (with the start of Covid) students focused on a Personal Protection Equipment item. In 2021, the students were required to explore and identify appropriate sustainability-based problems, and with this, opening the opportunity to target this problem with the development of a suitable implementable solution. This implementable solution needed to be sustainable and tackle the initial identified problem. The student group consisted of 21 students; however, I will unpack 1 of the student projects below. These projects effectively illustrate the Life Cycle product design process, and illustrates how the approach has allowed for promising relationships to be formed the South African manufacturing sector.

This paper will present one project outcome example undertaken by a 3rd year Industrial Design student, and will communicate their sequence of material development, followed by product development utilizing these materials. This project took place over a 6-week timeline, where students were able to work on the project for approximately 20 hours per week. The project

entailed a briefing session where students were introduced to the 'material experimentation' part of the project.

Due to Covid protocols, and university access restrictions, this project was undertaken as a blended learning project with students not having full access to university workshops and resources. It therefore meant that students undertook the experimentation and development at their homes, often using whatever resources they had at their disposal. Kitchen supplies, kitchen and workshop appliances and standard food processing equipment. Kitchen scraps, garden clippings, waste paper… anything and everything can be re-envisioned as material inputs for generating new physical materials. If these materials are more sustainable and create lesser impact than alternative materials, then they should be considered for utilization within products.

Can you develop a material that- if discarded and thrown on the ground- may actually benefit the environment in some way, rather than aiding in destroying it? This is the type of question pitched at students in an attempt to encourage them to grapple with environmental impacts of their material specifications.

As with prior years, the 2021 collection of student product outcomes were extremely interesting and stimulated much discussion and opinion. I will present one of these student products, and discuss the design process and steps undertaken in the development of proposed solutions. These solutions followed the stages of a studio-based Industrial Design Process as illustrated in Figure 4.

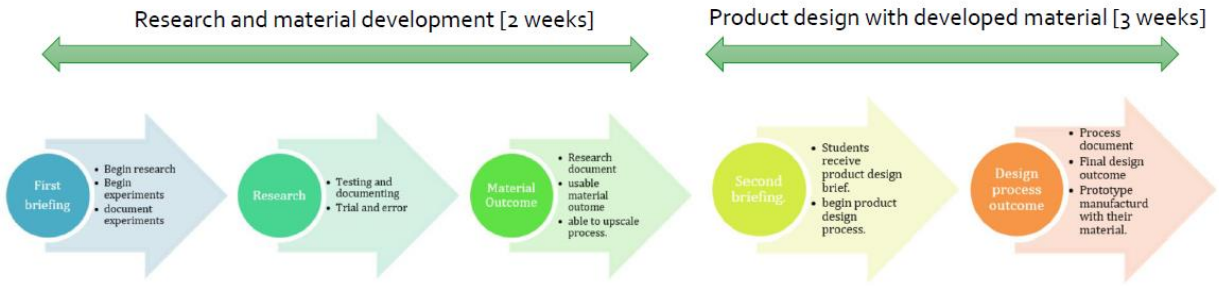

***Figure 4**: Academic Industrial Design Process followed. Image by author.*

DISCUSSION: REUSABLE BIO MATERIAL COFFEE CUP, designed by Jeanne Jansen van Vuuren, 2021 3rd year Industrial Design Student.

This project example illustrates how a student initially identified a problem within the broad sector of manufacturing and the impacts of large-scale production within the single-use food packaging sector. The largest concern was the huge amount of waste at the end of life for products. The staggering figures of single-use paper coffee cups are illustrated in Figure 5 and was chosen as the focus of the project.

***Figure 5**: The Problem, 500 billion disposable cups are manufactured annually. (Jansen van Vuuren, 2021).*

Research starts the process, which retrospectively looks back at what has been completed in the past, and what lessons can be learnt. Extensive precedent analysis leads through images, writeups, and patent searches (Figure 6).

***Figure 6**: Product research (Jansen van Vuuren, 2021).*

Concurrent material development and concept refinement is able to take place, guiding the problem solving along towards a final suitable solution. The student completed over 38 different material recipes, each one doccumenting the outcomes and analysis therof. How does my material need to change to allow for it to best suit what it needs to be? Can I manipulate the recipe to achieve desirable material outcomes? (Figure 7).

Figure 7: *Extensive material development, (Jansen Van Vuuren, 2021).*

FINAL OUTCOME

The final design outcome incorporated two of the developed materials. One more suitable for retaining the coffee, and one that was more suitable as an insulation material. These were Material 4: Sawdust for heat retention, and Material 27: Fine eggshell composite.

Figure 8*: Final Design Outcome: Mixed Media Render. (Jansen van Vuuren, 2021).*

The final form was refined to suit press-forming of the material into the cup form (figure 8). The design is now at a stage where it can be taken further to material and cup prototyping, resulting in real world setting evaluation, as well as material testing within the laboratory environment. Several other product outcomes will be presented in the Conference Presentation, but due to the images, only one project unpacking was considered for this paper submission.

ALIGNMENT TO INDUSTRY: PARTNERSHIPS AND COLLABORATION

After this project was completed, a call was circulated throughout the university calling departments who may be interested in aligning with the Universities Process, Energy and Environmental Technology Station, in particular to sustainability. The student project was

presented to the technology station, and it allowed for the sharing of ideas relating to the importance of undertaking projects of this nature within the university. The university was in the process of signing up as a partner within the SA Plastics Pact, which is a collaborative initiative that will create a circular economy for plastics packaging in conjunction with other local initiatives (SA Plastics Pact, 2021). "In line with the Ellen MacArthur Foundation's New Plastics Economy vision, we will work together so plastic never becomes waste or pollution in South Africa." (2021). Through sharing all of the student project outcomes with the Plastics Pact organisers, it resulted in the department being invited to present some of the thought-provoking outcomes to many of the participating stakeholders. Two students: one the presented designer above, and lecturer (myself) were invited to present projects and outcomes in a working group. This allowed for the outcomes to leave the academic space, and be seen by key players in South African large industry. What started as an internal student project, now resulted in the design process and outcomes to be seen by a large audience.

Several industry partners, and interested collaborators indicated their interest and willingness to help take the projects further. One such partner is one of the largest retailers across Southern Africa servicing over 850 stores nationwide and the project will be taken further as an industry-university collaboration being unpacked as ongoing departmental research, resulting in the majority of this year being dedicated to taking the product further through to pilot implementation and laboratory testing. This groundwork has allowed for future projects to align directly with industry from the start, and students can engage with industry key players in developing appropriate solutions.

CONCLUSION

The project will undoubtedly be undertaken again this year with the new 3rd year students, and this time will be informed directly by the voices of industry role players within the South African Plastics Pact, and will be guided by initial touch points seen as problems within the South African context. These are the problems that the industry are facing, now go and develop sustainable solutions. Hopefully the industry partners can inform the process and provide valuable access and input in guiding implementable solutions able to solve the identified problems, whilst at the same time yield graduates able to effectively solve many problems going forward. The purpose of this paper was to present an ongoing student project undertaken with the Industrial Design students and the method and relevance thereof, in teaching sustainable material and process considerations to design students. This was illustrated and explained with an in-depth example of one successful student project example. The department hopes to foster design graduates who provide beneficial sustainable impact into their future industries.

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ANALYSIS OF ROOFTOP GRID CONNECTED SOLAR PV VS UTILITY SCALE PV POWER PLANT, SUDAN CASE STUDY

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Abstract
Solar PV is now considered one of the most promising renewable energy sources; due to the advances in its manufacturing, efficiency and price. Rooftop PVs for grid connected houses is now recognized internationally, It can be considered as one of the appropriate technology to be utilized by the householders to solve their power shortage and to feed in the public grid. A grid connected PV system solves the need for power in the Sudan. Now the Sudan government is considering permitting the feed-in from private sector and to end the monopoly of power generation. This paper studies the technology and the economics of utilization of solar PV from small sources and utility scale PV power plants. Alfashir 5MWp PV power station and the many rooftops established PV systems in houses (up to 7kWp) in Sudan were analyzed. The residential PV system has the advantage of saving the area and distribution of the needed finance but has long payback (25years) and higher cost of electricity; whereas the utility scale saves the price of erecting and operating the system results in shorter payback (3.2years) and lower cost. The paper resulted in recommendations to assist the decision makers to set the strategies of how and when to use small or micro grid connected PV systems.

Keywords: Rooftop PV, Grid Connected, Utility Scale PV Plant, LCOE, Sudan Government.

INTRODUCTION

Sudan has great opportunities to solve its electricity shortage using renewable energy. Now 50% of the production is fulfilled from renewables, in which hydro has the biggest share of 2,550 MW from the five dams, together with utility scale solar PV of 2x5 MW. In order to fill the gap of electricity production and the reach a full renewable production, nowadays the use of solar PV panel became a norm of power generation in residential areas all around the world. At the same time there is a large competition to install utility scale PV power plants. Sudan, one of the developing countries, has great opportunities to solve its electricity shortage using renewable energy. Now 50% of the production is fulfilled from renewables, in which hydro has the biggest share of 2,550 MW from the five dams, together with utility scale solar PV of 2x5 MW. This paper addresses the economics and the gain/loss calculation of using residential rooftop PV modules for grid connected urban area in such countries, in comparison with the other end of constructing a large solar farm, Figure 1. Large scale photovoltaic power station normally greater than $1MW_P$, is enough to be classified as 'utility-scale'; whereas rooftop solar is usually smaller. The paper objective is to assist the governments and the decision makers to perform a vivid strategic solar energy plan. The reason of the paper is the rules and bylaws laid in many countries supporting the use of solar PV for small applications and ignoring or prohibiting or not supporting the insulation of solar PV large scheme (solar farms) from the private or governmental sectors. The analysis below will determine when, where and why to implement each type.

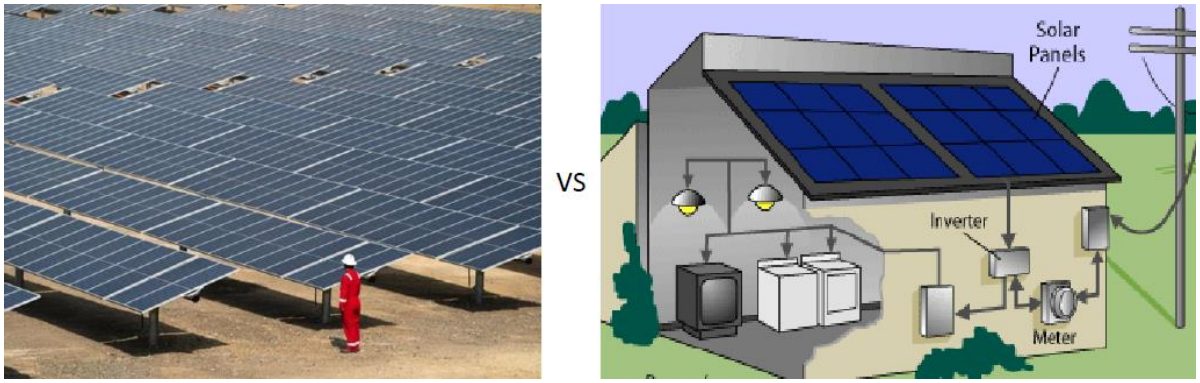


***Figure 1**: The paper framework.*

The use of PV modules can be considered as an appropriate and available technology application. In general, the need for solar PV in urban areas of developing countries serves as:

A. a supplementary source of energy during power cut at daytime. (In this case only PV modules and an inverter are needed), Figure 2-A.
B. As a supplementary source of energy during power cut at day and night-time. (In this case; PV modules, battery, current controller and an inverter are needed) Figure 2-B.
C. As a prime source of energy during the daytime. (In this case; only PV modules with or without an inverter are needed), Figure 2-C.
D. As a prime source of energy during the day and night-time, (in this case; PV modules, battery and an inverter are needed). Figure 2-D.

Figure 3 illustrate a pictorial view of the grid connected system, in developed countries; hybrid - grid-connected solar PV system without battery storage is common or allowed by the electricity supplier for residential housing, Figure 4. In the Sudan feed-in meter type is prohibited, because of safety precautions and the needed level of technology and the type of house buildings.

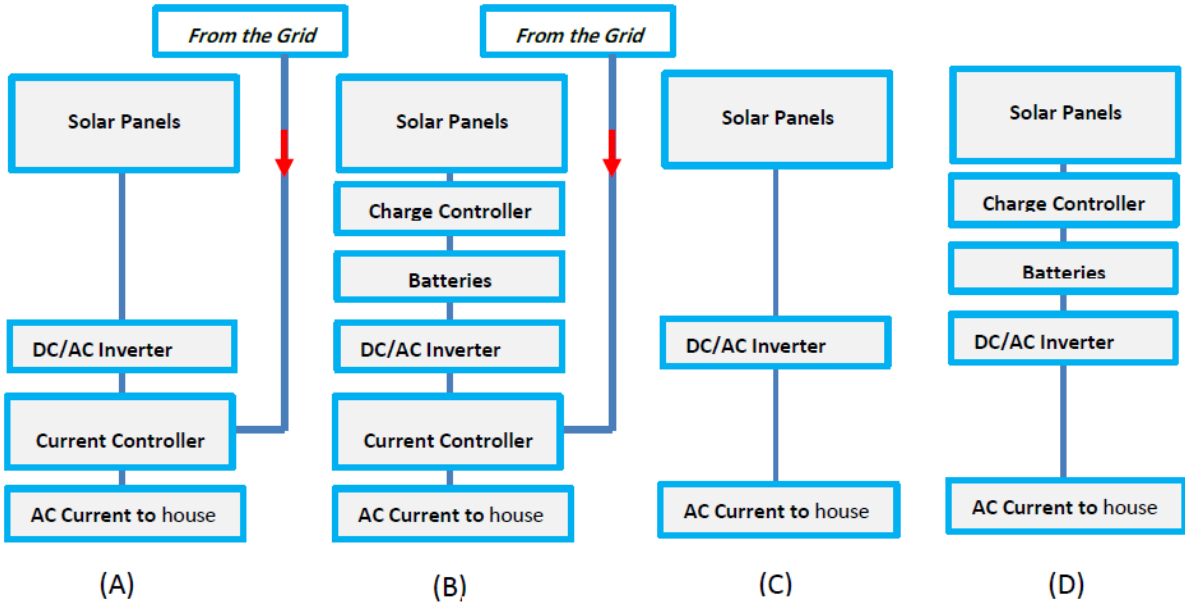
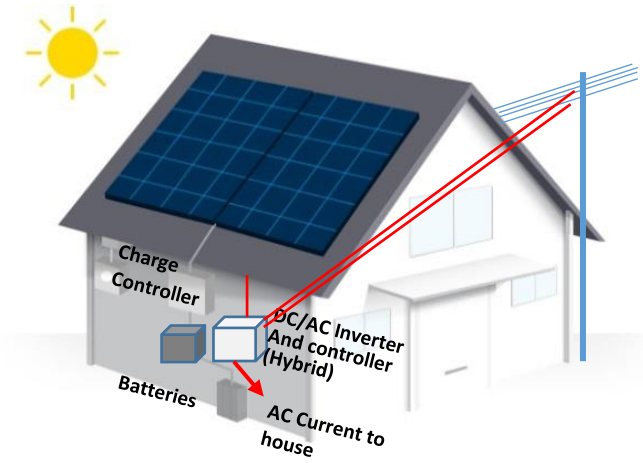


***Figure 2:** Different configuration of supplementary and prime source PV systems.*



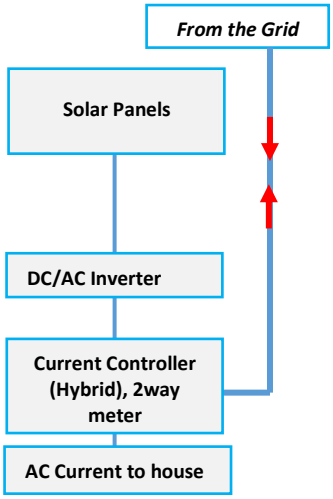


Figure 3: *Ideal grid connected PV system.*

Figure 4: *Two-way grid connected System.*

Engineering Concepts

- kWp = power of a PV module that give 1kW at peak normal solar radiation.
- Energy {kWh} = power {kW} * time {hours}
- Daily energy from 1kWp module = 1 {kW} * 24 hours * Capacity Factor (CF).
- Capacity Factor, or utilization factor (CF) = 25%-10% (Al-Badi et al. 2011), 25%-17% (Ismail E A and S M Hashim 2018).
- The capacity factor for solar PV depends on location and time of the year, from the above references an average annual value of 22.5% can be adopted for this study.
- Annual energy = Power * number of hours * capacity factor (~22.5%) e.g., 1 {kWp} * 365*24 {hours}* 0.225 (CF) = 1971 {kWh/year}.
- The levelized cost of electricity (LCOE) concept: The (LCOE) is a life-cycle cost concept to account for all materialistic resources required to deliver a unit of electricity energy; Kilowatt-hour. It appears as a measure to justify an investment in a particular power generation facility.

The average use of electricity in urban house in Khartoum

Table 1 illustrates the load of an average house in grid connected zone. Such table is usually used to determine the capacity of the solar PV system; but the most important thing is to notice these appliances are not use simultaneously, nor needed all the year round.

Appliance Name	Load's watt	Qty	Total watt
Electric cooker	500W	1	500W
Washing machine	250W	1	250W
Water pump	200W	1	200W
Fan	80W	2	160W
LED lights	11W	8	88W
Refrigerator	100W	1	100W
computer	100W	2	200W
TV and receiver	125W	1	125W
Air conditioner(1.5HP)	1125W	1	1125W
Total			**2748W**

Table 1: *A typical house appliances load for a 3kW solar system.*

RELATED STUDIES

The residential PV system gained popularity because of the frequent electricity cutoff. (Elhassan et al. 2018) showed the use of photovoltaic systems in housing at Khartoum, with 24kW batteries backup, and a peak power 1.5kW; and a daily energy consumption of 3.8kWh. It is noticed that in their design large battery storage is needed. (Ismail E A and S M Hashim 2018) assessed the economics of grid connected Photovoltaic system for a residential house in Khartoum the without a battery storage. The LCOE in their study was $0.51/kWh. Generally, the operation and maintenance cost (O&M) of solar PV system of minimal; ranges between 0.7% to 1.5% of total investment. The life time of the PV is taken as 25 years, 15 years for the inverter and 3 years for the batteries, (Asim 2022), (ElTayeb A/Moniem 2022) and (Hasim et al. 2014).

MATERIALS AND METHODOLOGY

The materials for this paper are the experience of private and governmental sectors installing and using PV module for houses in grid connected zones, in contrast with large PV power plant. The result of similar research was fruitful to writing this paper with added criticism and comments from the authors. The methodology applied is to evaluate the residential PV systems and the utility scale PV system (mainly the new Alfashir 5MWp power plant) in terms of cost and performance. The levelized cost of electricity (LCOE) concept is used as the method to annualize both systems of supplying electricity. The dependability and availability are also used as a measure to compare between these systems.

Residential PV Systems

In the case of Sudan; most PV systems at grid connected zones are installed in big cities mainly the capital city Khartoum. The rate of installation depends upon the rate of electricity shortage. There is a real lack of information about such system in terms of number, types and capacities. Personal communication with the engineers of M. Motors, and Solar M. Companies in Khartoum was successful in envisioning the information. The following are estimates drawn from the resent experience with the market of solar energy appliances and the values drawn from (Ismail E A and S M Hashim 2018), (Asim 2022) and (ElTayeb A/Moniem 2022). Most house owners prefer to use 2kWp - 7kWp systems according to need and financial status. Table 2 estimates the cost of 5kWp system. The whole life most expensive item is the batteries because of its short life. $1,700 is the total cost installing 1kWp. In Table 3; $56.3M is the total investment on roof top PV systems in Khartoum, for an annual output of 65,28MWh which may be partially utilized. In order to reach full utilisation a feed-in meter makes may be used; which will increase the usage value of the system in grid connected zone by four folds, then an accepted LCOE will be reached. But safety precaution must be strictly followed.

Item	Life {y}	5kWp Cost {$}	Cost/kept {$}	25-year cost/kWp {$}
PV modules +installation	25	3,400	680	680
Inverter Hybrid	8	1,200	240	750
Batteries 8*180Ah	3	3,900	780	6,500
Total		8,500	**1,700**	7,930

Table 2: *Cost of 5kWp PV system* (ElTayeb A/Moniem 2022) (Asim 2022)**.**

PV panel power {kWp}	<3kWp	3-5kWp	>5kWp	Total
No. of houses	2,500	3,250	2,750	8,500
Average Power {kWp}	5,000	13,000	15,125	33,125
Annual Energy {MWh}	9,855	25,623	29,811	65,289
Cost* $	8,500,000	43,559,100	25,712,500	56,312,500
* $1700/kW, 1$US ≡ 440SDG (Central Bank of Sudan (CBOS) 2022), prices are present price, i.e., not historical.				

Table 3: *The use of PV system in residential grid connected zones in Khartoum.*

Analysis of residential PV system

For the total of 8500 houses, $56,000,000 was invested in installing roof top PV systems. There are two scenarios of utilization of the generated energy: the first is considering most of kilowatt-hours produced are utilized fully in the house. The second scenario is utilizing electricity during the blackout periods only. The second scenario is the most applicable with the PV system in Sudan. It needs only an automatic on/off sensor switch to detect the electricity cutoff, and no need to cater for the excess electricity generated from the PV modules (Asim 2022). Some owners prefer to apply this second scenario due to lack of knowledge of system operation or uncertainty; even though they invested a lot in the system, (ElTayeb A/Moniem 2022). The analysis is mainly to assess the viability of new investments in the field.

Economic measures

The real cost of the PV systems in reflected by LCOE calculation, and payback period PBP which are essential parameters.

$$\text{LOCE} = \frac{\sum_{t=1}^{n} \frac{It+Mt+Ft}{(1+r)^t}}{\sum_{t=1}^{n} \frac{Et}{(1+r)^t}}$$ where:

It ⟶ Investment expenditures in year t (including financing)
Mt ⟶ Operations and maintenance expenditures in year t
Ft ⟶ Fuel expenditures in year t
Et ⟶ Electricity generation in year t
r ⟶ Discount rate
n ⟶ Life of the system

Et, The Electricity generation in year t, usually is considered as how many kWh can be produced by the power plant, which is simply the product of the rated power times the capacity factor (CF) times 8766 hours/year, scenario 1. The best measure for Et is to use the actual electricity utilised, in this case utilization factor is used which is normally less than the capacity factor. (Klimstra 2013). Table 4 shows the result of LCOE for the two scenarios.

The payback period (PBP) is the breakeven point between expenditure and return, the cost or recurrent items must be taken into account. The payback period normally used when the expected period is short, i.e., months or few years, but it is simple and gives a general picture of the investment. The simple PBP is used here because the authors aim to compare between systems rather than to show the commercial assessment. Table 4 illustrates that the PBP for scenario 1 is 17.25 year, which is reasonable with a total life of 25 years of the PV panels. But for scenario 2 the PBP is very extraordinary due to the obvious non-utilization of all the PV power.

Total life cost of 31,750kWp {$}	134,810,000
Total energy in 25 years (scenario 1) {MWh}	1,564,481
Total energy in 25 years (scenario 2) {MWh}	312,896
LCOE (scenario 1) {$/kWh}	0.04
LCOE (scenario 2) {$/kWh}	0.1624
Pay Back Period PBP* (scenario 1) {y}	10.78
Pay Back Period PBP *(scenario 2) {y}	50.75

* $0.08/kWh

Table 4: *Economic measures of residential PV system.*

Utility scale PV system

The trend of construction large PV plant is spreading all around the globe, (Solar Energy Industries Association 2021), (Abdalla and Ozcan 2021). In neighbouring countries Ethiopia (Gebrehiwot et al. 2019); and Egypt 100s MW PV plant are planned or in operation. Alfashir 5MWp solar PV power plant commissioned in 2020 represents a real life and most recent application of utility scale PV in the Sudan, (Modwi 2021). Figure 5 shows the performance of the plant in 2019; compared with that old existing thermal plant. This Alfashir plant serves as a real example of utility scale PV power plant in the Sudan. It was recommended to expand the project with other 4 similar PV plants to fulfil the day base load. In Table 5 the economic parameters.

Figure 5: *AlFashir Energy Demand and PV participation and the proposed PV participation* (Modwi 2021).

Initial Capital Cost {$}	8,640,000
Capacity Factor	0.225
Life {year}	25
Annual Operation and maintenance cost. {$/year}	250,000
Total expenditure in life time {$}	14,890,000
Plant capacity {kW}	5,000
Annual energy yield {kWh}	9,855,000
payback period (according to the price of fuel saving*) {year}	3.81
payback period (according to global price Feb. 2022**) {year}	7.33
payback period (according to electricity price Feb 2022***) {year}	11.91
LCOE $/kWh	0.06

* 0.25 $/kWh; **0.13 $/kWh (Valev 2022); ***0.08 $/kWh

Table 5: *Performance and economic parameters of AlFashir PV plant.*

The dependability and availability

The dependability of the residential PV systems is quite acceptable provided the owner is capable of the responsibility the routine work of cleaning and replacing the batteries, inverter and the control at the proper times. If the system is used as standby power supply the dependability decreases. Likewise for the utility scale system routine check must be assumed for all the components. The same can be said about the availability. The residential system can be conceded available; once the cash or finance is available, depending upon the house owner. But it is not that a good investment. The utility system is the responsibly of the government; and needs a good will to implement. This will need a good finance policy to attract the capital cost from public, and local, regional and international agencies.

RESULTS AND DISCUSSION

Residential systems

These systems use nowadays have high LCOE ($0.16/kWh), and a very long payback period (more than 25 years) this is due to the high price of the batteries and the frequent rate of their replacement. Improved payback period (10.78 years) can be reached if all the generated electricity is utilized.

Utility systems

These systems have good LCOE ($0.06/kWh), and a reasonable payback period (3.81 years) this is due the absence of the batteries and the frequent rate of replacement.

CONCLUSION AND RECOMMENDATION

- Utility scale PV power plants have a higher economic value compared to residential PV system, in terms of BPB and LCOE.
- Residential PV system serves as an appropriate technology to solve the personal problem of the owner; and as a roof top mounted conserves area. The use of a smart meters makes full use of all energy generated will increase the usage value of the system in grid connected zone by four folds to have an accepted LCOE.
- The governments (state or federal) are advised to invest in utility scale PV power plants, and to attract the public to invest in large power projects rather than personal small residential PV system within the grid connected zones. The money spent for residential backup PV systems will lead to triple energy generation.
- The application of two-way grid connected system will certainly increase the economic value of PV systems in grid connected zones and deserve through investigation, so that will be a good appropriate technology opportunity.
- Further investigation must be done to encourage the industrial sector to invest in utility scale PV with backup from the national electricity provider.
- A reasonable electricity pricing will *push* the three points further for the Sudan development.
- Special care should be taken to the dynamics of solar PV systems prices.

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INNOVATIVE METHODS TO IMPROVE AERODYNAMIC PERFORMANCE OF SAVONIUS TYPE WIND TURBINE

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Abstract
Aerodynamicists often resort to simple innovative means to bring about large aerodynamic performance improvements on aircrafts. In the present work, similar means are proposed to be used to improve aerodynamic performance of Savonius type Vertical Axis Wind Turbine (VAWT). It is well known that the power output in Savonius turbine is greatly diminished by the negative torque resulting from the retarding blade. It is therefore hypothesized that placing a cylinder ahead of the returning blade of the turbine or adding a curtain to the configuration would reduce the drag produced by the blade moving against the wind. Thus, improving the aerodynamic performance of the turbine. In this study chimera mesh was constructed around a two blades model of Savonius type turbine. Reynolds averaged Navier-Stokes (RaNS) method was used to investigate the flow-field about the wind turbine at Reynolds number of 150,000 based on the turbine diameter and the wind velocity. The model was validated using recent experimental data at the same operating conditions and similar flow configuration, and the numerical results were compared with acceptable accuracy to the experimental data. The flow-field and power coefficient were compared with and without the presence of the cylinder and the curtain. The results shows that the presence of the cylinder and the curtain has indeed improved the aerodynamic performance of the turbine. The coefficient of performance has increased by 37% in the case of the cylinder, and by 53.7% in the curtain system case.

Keywords: Wind Energy, Unsteady Aerodynamics, Chimera Mesh and Flow Control.

INTRODUCTION

Wind turbines are mechanical devices that extract kinetic energy available in the wind and convert it into useful mechanical power, they are classified into two main categories according to the main rotor shaft to the ground: Horizontal Axis Wind Turbines (HAWT) and Vertical Axis Wind Turbines (VAWT). Among them we have Savonius type wind turbine which was invented in 1925 by Sigurd Johannes Savonius according to Shah (2020), it is usually designed as a VAWT and consists of two or more half cylindrical parts attached on a vertical shaft and mounted opposite to each other. It can be classified according to:

1. Number of blades: Into two, three and four bladed turbines.
2. Blade structure: Into straight bladed and helical bladed turbines.
3. Blade shape or rotor geometry: Mainly into Semi-circular blades and Elliptical blades, Bach type blades and other types are created by changing the blade curvature and thickness.
4. Number of stages: Into single or multiple stage turbines.

Savonius type wind turbine has many advantages that include: simple construction, independency from wind direction, low noise and vibration, wear reduction, variety of possible rotor configurations and self-starting, It is therefore considered as soft energy technology as it is suitable for small scale energy needs. But since its operation depends upon drag force, its

rotation speed is restricted by wind speed and cannot rotate faster than it [Low tip speed ratio]. In addition to that, during its rotation one blade moves in the same direction as the wind resulting in a positive torque, and the other blade moves against the wind direction causing negative torque. The consequence of this negative torque is a low power coefficient (c_p), which is the main disadvantage of the turbine. The objective of this work is to enhance Aerodynamic performance of Savonius type wind turbine by increasing the value of net toque generated and hence power generated.

RELATED STUDIES

Over the past years, many experiments were done on Savonius rotor using both experimental and mathematical solutions in order to enhance its performance. Altan (2008) introduced a new curtaining arrangement that was placed in front of the rotor preventing the negative torque opposite the rotor rotation, they tested different curtain arrangement with different geometrical parameters. Power coefficient increase by 38.5% was achieved with the optimum one.

Ali (2013) conducted an experiment to study the effects of number of blades on performance, showed that the two blades model results in higher power coefficient values than three blades with a maximum value of 0.21. Also, Alom (2019) studied the influence of blade profiles on Savonius rotor performance and concluded that the maximum power coefficient obtained numerically was found to be 0.272, 0.294, 0.304 and 0.34 for the semicircular, Benesh, modified Bach, and elliptical, respectively. And experimentally 0.158, 0.159, 0.162, and 0.19 in that same order. In addition to Kacprzak (2013) who has numerically investigated the performance of two Savonius rotor configurations, the Bach and the elliptical, compared to the conventional Savonius rotor.

An optimisation of performance was also achieved based on the idea of installation of a barrier; Yuwono (2020) installed a circular cylinder upstream of the returning blade and an increase in power coefficient was achieved by 12.2%, 6.7% and 1.7%, this variation depends upon cylinder parameters [diameter and displacement]. On the other hand, Mohamed (2010) suggested the usage of an obstacle shielding upstream the returning blade, which increased the coefficient of performance by 27%. Another theory of a new blade shape and curtaining system was studied by Tartuferi (2015), two new blade shapes were tested in addition to a curtain system composed of two separate appendages partially enclosing the rotor.

Liang (2018) studied the solidity effect using three factors; number of blades, chord length and rotational radius. The authors concluded that the change in number of blades and rotational speed had almost the same influence since they both did not affect Reynolds number, unlike changing chord length which affected local Reynolds number of the blade. Another important parameter in Savonius rotor is overlap ratio which achieved the best efficiency at overlap ratio 10% and 13% for high speeds and 15% to 28% for low wind speeds according to Bachtiar (2019). Manganhar (2019) suggested using housing of an area of double the rotor area, wind velocity increased up to 1.52 times, and the power coefficient increased from 0.125 to 0.218.

A blade combination was made where the circle-shaped conventional model is combined with the one of a concave elliptical model by Sanusi (2016). Also, Modi (1984) was willing to create an optimum prototype of Savonius rotor used in irrigation of a 5 acres farm in average. Nimvari (2020) suggested the usage of Porous deflector in front of the returning blade in order to direct the flow including some parameters (deflector height and length, porous deflector angle).

METHODOLOGY

A 32 cm diameter rotor of Savonius type wind turbine was considered for validation purposes (Atlan 2008). The free stream velocity was taken as 7 m/s and Reynolds number of the flow was estimated to be 150,000 based on the rotor diameter and wind speed. The tip speed ratio is 0.3 and the angular velocity of the rotor is 13.2 rad/sec. A chimera mesh was then constructed consisting of two overlapping meshes (background mesh and foreground mesh) using Pointwise software. The background mesh is circular (O-mesh) and of a radius of 20 rotor diameters. The foreground mesh contains the moving parts and rotates with respect to the background mesh at a constant speed. The next step was adding the cylinder to the existing mesh in order to compare the value of the coefficient of performance with and without a cylinder under the same circumstances. This was done by placing the cylinder in front of the retarding blade. It was assumed that the presence of the cylinder would create a low-pressure region at the wake, pushing the retarding blade forward. The diameter of the cylinder is half the rotor diameter and placed upstream the turbine at a distance of 45 cm from the center of the turbine.

The curtain mesh was generated the same way, using overset technique. The curtain was assumed to act as a flow shield that blocks the retarding blade and minimizes the pressure in the downstream region. It was also considered as a flow conveyer towards the advancing blade that builds up the possibility of increasing the positive pressure. The length of the curtain was taken to be 45 cm, the inclination angle of the curtain was set to 45^o and the distance between the upper tip of the curtain and rotor center was chosen to be 19 cm. Figure 1a shows the Chimera mesh, and the rotor configuration.

Two different sets of chimera mesh were generated and each was run twice, first without the addition of tested object (cylinder\curtain system) and the second time including the tested object (cylinder\curtain system) in order to compare the variance in output power for each case. The background mesh (shown in red color) is constructed of 250 and 300 grid points in the azimuthal and radial directions for the cylinder and 350 and 350 for the curtain, respectively. The foreground mesh in figure 1a (shown in black color) is constructed of 1650 and 242 grid points in the directions normal to the wall and the direction tangential to the walls in cylinder case and 1650 and 255 for curtain system in that same order. The mesh around the rotor is shown in figure 1a, and zoom-in squares show mesh distribution around the tip of the turbine blade (red) and around the blade-shaft junction (blue). Figures 1c and 1d show the chimera mesh of the turbine rotor together with the cylinder and the curtain, respectively. A 250×180 and 167×61 grid points were constructed around the cylinder and the curtain, respectively.

Ansys-Fluent commercial CFD package was used to carry out the simulations. Spalarat-Allmaras turbulence model was used to close the Reynolds averaged Navier-Stokes (RaNS) equations which are then discretized using coupled method of pressure velocity coupling. The incompressible form of Navier–Stokes equations in Cartesian coordinates are given by:

$$\frac{\partial\, \tilde{u}_i}{\partial\, t} + \tilde{u}_j \frac{\partial\, \tilde{u}_i}{\partial\, x_j} = -\frac{1}{\rho}\frac{\partial\, p}{\partial\, x_i} + v\frac{\partial\, \tilde{u}_i^2}{\partial\, x_j^2} \quad (1)$$

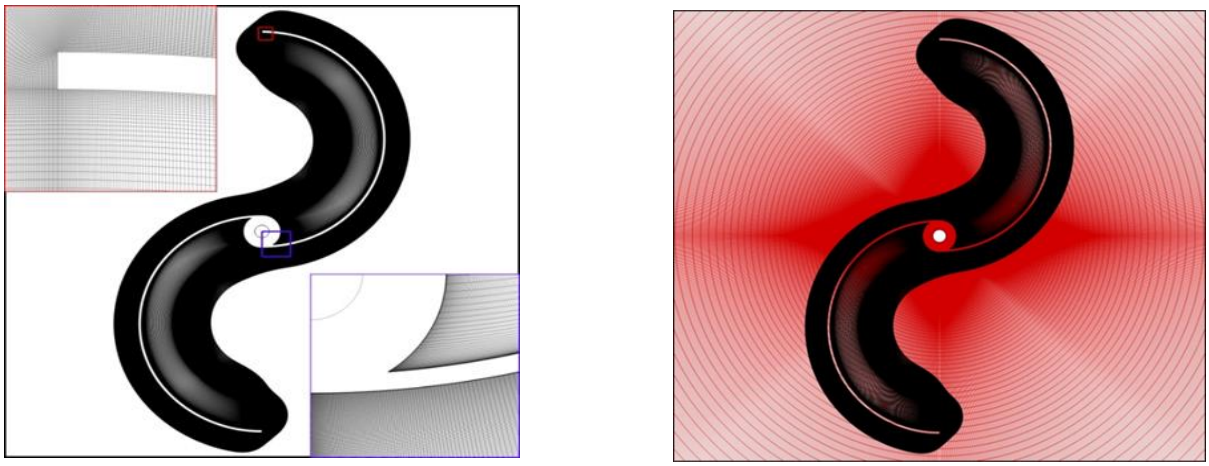
where $\tilde{u}_i$ is the instantaneous velocity component in the i-direction, p is the instantaneous pressure, and the kinematic viscosity v is defined by:

$$v = \frac{\mu}{\rho} \quad (2)$$

The simulations were run until the transition of the solution is decayed and the flow became stationary in time. Time history of the drag force for each blade was recorded at each time-step. Continues average technique was used to assure that the length of data record is long enough for the mean to converge to the true mean of the data. Instantaneous samples of the streamwise velocity, wall-normal velocity, and the static pressure were recorded for visualization purposes. The drag force of each blade was computed by averaging the instantaneous values of the force at each position of the blade per each cycle. By considering which blade was advancing through half a cycle, the average net drag force per half a cycle was estimated. Continues average was used again to assure low data variability. That is, the time-averaged drag force was estimated for the first cycle, then for the first and the second together and so on until obtained time-averaged value was noticed to be constant. After that the power generated by the blades was estimated and scaled by the corresponding power available in the wind to obtain the power coefficient.
The improvement of the aerodynamic performance can be noticed through the increase in the value of the instantaneous net drag force at each position in the case of the curtain and the cylinder when compared to the values estimated for the plain rotor. This increment will result in a higher tourque and thus a higher power output.

(a) *The mesh around the rotor*

*(***b)** *Chimera mesh.*



(c) *The Chimera mesh of the rotor and the curtain cylinder configuration.*

(d) *The Chimera mesh of the rotor and the Configuration.*

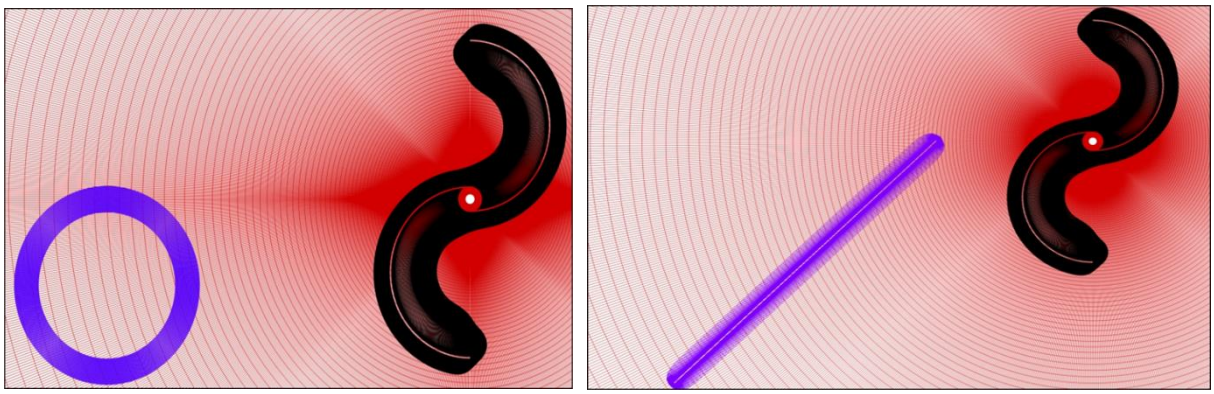


Figure 1*: The flow configuration and computational mesh.*

Similar studies were carried out to enhance the performance of the Savonius type turbine experimentally. Numerical approach was introduced in some works with the use of unstructured meshes. The use of a structured chimera mesh with the features mentioned previously is considered to be a first-time applicable idea to be accomplished in this field of study.

RESULTS AND DISCUSSION

figure 2 below shows snapshots of color maps of the instantaneous spanwise vorticity which span a half cycle. As seen in the figure, a clockwise rotating coherent structure (blue color) develops in the wake of the advancing blade, and an anti-clockwise vortex (red color) evolves in the wake of the retarding blade. Both vortices advect downstream by the flow. These vortices reduce the pressure in the wake of the turbine and increases the drag force exerted by the air on both blades. Figure 3 shows color maps of the instantaneous streamwise velocity for the turbine-cylinder configuration. The pressure drops drastically in the wake of the cylinder; thus, reducing the drag exerted on the retarding blade. Hence, the presence of the cylinder increases the net drag force and consequently the power coefficient, and improve the aerodynamic performance of the turbine. Color maps of the streamwise velocity for the rotor and curtain configuration is shown in figure 4. The curtain has indeed decreased the pressure upstream the retarding blade, and increased it upstream the advancing blade. Thus, the drag force across the advancing blade increases and decreases across the blade moving against the wind. Hence, the overall turbine performance is improved and the coefficient of performance is increased due to the presence of the curtain.

Figure 5 shows time histories of the net drag force for the rotor (black color), the rotor and the cylinder (blue color), and the rotor and the curtain configuration (red color). The presence of the cylinder has reduced the opposing drag as discussed above, and the net drag force is higher than that of the rotor without cylinder as seen in the figure. The propelling drag has increased and the opposing drag has decreased by the presence of the curtain. Thus, the net drag force in the case of the rotor-curtain configuration is higher than that of the rotor and the rotor-cylinder configurations.

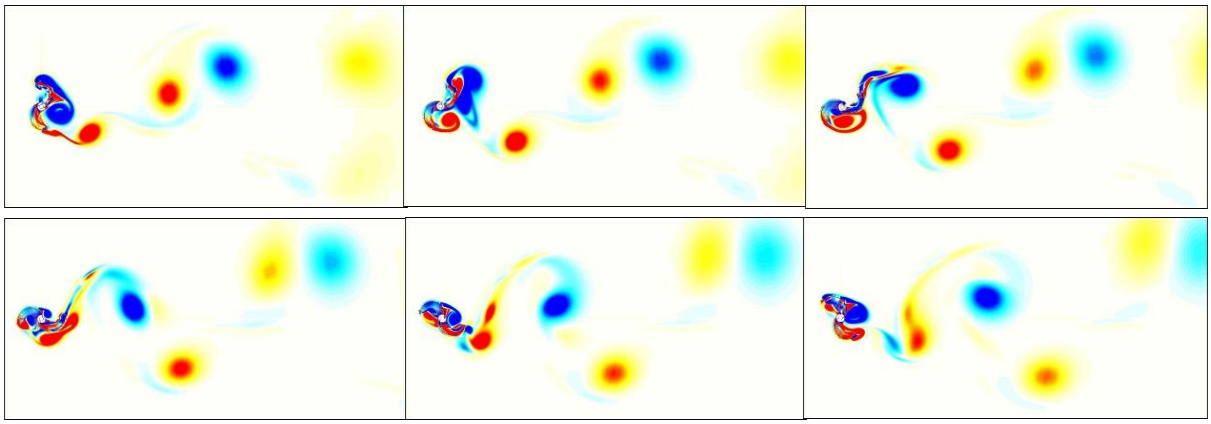


***Figure 2**: Color maps of the spanwise vorticity through half of a cycle.*

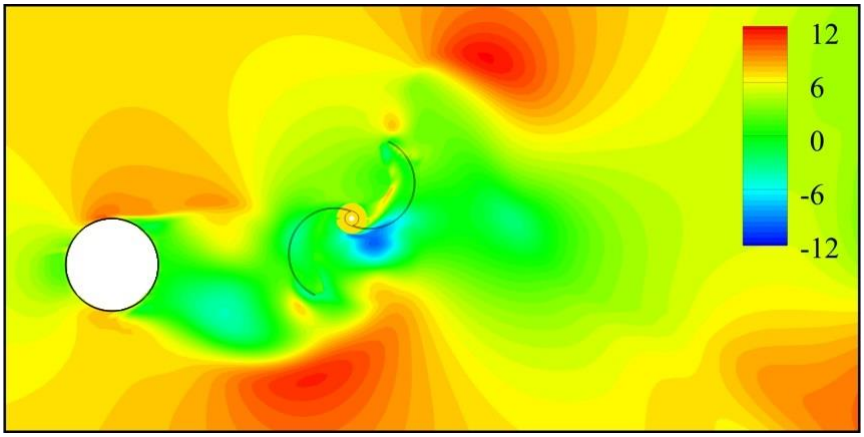


***Figure 3**: Color maps of the streamwise velocity for the turbine-cylinder configuration.*

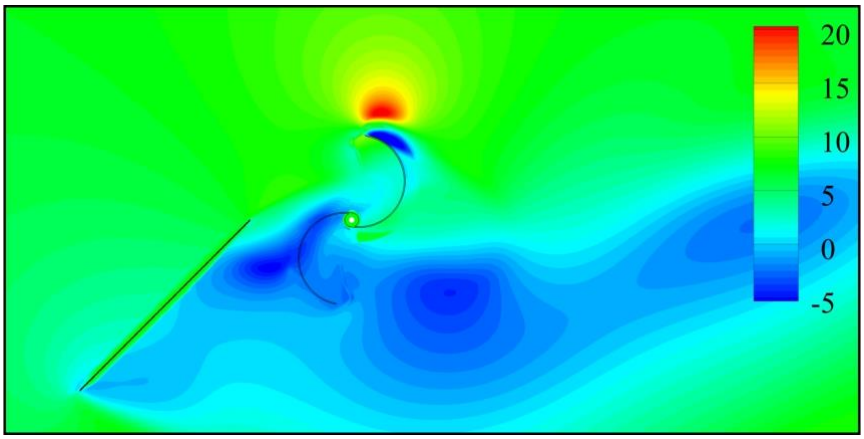


***Figure 4**: Color maps of the streamwise velocity for the turbine-curtain configuration.*

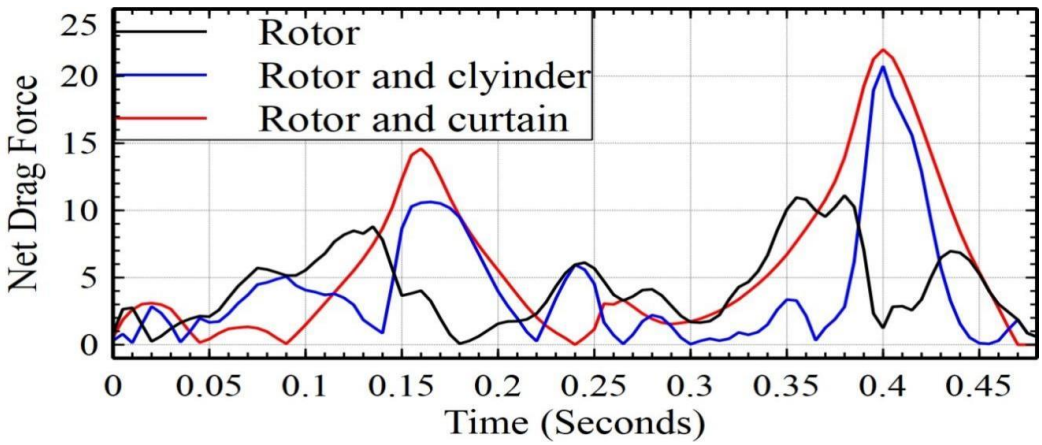


***Figure 5**: Time histories of the net drag force for rotor (black), rotor and cylinder (blue), and rotor and curtain configuration (red).*

The value of power coefficient for each case is calculated by first calculating the net drag force of one cycle, the value of instantaneous net drag force equals the absolute value of subtract of advancing blade drag force minus returning blade drag force, then the average value of drag force is calculated and multiplied by radius to obtain the resulting torque.

$$T = Average\ net\ drag\ force * r \tag{3}$$

The Output power is then calculated by multiplying the resulting torque by the angular velocity. After that the output power is divided by the value of available power to calculate the coefficient of performance. Applying this approach on all cases, the value of coefficient of performance obtained was 0.135 compared to 0.16 from the experimental data which is valid for an amount of uncertainty of 8.59%.

CONCLUSIONS

The objective of the present work was to improve the aerodynamic performance of a Savonius type Vertical Axis Wind Turbine (VAWT), which was done by: first, investigation of the flow field around the plain rotor, and examination of the effects of placing an obstacle upstream the turbine on its efficiency in converting kinetic energy of the wind into useful mechanical work. The power output of Savonius turbine is affected by the opposing drag force exerted by the air on the blade moving against the wind. It was therefore hypothesized that placing a cylinder ahead of the returning blade of the turbine or adding a curtain to the configuration would reduce the drag produced by the blade moving against the wind, increase the drag produced by the advancing blade, and improve the aerodynamic performance of the turbine.

The results compared with acceptable accuracy to recent experimental data at the same operating conditions and similar flow configuration. The flow-field and power coefficient are compared with and without the presence of the cylinder and the curtain. The results shows that the presence of the cylinder and the curtain has indeed improved the aerodynamic performance of the turbine. The power coefficient has increased by 37% in the case of the cylinder, and by 53.7% in the curtain case. This work is willing to shed light on the significance of utilizing wind energy as an important type of sustainable energy. Savonius type was considered in this research mainly because of its simplicity and thus the possibility to be used in Sudan in both private and agricultural sectors. Small scale utilization is considered as a first step. Extra exertions in the direction of optimizing the discussed wind turbine will upgrade its utilization to be used in large scale agricultural ventures and industrial sectors.

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CONTROL OF DYNAMIC STALL ON A PITCHING AIRFOIL USING A LEADING-EDGE ROTATING CYLINDER

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Abstract
This work deals with dynamic stall mainly encountered in the Darrieus type of Vertical Axis Wind Turbines (VAWTs). A two-dimensional NACA 0024 pitching airfoil with leading-edge rotation was investigated to obtain the control law for the cylinder's rotational speed that realizes optimal operation of the airfoil, and as such proves that with a suitable control law, a rotating cylinder is capable of controlling an airfoil's characteristics during dynamic stall so that the desired operating condition is achieved. Reynolds averaged Navier-Stokes (RaNS) method was used to simulate the flow-field around the pitching NACA 0024 airfoil at chord Reynolds number of 65,000. The model was validated with and without the leading-edge rotation using past experimental data. The model's ability to capture the major dynamic stall features was also validated qualitatively. Upon comparing the aerodynamic and flow-field variables with and without leading-edge rotation flow control, it was clear that the flow control was able to counter the effect of the dynamic stall to a great extent, thus improving the aerodynamic performance of the airfoil. These results have profound implications on the aerodynamic performance and structural damage prevention for the Darrieus type VAWTs, and many other applications that encounter dynamic stall.

Keywords: Wind Energy, Unsteady Aerodynamics, Dynamic Stall, Flow Control.

INTRODUCTION

The VAWT Darrieus-type has been used in the power-generation industry for decades now. Utilizing airflow caused by wind around multiple airfoil blades attached to a vertical shaft, the VAWT turns the aerodynamic forces acting on the blades (mainly lift) into rotation of the main shaft of the system, and thereafter into electricity. VAWTs showed a lot of promise due to their simplicity in design, manufacturing, installment, and applicability. They opened a whole new door of possibilities for the future of wind energy and environmentally sustainable power generation. However, its limitations restricted any expansive use of the turbine, the major one of which is the dynamic stall (Castelli *et al.*, 2011).

Dynamic stall is a highly non-linear aerodynamic phenomenon that occurs in airfoils experiencing relatively-rapid changes in their angles of attack, which is constantly the case in VAWTs. Due to the constant angular motion of the turbine's blades relative to free stream velocity and the relative air motion produced thereof, the VAWT's blades experience a constant change in the effective airflow's incidence angle which is equivalent to a periodic (near harmonic) pitching of the airfoil (El Kasmi and Masson, 2008). In the extreme case where the tip-speed ratio is 1, the effective angle of attack varies from 45 to -45 degrees. The effective angle of attack range diminishes as the tip-speed ratio λ increases, rendering the problem of dynamic stall in VAWTs relevant only in tip speed ratios of 1 – 3.

Dynamic stall develops due to the complex interactions between potential and viscous flow in pitching airfoils, which delays flow separation. Dynamic stall is characterized during its pitch

up phase by vortex generation at the leading edge of the airfoil, followed by the vortex convection down the airfoil, then by stall onset, and finally entering the stalled stage. Flow reattachment occurs during the pitch down phase with a bit of delay. Flow separation is delayed due to the vortex generation and convection, which results in an overshoot of the lift after the static stall angle of attack. However, upon the stall onset, the lift experiences a sudden drop in lift which persists during the pitching down phase (Mathew *et al.*, 2016). These great fluctuations in lift (and drag) can cause damage to the structure supporting the airfoil experiencing dynamic stall, and does indeed greatly hinder their operation and functional purposes. As such, researchers have strived to gain a more nuanced understanding of dynamic stall, and explored methods by which it can be controlled, and its effects reduced.

RELATED STUDIES

In an attempt to develop a nuanced understanding of dynamic stall, Mathew *et al.* (2016) conducted an experimental study to investigate the complex flow phenomena over a scaled non-rotating three-dimensional blade dynamically similar to a rotating full-scaled NREL 5 MW wind turbine blade, by quantifying the vortex size, separation angle, and separation point throughout a dynamic pitching cycle. Proper orthogonal decomposition (POD) was used to obtain the transition's time scales and the angles of flow separation and reattachment. It was also used to reconstruct the velocity fields due to it being able to capture the large-scale structure of the flow. Vortex detection from PIV snapshots was achieved through the Eulerian identification method. They found that before the beginning of the cycle, the average vortex size d_v fluctuates greatly with time, inferring static stall. As the airfoil begins to pitch, the vortices' size increases immensely while the shear layer angle β remains relatively constant. At mid-cycle, both β and the average vortices' size were found to reach their maximum values, meaning that the vortices are growing while shifting away from the surface, and that the flow reached its fully stalled stage. Past this point, the flow reattaches as is indicated by the rapid drop in β and the average vortices' size.

Tayler and Amitay (2015) conducted an experimental study to understand the process by which dynamic stall on a sinusoidally pitching finite span S809 airfoil develops, in an attempt to control it via synthetic jets. It was found that characteristics of the flow field for equal angles of attack are different for airfoil static, pitching up, and pitching down conditions, conforming that the stall phenomenon experienced in these tests are indeed dynamic rather than static. Upon applying active flow control via synthetic jets, it was found that momentum injection not only delays or prevents the transition from trailing edge separation to fully separated flow, but it also alters the flow field characteristics of the trailing edge separation, the effects of which are more pronounced for higher coefficients of momentum and at higher angles of attack during pitching conditions. It was thus clear that momentum injection control methods can produce favorable results pertaining to dynamic stall.

One of said momentum-injection control methods is leading-edge rotation, in which a cylinder incorporated at an airfoil leading edge rotates clockwise, imparting some of its angular momentum to the air flowing atop the airfoil and thus delaying the flow separation. Al-Garni *et al.* (2000) conducted a two-dimensional experimental investigation on a NACA 0024 airfoil equipped with a leading-edge rotating cylinder, testing various cylinder rotational speeds and angles of attack for their effects on the lift and drag coefficients, stall angle of attack, and flow separation. The effect of rotating-cylinder induced circulation was a noticeable increase in lift, while the drag remained constant for small angles of attack. At what was found to be the

optimal velocity ratio $\zeta = 4$, the lift coefficient increased by 92%, and the stall angle was increased by about 160%. Hassan and Sankar (1992), Anfal (2019), and Tennant *et al.* (1976) produced similar results.

Many researchers adopted computational fluid dynamics (CFD) methods to simulate the flow fields around dynamically pitching airfoils, and airfoils with leading-edge rotation. Thereby demonstrating the method's strengths, viability, and pitfalls. They have also tested and provided varying models and meshing techniques for maximum accuracy pertaining certain problems. Argin Nazari (2015) simulated a NACA 0024 with a rotating cylinder incorporated at its leading edge for different geometries and angles of attack using ANSYS CFX. He then compared the CFD results with experimental results obtained by Al-Garni et al. (2000) which showed acceptable agreement for angles of attack less than the stall angle, after which the CFD and the experimental results showed great variance. He found that at a velocity ratio of 4, the lift coefficient was increased by 60%, and the stall angle was increased by approximately 80%.

Lakey and Sangolola (2007) conducted a numerical simulation of a pitching NACA 0015 airfoil using ANSYS-CFX10 commercial package in an attempt to test the package's ability to simulate the dynamic stall phenomenon. They used an experimentally tested model and used the experiment's results to validate the simulation's result. Various turbulent models were tried including the SST and $k - \omega$ models. The results showed great conformance between the SST and BLS models with the experimental results, bar a tendency of the SST and BLS methods C_l curves to slightly shift above the experimental C_l curve. However, the models failed to predict the leading-edge vortex shedding.

METHODOLOGY

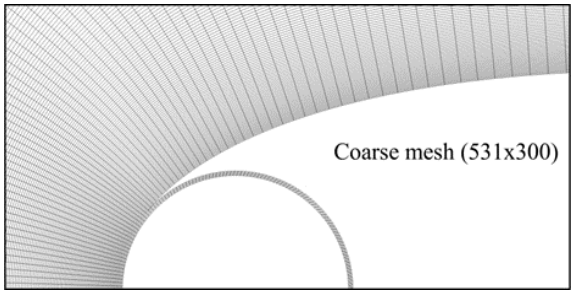
The airfoil on which the leading-edge rotation validation tests were conducted was a NACA 0024 airfoil. The airfoil and cylinder dimensions are identical to Al-Garni et al. (2000) model. The free stream velocity is 5 m/s and Reynolds number is 65,000 based on the free stream velocity and the airfoil chord are also identical to Al-Garni et al. (2000) flow conditions. The turbulence model chosen was the strain/vorticity based Spalart-Allmaras model with curvature correction.

First, three grids of type C-mesh were generated with different degrees of fineness to obtain the mesh with the optimal degree of fineness. The optimization problem referred to here is a tradeoff between the accuracy of mesh results and the equivalent computational cost. These three grids were only developed to validate the simulation accuracy and its ability to capture the rotating cylinder's effect on the lift generated, and thus were developed as static meshes. Close up view in the vicinity of the airfoil leading-edge of the coarse, medium, and fine grid are shown in figures 1a, 1b, and 1c, respectively.

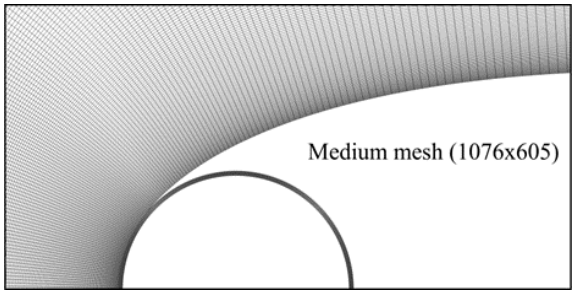
In order for the dynamic stall phenomenon to be studied using CFD, the airfoil in question must produce a pitching in a free stream. The three meshes developed above lack the ability to simulate motion of the airfoil. However, with the optimal number of elements already decided in the case for a stationary airfoil with a rotating leading-edge cylinder, the dynamic stall phenomenon was already set for testing. Two meshes were developed to simulate the pitching motion. The sliding mesh was developed for the same NACA 0024 model, and took an O-shape mesh rather than a C-shape as shown in the left side of figure 1d. The inside circle rotates in whatever direction and under whatever function as the outer ring remained stationary. This allowed for only the boundaries of the airfoil to change while the major flow characteristics

remained unchanged, thus perfectly simulating a pitching motion. The C-shape was omitted due to the arduous and almost impossible nature of generating a moving circle-portion of the mesh inside a non-circular outer-ring-portion of the mesh. The validity of this model is tested through the inspection of vorticity contours at different times of the cycle, and also through the resulting Lift graph shape. The Lift force was the parameter used to also demonstrate the results of Leading-edge rotation, since it is the parameter of the most importance in most applications. The angular velocity equation by which the inner circle rotates is $(5\pi/3)\sin(\pi + 10\pi t)$, which means that a cycle takes 0.2 s to complete. The equation of motion was introduced in the computation using an ANSYS-Fluent expression. These results showcase the development of the leading-edge vortex and its shedding at the start of the pitch down, as described by Mathew *et al.* (2016) and the development of the trailing-edge vortex (TEV) at the end of the cycle.

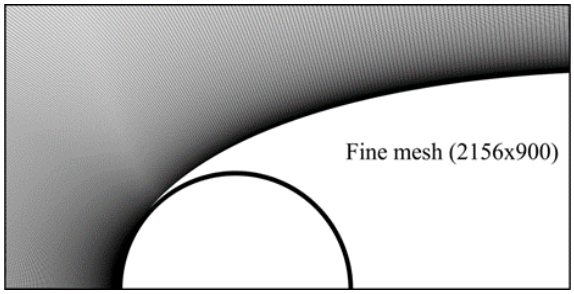
The dynamic stall phenomenon can also be studied by not pitching the airfoil, but changing the angle at which air enters the C-domain mesh as shown in the right side of figure 1d. For Darriues type VAWTs specifically, the dynamic stall phenomenon results from the change in relative flow direction rather than an actual pitch motion. The variation results in a change in the relative angle of attack, which is governed by the equation $\alpha = \tan^{-1}\frac{\sin\theta}{\lambda+\cos\theta}$, and which can be simplified into simple harmonic motion. A User Defined Function (UDF) was written, interpreted, and hooked in ANSYS-Fluent to define the varying inlet boundary condition. Thus, by using the medium grid distribution shown in figure 1b, and subjecting the air flow's incident angle at the boundary conditions to a simple harmonic motion governed by $\alpha = \frac{\pi}{6} * \sin(\omega t)$, where $\omega = 14.24\ (rad/s)$ is the azimuthal angular velocity, VAWT operation conditions can be recreated. The amplitude of this harmonic motion varies with the tip-speed ratio. However, to demonstrate the leading-edge rotation's ability to enhance the performance of VAWTs, the tip-speed ratio was taken as 1.78, where the dynamic stall effects are most pronounced as was touched upon. The radius of the VAWT was taken as 1 meter for simplicity.



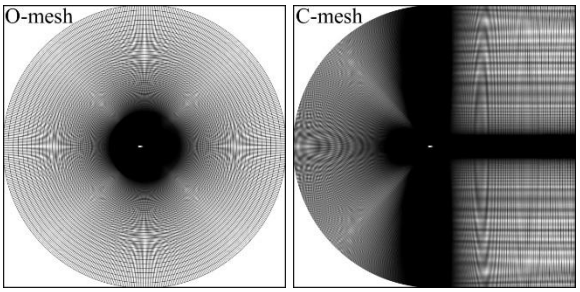
(a) Coarse mesh



(b) Medium mesh



(c) Fine mesh



(d) O-mesh and C-mesh

Figure 1: *Flow domain and computational mesh.*

RESULTS AND DISCUSSION

The O-mesh was used to simulate the dynamic stall by pitching the airfoil up and down. The pitching motion was introduced in the computations by rotating the inner mesh, which contains the airfoil, around the tailing-edge of the airfoil. The airfoil pitch up until its chord make an angle of 30^o with the horozintal axis then pitch down to -30^o. Figure 2 shows a sequence of color maps of the instantaneous spanwise vorticity spanning a complete cycle. The vorticity contours show clearly the development and shedding of the characteristic dynamic stall leading-edge vortex and the development of the TEV near the end of the cycle. However, the size of the vortex was found to be smaller than the non-controlled case as per Mathew *et al.* (2016), showcasing the cylinder's control ability. The figure covers a complete VAWT blade cycle, where the effective angle of attack goes from -30^o to 30^o. Figure 3 shows time histories of the lift and drag force during one complete cycle of the dynamic stall. The lift coefficient was found to be greater for the controlled airfoil throughout the cycle, while the drag coefficient was found to be either equal or less than the non-controlled airfoil throughout the cycle; as is desirable.

The second attempt to model the dynamic stall was by fixing the airfoil at zero angle of attack and vary the free stream direction. The C-mesh was used and the direction of the velocity at the inlet boundary condition was changed with time using a user defined function. The direction of the free stream was changed from -30^o to 30^o and the velocity magnitude was changed from $22.24\,m/s$ (maximum velocity) to $6.24\,m/s$ (minimum velocity). Figure 4 shows spanwise vorticity of the resulting flow field. The free stream velocity is at its maximum magnitude at the beginning of the cycle; thus, the vortex shedding was strong. After that the velocity decreases and the angle of attack of the incoming flow increases until it reaches 30^o. Consequently, the intensity of the vortex shedding decreases and the wake of the airfoil moves upward. As the free stream change its direction downwards and the amplitude of its velocity decreases to its minimum value, the wake of the airfoil extends behind it without significant vortex shedding.

The leading-edge cylinder was rotated to counter the effect of the oscillating free stream or the dynamic stall. The cylinder rotates in the clockwise direction to increase the lift force (and consequently the tangential force) when the incoming flow angle of attack is positive and vice versa. Figure 5 shows time histories of the normal and tangential force with and without the presence of flow control. The rotating cylinder has increased the tangential force and improved the performance of the airfoil as seen in the figure. This is due to the momentum injection (caused by the rotating cylinder) atop the airfoil where the leading-edge vortex is generated, which helps suppress it and thus diminish its effects. The increase shown in VAWT tangential force amounts to a 10% increase in the power output of the VAWT.

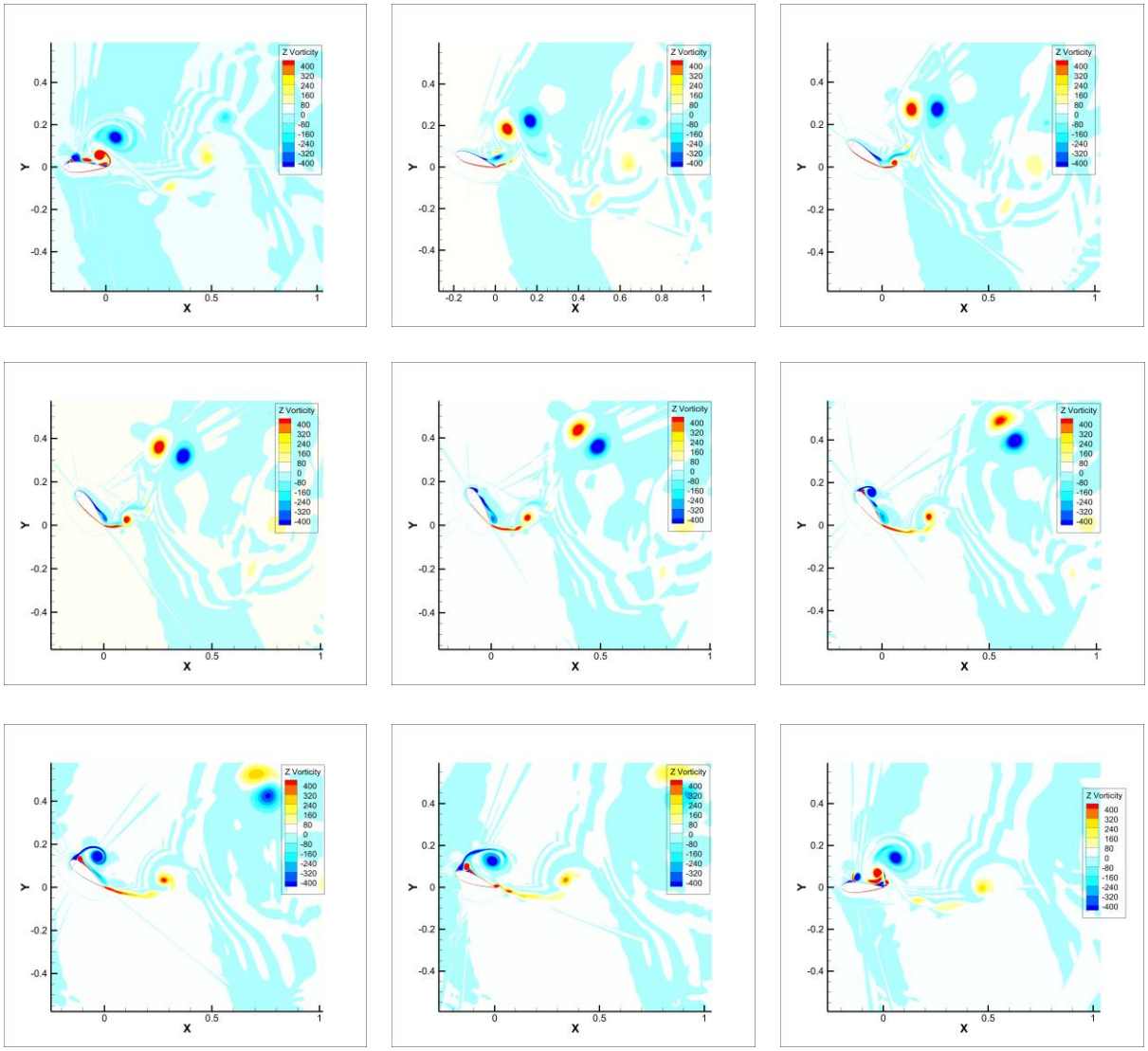


Figure 2: *Color maps of the instantaneous spanwise vorticity spanning a complete cycle of dynamic stall (pitching airfoil model).*

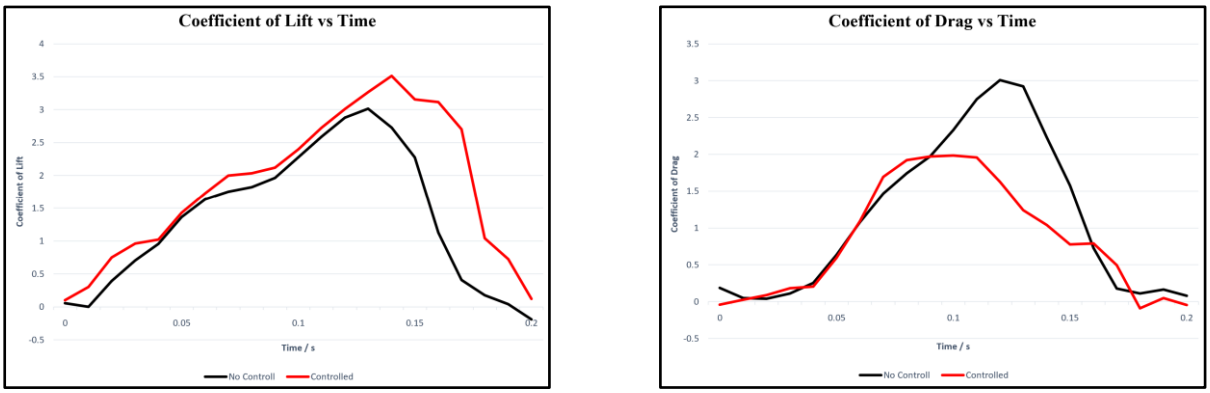


Figure 3: *Time histories of the lift force (left) and the drag force (right) for airfoil equipped with fixed leading-edge cylinder (black solid line), and airfoil equipped with rotating leading-edge cylinder (red solid line).*

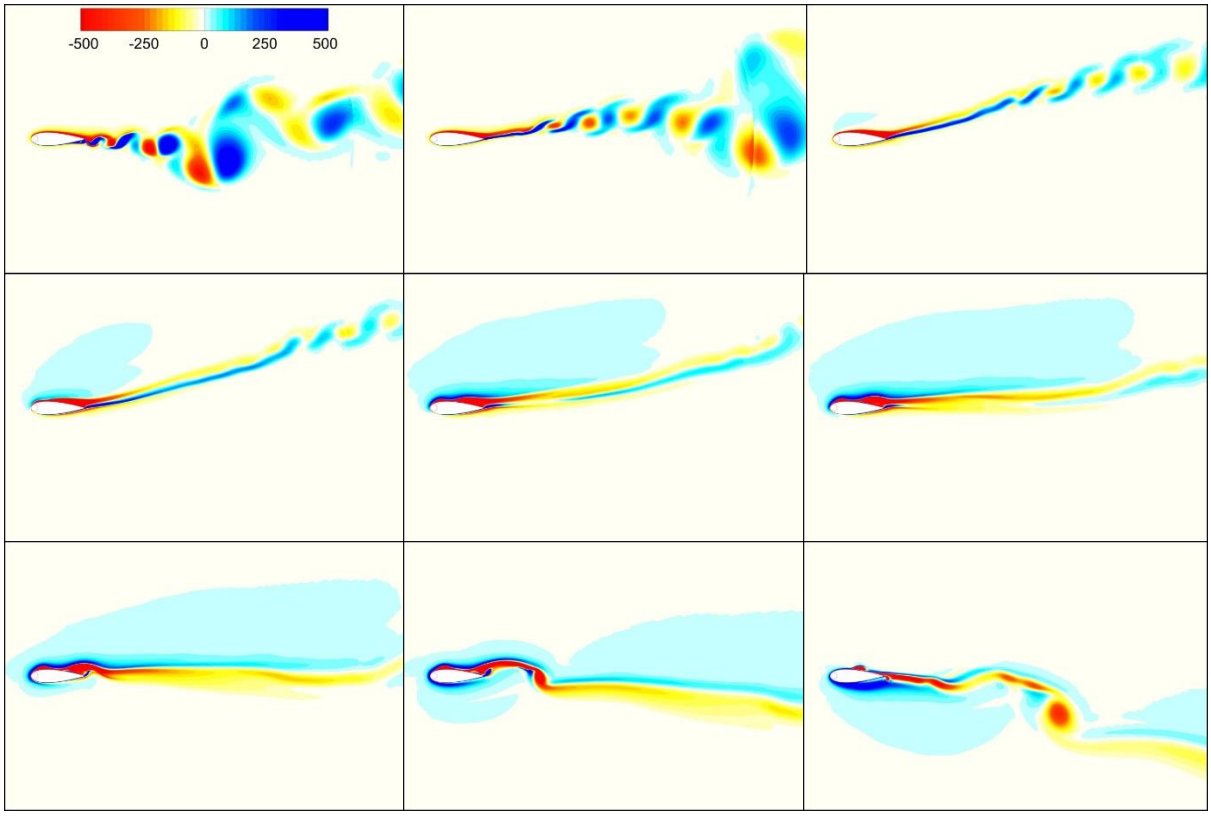


Figure 4: *Color maps of the instantaneous spanwise vorticity spanning a complete cycle of dynamic stall (Swinging free-stream model).*

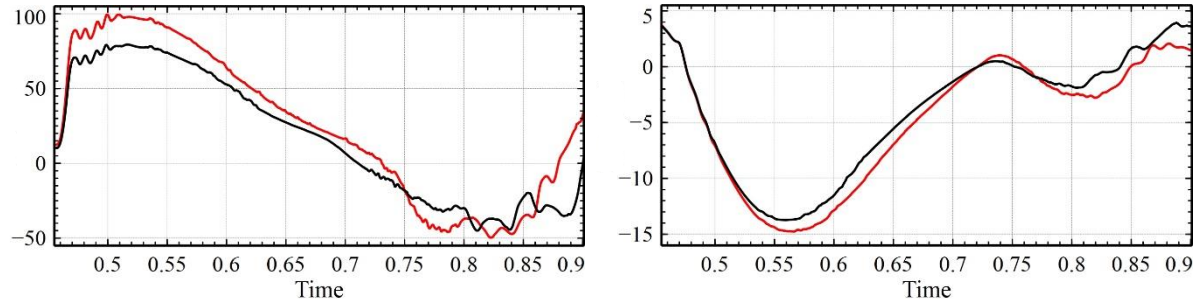


Figure 5: *Time histories of the negative Normal force (left) and the negative Tangential force (right) for airfoil equipped with fixed leading-edge cylinder (black solid line), and airfoil equipped with rotating leading-edge cylinder (red solid line).*

CONCLUSIONS

The objective of this study was to investigate the dynamic stall phenomenon numerically and explore the possibility of using a leading-edge rotating cylinder to eliminate the undesired effects of the dynamic stall. Various models and meshing techniques were used to model and control the phenomenon. One-equation Spalart-Allmaras turbulence model was used to close the Reynolds averaged Navier-Stokes (RaNS) equations. The free stream velocity was set equal to $8\ m/s$ and the airfoil pitched up and down either by rotating the airfoil around its tailing-edge or changing the free stream direction. The effective angle of attack varies from -30^o to 30^o. The results showed that the simulations have captured the dynamic stall phenomenon. It

was also found that the leading-edge rotating cylinder increases the lift force (and tangential force for swinging free-stream model) and improve the performance of the airfoil during the dynamic stall, increasing its power output by 10%. This increase in power output gets larger as the tip speed ratio diminishes.

Further studies in more nuanced control techniques of dynamic stall using leading-edge rotation are believed capable of producing more astounding results, and as such recommended by the authors. VAWTs show great promise in the future of renewable energy in developing countries due to their cost-effective nature. The enhancement of their performances can only do wonders in that prospect, allowing farmers in the most isolated villages access to free energy around the globe.

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AIRFOIL GUST LOAD ALLEVIATION USING A ROTATING LEADING-EDGE CYLINDER

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Abstract
In this study, Reynolds averaged Navier-Stokes (RaNS) method was used to investigate the flow-field about a NACA-0024 airfoil at a Reynolds number of 65,000, based on the airfoil chord and the free stream velocity, and several angles of attack in the presence of airfoil-vortex interaction. The airfoil is equipped with a leading-edge rotating cylinder. The model was validated using previous experimental data. The rotating cylinder combined with airfoil wall motion is used as means to mitigate the impact of the gust on the aerodynamic performance of the airfoil. The lift coefficient is increased by rotating the cylinder in the clockwise direction and the upper wall of the airfoil in the streamwise direction, and vice versa. The flow-field and aerodynamic coefficients are compared with and without the presence of flow control. The results show that the effects of airfoil-gust interaction are indeed damped, and the aerodynamic performance of the airfoil is improved. The lift coefficient oscillates by an amplitude of about 100% of its mean value at the angle of attack of 10° and fluctuates with the magnitude of $\pm$ *0.825 at the zero angle of attack as a consequence of interacting with the gust. More than 50% of the oscillation in the lift was removed by the control at small angles of attack. The capability of the control to alleviate the impact of the gust decreases as the angle of attack increases. This has practical implications on aerodynamic performance and structural damage prevention for the constantly increasing applications operating in built and rural areas such as wind turbines, Unmanned Aerial Vehicles (UAVs), Micro Aerial Vehicles (MAVs), and other applications that operate in gusty environments.*

Keywords Wind Energy, Unsteady Aerodynamics, Atmospheric Gusting, Flow Control.

INTRODUCTION

When there are disturbances of significant strength and size present in the free stream, the aerodynamics of airfoils gets to be quite complex. Such extreme conditions might rise from operating an application in urban areas where the surrounding buildings generate vortical structures in their wakes and disturb the incoming flow. Plants generate similar disturbances in the incoming flow in farms and rural areas. A vortex-creation model was introduced in an otherwise uniform flow to perturb the free stream. It was thus possible to introduce gusting vortices of controlled frequency, size and strength and project them towards the airfoil. The objective is to alleviate the impact of vortex-airfoil interaction and improve the aerodynamic performance of an airfoil operating in a gusty environment.

The atmospheric boundary layer is characterized by turbulence caused by the interaction of different sized eddies due to the presence of velocity gradients. Strong pulses of wind gusts can occur within it which may pose a serious risk for many kinds of structures like bridges, oil rigs, underwater structures, and aerodynamic structures like wings, blades, and rudders. Airfoils encountering unsteady flow is a common problem to many engineering applications, from Unmanned Aerial Vehicles (UAVs) to wind and tidal turbines, such unsteadiness may take the

form of atmospheric turbulence and wake turbulence resulting from lift-generating devices that cause turbulence in their wakes which can affect their succeeding likes.

Disturbances in the free-stream can force a wing designed to sustain large lengths of laminar flow into early transition and, in extreme cases, separation that results in a major loss of lift which stalls the wing (Eljack, et al., 2015). These disturbances create vibrations and shaking that cause passenger discomfort and produce considerable noise, and -with prolonged exposure- can reduce the structure's fatigue life. This unsteadiness manifests itself in the form of gust loads on wings, propellers, and other lift-generating devices. These loads must be taken into consideration in the design process by either reducing its effects or eliminating it entirely through boundary-layer control.

RELATED STUDIES

(Al-Garni, et al., 2000) conducted an experimental investigation on a two-dimensional NACA0024 airfoil equipped with a rotating leading-edge cylinder. They studied the effects of various angles of attack, cylinder surface velocity ratio $Uc/U\infty$ and flap deflection angles on the lift and drag coefficients, stall angle of attack, and the size of the separated flow region. They found that at an optimum $Uc/U\infty$ of 4, the lift coefficient was increased by about 92%, and the stall angle of attack was delayed by about 160%. (Nazari, 2015) conducted a numerical study using a flow configuration similar to that used by (Al-Garni, et al., 2000). The author reported that his results were in good agreement with that of the experimental work of (Al-Garni, et al., 2000), and differ in the percent increase of the lift coefficient by 34% and the percent of stall angle delay by 50%. (Fazelzadeh & Jafari, 2008) used an active optimal integral feed forward control for a supersonic panel under gust disturbances using piezoelectric actuators, they minimized the panel deflection through use of linear quadratic regulator (LQR). The simulation results obtained proved the model was effective for flutter suppression and gust alleviation. (Rigaldo, 2011) described two types of gusts; one dimensional discrete gust and harmonic (sinusoidal) gust, he developed a new gust model and integrated the aerodynamic solver (elsA) to compute the aerodynamic simulations for gust loads and forced motions. He compared the results with those from a Doublet Lattice Method computation for validation, then he carried out a Chimera simulation to verify the applicability of elsA with industrial configurations.

(Eljack, et al., 2015) introduced a virtual isentropic vortex to the flow domain upstream of the airfoil which was achieved through the addition and subtraction of small controlled disturbances. This model is adopted to create the vortices (gusts) relevant to our problem. They used porous surfaces as means of reducing the effect of controlled vortices of known strength, size, and frequency, and conducted simulations on a number of cases with porosities of up to 20% and 22% near the leading edge and found that strategically placed porosities may dampen the effects of the unsteadiness of the incoming flow. (Eljack & Ibraheem, 2015) introduced a well-defined method for modelling large and small-scale vortex gusting through boundary conditions. They used Ansys-Fluent to carry out the simulations at a Reynolds number of 3×10^6 on a one-meter chord airfoil with a free-stream velocity of 45.6 m/s. For the unsteady flow computations, three cases with a vortex strength (which is characterized by the maximum gust speed at the gust core) of 5, 10, and 15 m/s, and 15 cases with different vortex sizes ranging from 1 chord to 100 chords were performed. They found that for vortices larger than 25 chords the gust effect becomes totally inviscid and variation in the lift coefficient is due to an effective angle of attack. They reported that the lift coefficient starts to respond to the vortex when it is located at 5 vortex radii upstream of the leading edge. They also reported that the minimum

value of lift when the vortex centre is at one vortex radius downstream of the leading edge (due to the gust-airfoil interaction) has a smaller magnitude than its maximum counterpart at one vortex radius upstream of the leading edge. This paper aims to exploit the Magnus effect caused by the rotation of a leading-edge cylinder and a moving surface in order to alleviate the gust load on an airfoil.

(Wu, et al., 2021) conducted numerical simulations on a NACA0021 VAWT with different numbers of blades to study the effects of various gust parameters on the power performance of the turbine. They used the Chimera mesh technique to implement the rotation of the grid around the rotor. They used the TAU code to simulate lateral sinusoidal gust which was realized by feeding it into the flow-field from left and bottom far-field boundaries that were necessarily revised as the non-reflecting far-field boundary condition. They found that the gust influences are not only present in the immersion period but in a much wider period due the mutual aerodynamic interaction between the gust and rotor. This period depends on the gust frequency as well as the direction and amplitude. They also found that VAWT power performance is more sensitive to horizontal gusts than lateral gusts (which is a primary reason why this is not a common topic). For the latter type, they found that lower gust frequencies and larger amplitudes caused more intense oscillations and variations in the power output. The longitudinal gust on the three-bladed turbine caused the worst deterioration in the power output by 29.02% in the immersion period. While a lateral gust with an amplitude of 8 m/s and a frequency of 2 Hz decreased the power output by 12.28%, and a gust with an amplitude of 4 m/s and a frequency of 1 Hz brought about an enhancement of 3.16% in the immersion period.

As is evident from the aforementioned literature review, alleviating the gust load through use of a rotating cylinder to control the boundary layer has never been attempted, and hence, this is a novel approach in achieving that objective. This research aims to increase the efficiency of VAWTs used for water pumping in rural area disconnected from the grid as VAWTs are extremely susceptible to turbulence due to their small size. This has great implications regarding agriculture through sustainable energy, reducing the burden of fuel cost on the farmers and providing a more sustainable alternative which not only benefits the farmers, but the entire population at large.

METHODOLOGY

The numerical study is to be conducted on a 0.2 m chord NACA0024 airfoil with a 30% exposed 25 mm diameter leading-edge cylinder as shown on figure 1. A C-type domain with the radius of the semi-circle and the length of the rectangular part in the wake being equal to 20 chords so as to eliminate the effect of the airfoil presence on the inlet boundary condition, as shown in figure 2.

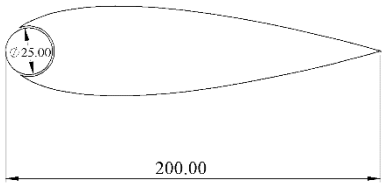


Figure 1: *NACA0024 airfoil with a leading-edge cylinder.*

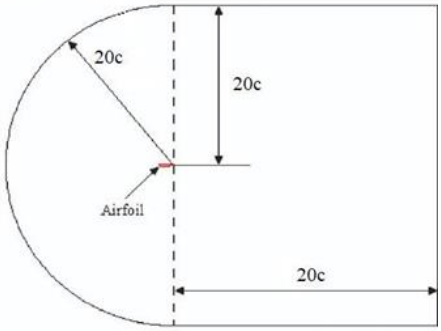


Figure 2: *The computational domain.*

Geometrical mesh quality is of utmost importance in controlling the error sources and propagation. This is achieved by reducing the mesh spacing in regions of rapid solution variation. A mesh sensitivity study is conducted by running the simulation on a given mesh and then halving the initial step size and doubling the number of grid points as shown in figure 3, and repeating the simulation. This is done until two consecutive meshes show no significant difference in the simulation results as shown in figure 4. The optimal mesh is chosen based on two criteria; the average value of the lift coefficient in one cycle after the solution becomes stationary in time, and the time-averaged pressure coefficient of the airfoil. The resulting mesh is shown in figure 6. For validation purposes, the flow was set to turbulent with a Reynolds number of 65,000 and a free-stream velocity of 5 m/s with a stationary cylinder. The strain/vorticity based Spalart-Allmaras turbulence model with curvature correction was found to be the best suited viscous model to the problem at hand. The aforementioned model was validated using the results obtained by Al-Garni (2000) as shown in figure 5.

The aforementioned simulations were carried out using Ansys-FLUENT CFD software, which is a commercially available software that yield relatively accurate results depending on the model chosen, its corresponding parameters, and other settings such as various physical variables. Third-order MUSCL (Monotone Upstream-Centred Schemes for Conservation Laws) discretization scheme was employed because it improves special accuracy for all types of meshes by reducing numerical diffusion. It is available for all transport equations.

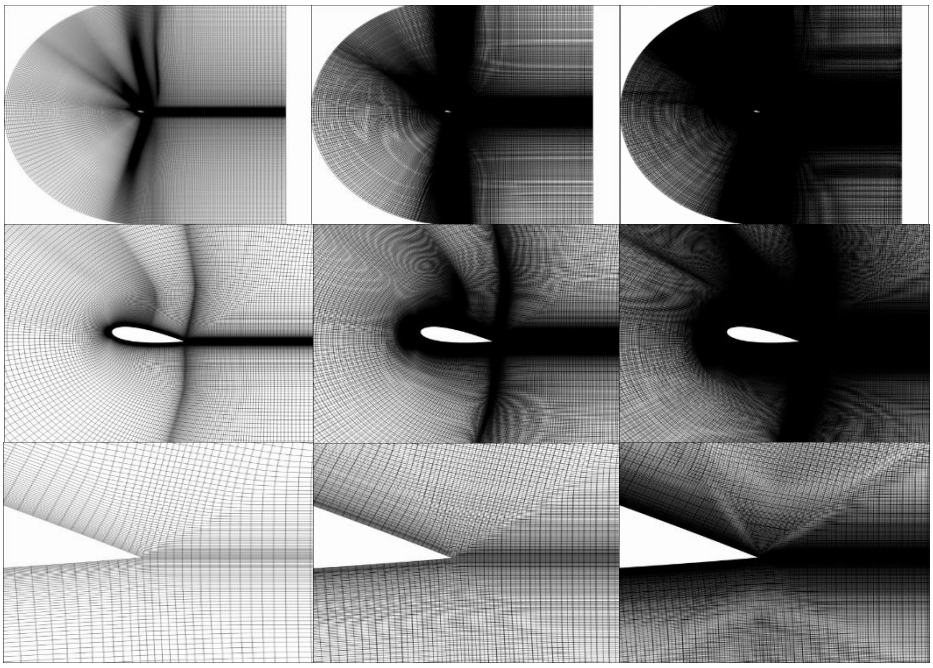
Governing Equations:

Continuity equation:

$$\frac{\partial \widetilde{u_j}}{\partial x_j} = 0 \tag{1}$$

Navier-Stokes' equations:

$$\frac{\partial \widetilde{u_i}}{\partial t} + \widetilde{u_j}\frac{\partial \widetilde{u_i}}{\partial x_j} = -\frac{1}{\rho}\frac{\partial p}{\partial x_i} + \nu\frac{\partial^2 \widetilde{u_i}}{\partial {x_i}^2} \tag{2}$$



Coarse mesh (512 x 234). *Medium mesh (1024 x 467).* *Refined mesh (2048 x 934).*

Figure 3: *Mesh sensitivity study.*

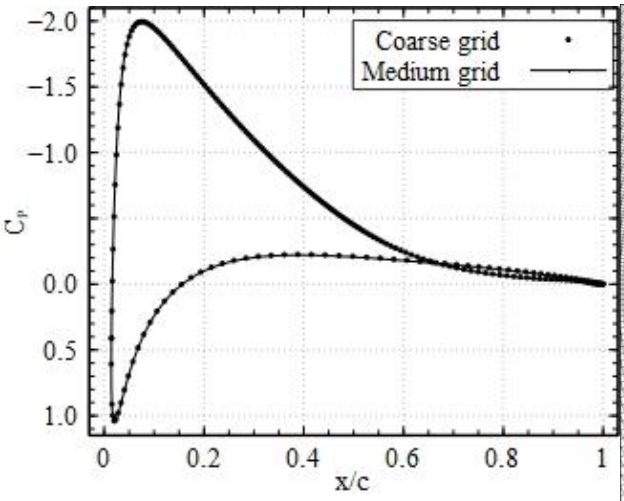
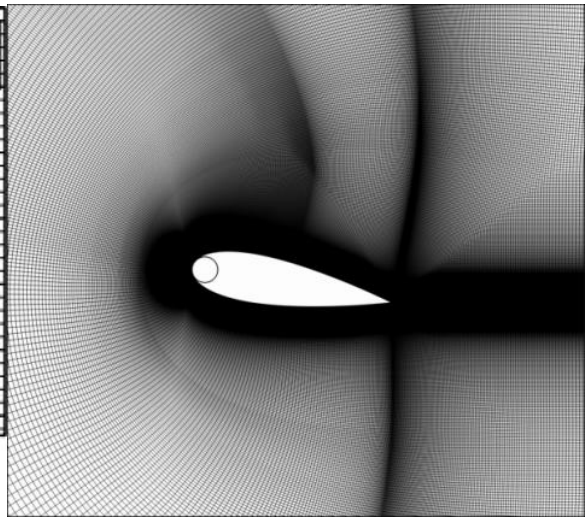


Figure 4: *The pressure coefficient for the coarse and medium meshes.*



Incorporation of the leading-edge cylinder.

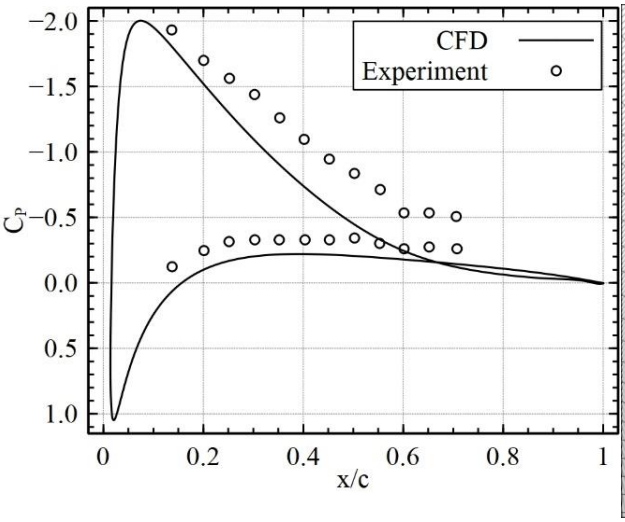
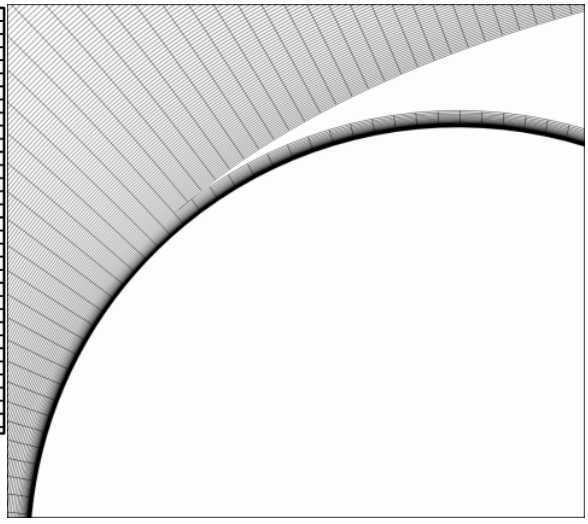


Figure 5: *Validation of the model.*



The airfoil-cylinder junction.

Figure 6: *The final mesh.*

After the model was validated, the gust was introduced using the model adopted by (Eljack, et al., 2015). A virtual isentropic vortex is introduced to the flow domain upstream of the airfoil by adjusting the local velocity components. This is achieved by using the following equations:

$$U' = U - \iota\frac{\Gamma y}{2\pi}\exp\left(\frac{1}{2} - \frac{1}{2}\left(\frac{r}{R}\right)^2\right) \qquad (3)$$

$$V' = V + \iota\frac{\Gamma x}{2\pi}\exp\left(\frac{1}{2} - \frac{1}{2}\left(\frac{r}{R}\right)^2\right) \qquad (4)$$

Where U' and V' are the perturbations in the x and y velocities respectively, U and V are the x and y velocities, ι is the vortex rotation direction (+1 for anti-clockwise rotation, -1 for clock wise rotation), Γ is the circulation, r is an arbitrary radius from the center of the vortex, and R is the vortex radius. It should be noted that the theoretical values from the velocity perturbations obtained from equations 3 and 4 differ slightly and insignificantly from the values computed within the simulation.

RESULTS AND DISCUSSION

The mean flow

The flow around a NACA0024 airfoil at an angle of attack of 10° was simulated in order to establish a base upon which further modifications are made such as incorporation of the leading-edge cylinder and introduction of the gust in the computational domain. Due to the transient nature of the flow, the instantaneous values for the flow variables were recorded in order to be time-averaged after the solution became stationary in time. In order to obtain statistics with low data variability, 1000 frames taken after the solution was stationary in time were time-averaged. The results are shown in figure 7. As the air flows on the suction side of the airfoil it is accelerated and hence a drop is the static pressure is noted. It can also be noted that, at this angle of attack, a separation bubble forms at the suction side near the trailing edge due to the adverse pressure gradient that forces the flow to reverse its direction near the walls while the fluid further from the wall maintains its direction which causes flow circulation in that region. This bubble is not coherent enough to withstand the shear downstream the trailing-edge; consequently, it breaks and shed into small vortices. This shedding causes predictable fluctuations in the lift value as shown in figure 8.

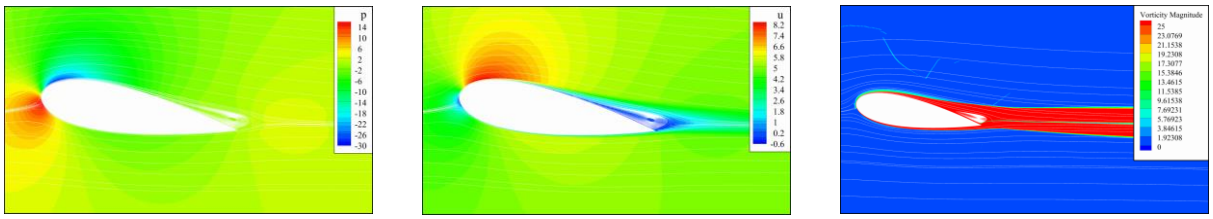


Figure 7: *Time-averaged colour maps of the static pressure (left), the streamwise velocity (middle), and the spanwise vorticity (right).*

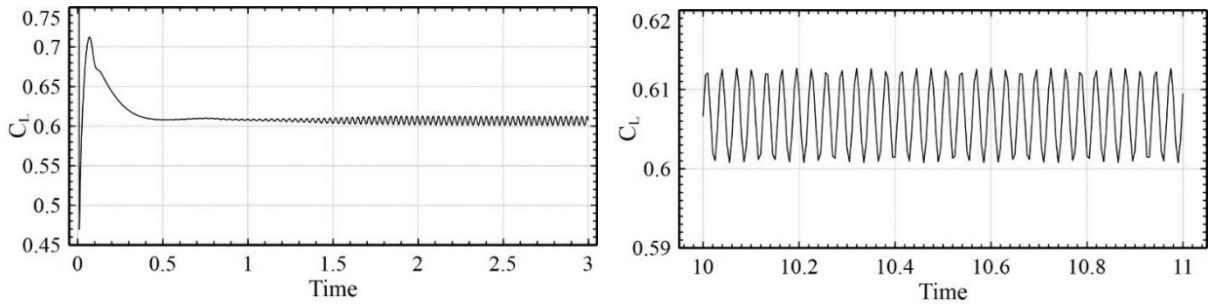


Figure 8: *Time histories of the lift coefficient at the angle of attack of 10°.*

Gust-Airfoil Interaction

A clock-wise-rotating vortex of a radius of one airfoil chord is germinated in the domain 5 chords upstream of the airfoil so as to not be affected by the presence of the airfoil and is convected by the free stream as shown in figure 9. It can be seen that the vorticity, which is expressed mathematically as the spatial rate of change of velocity, increases radially outwards from the vortex center as the velocity increases radially outwards. Then it decays as the slope of the of the velocity profile with respect to distance becomes negative after which an increase in the slope is noted while still remaining negative as shown in figure 10.

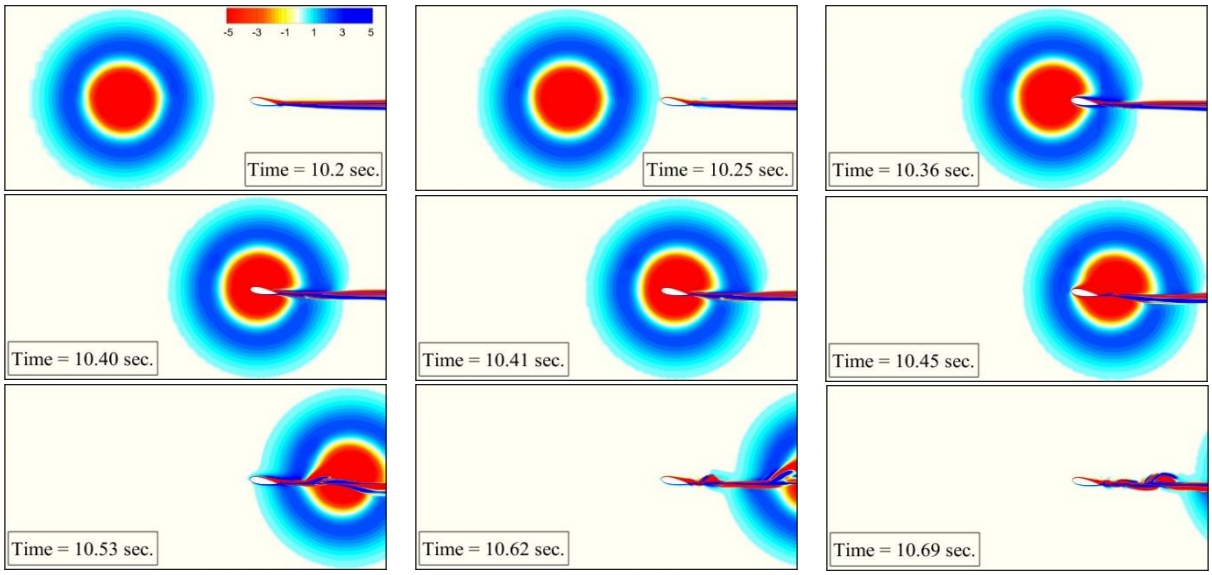


Figure 9: *Gust-airfoil interaction.*

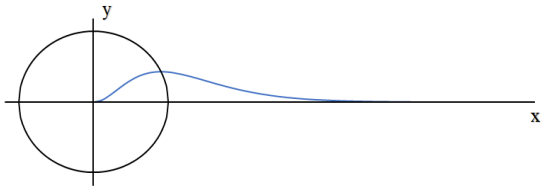


Figure 10: *Vortex profile.*

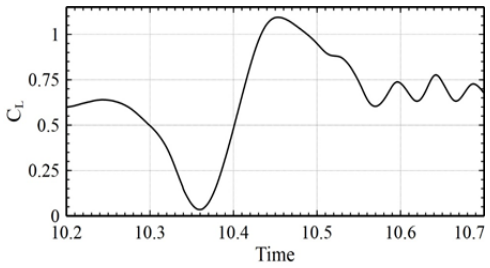


Figure 11: *Effect of vortex on the lift coefficient at the angle of attack of 10°.*

Since the vortex is rotating in the clock-wise direction, when it impinges on the leading-edge of the airfoil it decreases the lift coefficient due to the increase of the static pressure on the suction side. On the other half of the vortex, the opposite occurs as the static pressure increases on the pressure side as seen in figure 11. It worth noting that the vortex does not much affect the lift when it is centered at airfoil leading-edge as seen in figures 9 and 11 at time = 10.4 seconds.

Flow control

A mesh of 1251 × 400 was constructed around a NACA0024 at zero angle of attack. An anti-clock-wise-rotating vortex of a radius of five airfoil chords is initiated virtually outside the computational domain, and 50 airfoil chords upstream of the airfoil so as for the vortex to be defined as a boundary condition at the inlet boundary. The vortex was introduced in the computations using a User Defined Function (UDF). The center of the vortex was defined in the UDF to move at constant speed equals the free stream velocity. The left-hand side of figure 12 shows color maps of the spanwise vorticity which visualize the vortex entering the computational domain. The vortex at the middle of the computational domain interacting with the airfoil is visualized using color maps of the spanwise vorticity as seen in the middle and right side of figure 12.

An expression was used to introduce the control in the computations. The vertical velocity component upstream the airfoil at a distance of 10% of the airfoil chord is used as a feedback variable. The airfoil is mounted at zero angle of attack; hence, the vertical velocity has a mean value of zero. Thus, the control rotates the cylinder and moves the airfoil upper or lower wall to keep the vertical velocity fluctuating around zero. That is, when the vertical velocity increases, the control rotates the cylinder in the ant-clockwise direction and/or the lower airfoil wall in the streamwise direction to lower the magnitude of the vertical velocity. Consequently, the lift coefficient fluctuates around zero as it should before the presence of the gust. A comparison of the lift coefficient in the presence of the vortex with and without the control is shown in figure 13. The control has indeed damped the effects of gust and improved the aerodynamic performance of the airfoil. However, the control is more effective in increasing the deficit in the lift than decreasing the surplus in the lift as a consequence of gust-airfoil interaction.

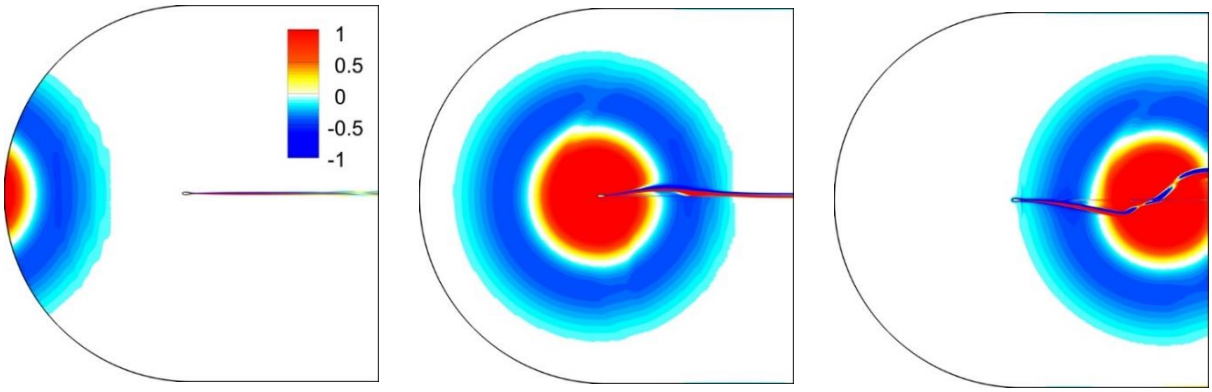


Figure 12: *Colour maps of the spanwise vorticity visualizing a large vortex projected towards a NACA0024 airfoil at zero angle of attack (left), interacting with the airfoil (middle), and exiting the computational domain (right).*

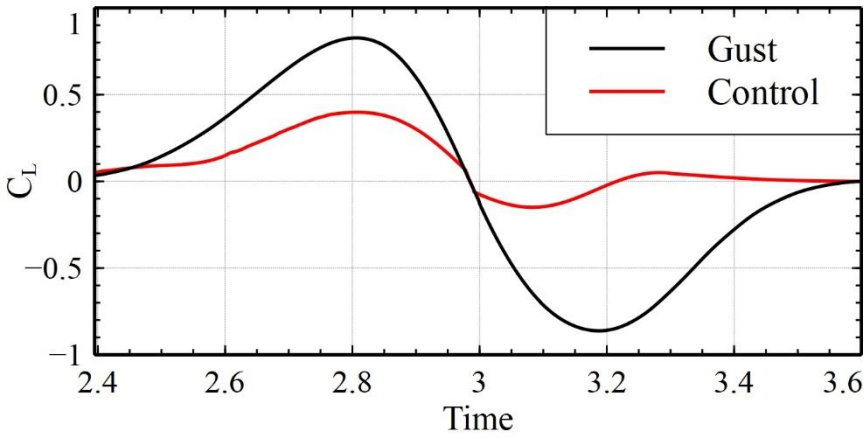


Figure 13: *Time histories of the lift coefficient at zero angle of attack with and without control.*

It can be noted that the aforementioned results compare favourably to those of (Eljack, et al., 2015). In the first half of the vortex, the effect on lift variation is dampened by about 50% while they were able to dampen the effect by about 33%. Moreover, in the second half, the effect on the lift variation was dampened by about 70% while they were able to dampen it by about 50%. Thus, this method is more effective in alleviating the gust loads than introducing porosity on the surface of the airfoil, even though the latter is a passive control method and requires no input or processing.

CONCLUSIONS

The objective of this study was to simulate gust-airfoil interaction and the subsequent effects on the aerodynamic performance of the airfoil and alleviate the gust effect on the airfoil through boundary layer control using a rotating leading-edge cylinder which employs the Magnus effect. The rotating cylinder and/or the upper/lower walls of the airfoil were used to alleviate the impact of the gust on the lift coefficient. The wall-normal velocity component was used as a feedback variable. The rotating cylinder rotates in the anti-clockwise direction and/or the lower wall of the airfoil moves in the streamwise direction to reduce the vertical velocity and consequently the lift coefficient, and vice versa. The effects of gust on the lift force were damped by the control. However, the control is more effective in removing a downwash than an upwash. Practically speaking, there is no uniform free stream. Thus, all moving objects encounter -whether in air or water- disturbances. The results presented in this study open the door for modelling the gust and control its undesired effects.

This study is but a foundation upon which further research is to be conducted. In order to fully understand the gust-airfoil interaction and the dampening effect of the rotating leading-edge cylinder, a parametric study should be conducted in which the diameter of the cylinder, the airfoil type, and the angle of attack are changed. Different types of gust should also be modelled to study the response of the airfoil and the consequent control techniques employed to alleviate the gust effects.

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ENVIRONMENT, AGRICULTURE, AND ECOVILLAGES

PAPERS

MUTUAL RELATIONSHIP BETWEEN LAND DEGRADATION AND POVERTY IN SUDAN

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Abstract
This research is attempting to explore relationship between land degradation and poverty in Sudan by using available data that estimate people affected by drought and desertification over half a century. Desertification and drought are phenomena distributed thought the world (include Sudan), and are increasingly connected with food insecurity and vulnerability to climate change and poverty. Sudan is located in arid and semi-arid zone, which is highly susceptible to desertification and drought and both these phenomena are taking place in rural areas where most of the poor people reside. The estimates report showed that 76% of Sudan population are in rural areas and a majority of them engage in the agricultural sector which includes; crop production, livestock and forestry. Previous studies indicated studies indicated 45% the Sudanese's land has been degraded as result of human activities including overgrazing (47%), improper agricultural practices (22%), deforestation (19%), and overexploitation of vegetation for domestic use (13%). Poor rural communities in Sudan depend on their fragile ecosystem for sustenance. Land in Sudan represents a key asset for the livelihoods of the rural poor, as it provides key resources such as food, energy provision, shelter, and fodder. So, when this land is degraded these services will reduce their food supply and income, and finally it worsening their poverty. Because of poverty they are deprived of used modern technology and pushed into the following vicious circle of poverty; poverty-overuse of fragile ecosystem-land degradation-desertification-reduction of productivity - increased poverty. The study highly recommended that Sudan urgently needed to eradicate poverty by developing for combating desertification or vice versa.

***Keywords**:* Land Degradation, Desertification, Poverty, Human Activities, Rural Communities.

INTRODUCTION

Sudan is located in northeast Africa and shares borders with seven different countries namely South Sudan, Central African Republic, Chad, Libya, Egypt, Eritrea, Ethiopia and South Sudan. Sudan sited 22-38° East longitudes and between 10-22° North latitudes. A total land area of Sudan is 1.88.068 million km^2 and these regarding the third largest country in Africa. It is classified into five climate zones due to the vegetation category and precipitation amount. These ecological zones are; (I) desert with 0-75 millimeters of rainfall annually, (II) semi-desert with 75-300 mm, (III) low rainfall savannah with 300-800 mm, (III) high rainfall savannah with 800-1500 mm, and finally (V) mountain vegetation with 300-1000 mm of precipitation (Harrison and Jackson,1958; MEPD, 2015), which represents 41.2%, 33.5%,18.1%, 3.4 % and 3.8 % percentage area of Sudan respectively. Annual temperatures average varies across the country between 26°C and 32°C. The soils of Sudan were classified, depending on location and the mode of formation of these ecological zones, into five types; desert region soil, arid region soil, semi - arid climate soil, monsoon climate soil and highland climate soil. The main water resources in Sudan are the River Nile and its tributers, rainfall and ground water (LDN TSP, 2018). These above-mentioned data reflect that Sudan is a huge country with considerable diversity of ecology. The country population of Sudan was 42

million with an average growth rate of 2.4 %. (Central Bureau of Statistics, 2018). The main driver of the national economy is agriculture and 80% labor force they employed in agricultural sectors (crop and animal production) (Mahgoub, 2014) and represents 32% of the country's economic output (African Development Bank, 2020). These results undoubtedly demonstration that the majority of the people of the country is directly rely livelihood and employment on natural resources. The suitable land for agriculture in Sudan is 122.6 million ha, and12.4 million ha is rain-fed agriculture accounts for 12.4 million ha (Ministry of Agriculture and Forests, 2018). The percentage of the Sudanese population living under the poverty line, is very high accounting about 46.5 % and this percent is varying from one state to another, Khartoum state records is the lowest rate (26.0 %) while North Darfur is the highest rate (69.4 %), addition to these rural areas records higher rates (57.6 %) compare to urban areas (26.5 %) (United Nations, 2014).

Poverty and land degradation are worldwide problems and have more effect in developing countries, including Sudan (Nkonya *et al*. 2008). So, the United Nations Sustainable Development makes two of the goals to compact these two issues; eradicate the poverty and attempt to reach a land degradation neutral world. The most important forms of land degradation in Sudan are overgrazing, poor agricultural practices, damage causes of land wood forestation by the urban need for charcoal and firewood and overuse of vegetation for local use (Ayoub,1998). The increased knowledge of the link between poverty and land degradation in Sudan is needed to implement policies to reduce both of them inappropriate way. In Sudan is an extreme shortage of research to looking to rigorously examine these relations, so, the dearth of appropriate data leads us to look to the relevant available literature. Therefore, the aim of this research is an attempt to explore the link between land degradation and poverty in Sudan focus on caused by anthropogenic and more emphasis on the practice which has been done due to poverty reasons.

MATERIALS AND METHODS

This study is based mainly on a review of the available sources on the relation between soil degradation and poverty in Sudan. A mini literature search using net websites retrieved from a series of scientific search engines such as Elsevier, Google, research Gate, Springer, and many other scientific journal publishing websites. In addition to this, Number of special technical reports on land degradation and poverty at the national levels such as the Department of Agricultural Planning and Statistics, Department of Natural Resources, and Department of Forest in the Ministry of Agriculture, Sudan, and Ministry of Environment, and Natural Resources, Sudan. And reports at the regional level such as African Development Bank and the Sudan country report in international organizations like; United Nations Development Programme (UNDP), Food and Agricultural Organization (FAO), United Nations Environment Programme (UNEP). The United Nations Convention to Combat Desertification Desert Encroachment Control and Rehabilitation Programme (DECRP). Article and reports were searched using the following key; Agriculture, Charcoal, Desertification, Drought, Deforestation, Energy provision, Environmental degradation, food insecurity, Fragile ecosystem, Forest, Firewood, Fuelwood, Farmers, Human activities, Land degradation, Livestock, low-rainfall, Modern technology, Nomadic tribes, Overgrazing, Overexploitation of vegetation, Poverty, pastoralists, Rural communities, Rangelands, Sudan population, socioeconomic, soil erosion, vulnerability to climate change, the vicious circle of poverty, Woodlands cover, Woodfuel and Woodcutting water. Papers and reports were gathered depending on selecting keywords.

LAND DEGRADATION

Special technical report on land and climate change defined land as "the terrestrial portion of the biosphere that includes the natural resources (water, soil, vegetation, and near surface air), the environmental processes, landscape, and human settlements and infrastructure that operate within that system" (UNCCD 1994; FAO 2007; Henry *et al*. 2018). While the definition of land degradation is a damaging occur to land condition, caused by human-induced processes comprising climate change and anthropogenic, stated as loss of at least one of the following: ecological integrity, biological productivity, or value to humans (Olsson et al. 2019). Land degradation also is a natural process and has been taking place since ancient history and at different rates. it includes soil and vegetation degradation. Soil degradation denotes adverse influences in the physical, chemical, and biological characteristics of the soil, while vegetation degradation is the decrease in the number of species and the vegetational composition. Land degradation is a worldwide problem and many authors have revealed is a link to poverty (Barbier and Hochard,2016; Gerber *et al.* 2014; Nachtergaele *et al*. 2010; Nkonya *et al*. 2011; Bai *et al*. 2008). And this is supporting by the remote sensing technique which found some relation between land degradation and the spatial distribution of populations (Nachtergaele *et al*. 2010, Bai *et al*. 2008; de Jong *et al*. 2011). Estimates data show that over 1.5 billion people are affected by land degradation (Bai *et al*. 2008) most of them are poor and live in a rural area (Gerber *et al*.2014, Nachtergaele *et al*. 2010; Nkonya *et al*. 2011). Land degradation is, the outcome of complex interconnection between biophysical and socio-economic issues which affect several populations and their land, especially in developing countries and this includes Sudan. Land degradation parameters related to soil erosion (loss of nutrients and organic matters), changes in soil, structure, texture and final soil fertility in adding to these changes in vegetation cover, decreasing in nutritious plant species, rises in unpalatable (Ahlcrona, 1988; Kibreab, 1996).

LAND DEGRADATION IN SUDAN

Land degradation is the country's first ecological threat, as half of Sudan's land is severely degraded (Abbadi and Ahmed, 2006; FAO, 2012). Land degradation in Sudan is seriously affecting all agricultural systems (agriculture, rangeland carrying capacity, livestock production and forestry), subsequent in socioeconomic and environmental decline and the resulting degradation of all quality aspects of life (Sudan LDN, 2018). The amount area of degraded land was increasing yearly as reported by (UNEP, 2007) which proposed that the boundary between desert and semi-desert had shifted southwards by 50 km to 200 km since 1935. The country has records that the about 2.4 % a year deforestation which is regarding the highest rates one in a developing country (Gafar, 2013) this conformed by (Dahlberg and Slunge, 2007) they noted that the country lost about 11 % of its forest cover in 15 years between 1990 and 2005. The 76% of the human population in Sudan live in rural areas of the most degraded area of the country (UNEP, 1977; FAO/UNEP, 1984; 1990; Dregne, 1991, Ayoub,1998). This means by a crowded population lives in limited land resources. For instance, land degradation also enlarges outwards from concentration points, such as human or livestock and watering points. Studies in western states of country has revealed that increase of bare soil about wells over time, rising in 30 years from 20% to 55% (Redfern, et al. 2005; Epaphras et al. 2008). Soil of Sudan is naturally are poor and extensively used with low and minimum inputs and this causes the land vulnerable to land degradation. Many recourses showed that 20 million ha of land are degraded from severe to very severe degradation by human activities, and there is a strong correlation that seems to occur between human

population densities and degraded soil. Land degradation in Sudan is due to the removal of woodlands cover and forests cover for charcoal and firewood for making energy and overusing of vegetation which degrading about 22M ha. Growing crops without suitable nutrients has degraded about 12M ha, especially in small traditional farming. Poor inhabitants in Sudan who live in the rural areas always looking for sustenance from the natural resource of their fragile environments. They depend on the natural vegetation for building homes, and for providing energy and animal enclosures. The main reasons for land degradation in country are overgrazing, poor agricultural practices, the damage causes to land woodland forestation by an urban need for charcoal and firewood and last overuse of vegetation for local use and this represents 47 % , 22 %, 19 %, and 13 % from total of land degradation respectively (Ayoub (1998).

Overgrazing

Rangelands occupy about half of the country's area. They extend on several ecological zones, in particular, the desert, semi-desert, and low precipitation savannah. They cover about 80 % of animal grazing necessities. Sudan has a huge population of Livestock such as; goats, sheep, cattle, and camels. Livestock is widely practiced under the traditional system and it is the second to crop production in relation to economic activity. Natural grass has many roles to conserve soil such as; carbon sequestration, watershed protection, desertification control, maintaining biodiversity, and release of plant nutrients from plants (Musnad, 1970; Quideau, 2005). According to Ayoub (1998), overgrazing caused about 46.9 % of soil degradation. It is the most damaging process. Overgrazing in the dry soil of Sudan for instance has led to soil degradation via soil compaction and erosion by damaging the vegetation on the soils, the appearance of new type grasses of which low-nutrient e, and upsurge of invasive plant species hereafter leading to decrease of productivity of the land. Overgrazing is more damaging to land degradation especially for nomadic tribes that are totally dependent on local ecosystem facilities for life hood and feed their animal.

Poor agricultural practices

The crop production in marginal land in low-rainfall areas, with accompanied poor agronomic practices such as; improper tillage, absence of soil amendments, and reduced fallow time are a vital cause of land degradation in Sudan, this may be led to a loss of soil biological activity, soil nutrients, permeability and end resulting reduction of soil fertility (DECRP 1976; LDN TSP, 2018). Agricultural expansion, in the absence of an agricultural system that conserves the soil, is seen as one factor contributing to land degradation (Hano, 2014). According to Ayoub(1998) the growing crop with improper agricultural practices causing to a degraded of approximately out 22% of land degradation in Sudan. On the other hand, land suitable for cultivation if not managed in a proper way and accompanied by the ecological setting may become degraded. Rural poor people in Sudan grow crops to feed themselves in marginal land (traditional farming), for instance, the western part of the country exhausts soil organic matter, reduces soil fertility, which results in enhanced soil erosion and accordingly degraded the land. For example, the available data from the ministry of agriculture and forestry showed that the yields of four crops namely sorghum, millet, sesame, and groundnuts were decreased in from1961 to1996. And the reduction of the four crops yield was 40% for groundnut, 44% for sorghum, 58% for millet 50% sesame during the same period (Mustafa, 2007). Replication of growing crops led the vegetation cover and exposure the top fertile soil to wind erosion and the land becomes more vulnerable to degradation (Khairalseed, 2015). Another example of the gum-Arabic belt, the growing crop and forest fallow rotational system, which are a quite more sustainable system was abandoned due to increased population and consequently increased need for growing crop for food Mustafa, 2003. Making fire in forest shrubs and grass and

cutting off bushes for wood to prepare land cultivated are also reasons for land degradation (Mohamed et al. 2016). Burring is often practice in various location of central Sudan. Fires destroy the soil cover or vegetation cover leaving it susceptible to land degradation and desertification (DECARP ,1976; Ministry of Agriculture and Forestry 2006; NDDCU,2001) also stated that fire burning destroys 15–30 % of the herbaceous vegetation every twelve months in Central Sudan.

Deforestation

The main reason causing deforestation in Sudan is cutting wood by pastoralists and farmers for charcoal making or fuelwood, building their home, bush fencing enclosure for their animals. In Sudan, people use three sources of energy are utilized and electricity (hydro and thermal), oil products, natural gas, and biomass (vegetation, wood fuel, and agricultural residues). These three types of energy constituted 2, 17, and 81% of the total energy used in 1990. Rabah et al. (2016) noted that biomass offers 56% of using energy requirements in the Sudan and the majority of it is from fuelwood. Previously natural gas is expensive because was imported and recently is produced locally, but it is still quite expensive for the poor rural communities.Alternative energy sources, such as; solar cookers, gas, and kerosene are still expensive for the poor population who lives in rural communities. Using traditional stove procedures such as the three stones(adayat) and charcoal stove (Mangad) is very high biomass consumption due to its inefficiency of using. As estimated by (Ibrahim,1980) the nomads remove a minimum of 548 million shrubs per year for making food.

Ibrahim (1980) also estimated that in 1977, the average weekly consumption per family in Darfur was about a donkey load of wood, which is about 50kg, and much more wood is employed to build the home and animal enclosures. The annual consumption of timber per family in northern Darfur states is 194.5 in form of bushes or trees are calculated by (Ibrahim,1980). Fuelwood consumption in 2020 ranges from 15.5 million cubic meters as estimated by (Gafaar, 2011) to 25.7 million m3, rising to almost 30 million m3 in 2030 (FAO,2010). Charcoal and Wood fuel by cutting of trees are the main sources of energy throughout the country, and cause the damage is higher in the northern states of the country owing to limited resources. Also, remark the forest area of the near urban area under concentrating pressure. Wood consumption data are usually out of date and if it is available is incomplete, mostly in the rural areas where the majority of the population are poor.

Overuse of vegetation for local use

Vegetation cutting is normal practice by farmers around the villages to clear the land for crop production in traditional farms and after harvesting the crop use seed feed and rest parts of the crop are employed to animal enclosures and building homes and for fuel for cooking. Intensive use of water resources, dropping of the water table in boreholes, which led to lowering groundwater. Increased water practices are explained by, over-cultivation, over-grazing, and overpopulation. The lowering of underground water also is due to the pumping of groundwater for drinking resulting to increase land degradation on agricultural land (DECARP, 1976). Overgrazing, if in small herd grazes near the village and at water points it uprooting of shrubs, burning of grasslands, forests, and shrubs.

Nomadic tribes and travelers, also, set a fire for the night, to hold away the animals of prey or to see cattle thieves. So, if you forget this fire, the fire will be broken out and cause great damage throughout the areas. Particularly in the dry season, in which grazing was expected will be limited, thus the loss of vast pastures will be critical. Moreover, until now some traditional bakeries in some urban areas (cities and villages) use wood fuel.

THE VICIOUS CIRCLE OF POVERTY

These unavoidable adverse activities have been done by poor communities in rural areas in Sudan lead to enhancing land degradation, which causes more poverty, and more dependent on the fragile ecosystems and thereby completes a poverty vicious circle. Because of poverty they are not enabled to use of modern technology and pushed into the following vicious circle of poverty: poverty-overuse of fragile ecosystem -land degradation-desertification-reduction of productivity-increased poverty. Land degradation is both a cause and a result of poverty, which at the end of the day forces affected people to search for their livelihoods from fragile resources and which causes endemic degradation (UNEP, 2020). In Sudan, land degradation and poverty are mutually linked. Poverty is caused partially by, the misuse of environmental resources and natural disasters. Human deficiency and environmental degradation are mutually strengthening since poor people are enforced to create income by abusing natural resources, for instance, a drop in crop, or forest or rangeland productivity may result in decreased profits for pastoralists and farmers, higher prices of food and, more unemployment, greater dependence on disaster relief and an increase in rural-urban migration. Rural-urban migration causes a rise in the burden of social services, which often lead to greater poverty. The link between land degradation and poverty is directly influenced by all those who are dependent on the land as a basic resource, whether for crops production or forest and livestock.

CONCLUSION

Further detailed studies are needed to confirm these scattering data to clear the relation between poverty and land degradation in a view of occurrence and extent in Sudan because the linkage between two factors is more complex and interaction with another factor such as; socioeconomic or environmental factors. the national and international effort should be coordinated to solve these issues and simultaneously due to the fact any neglect of one issue maybe affects the other, to eradicate both problems because too difficult to these local poor communities. Some solutions are recommended to minimize the influence of poverty and land degradation such as; agroforestry cultivation, appropriate land use planning and regulation, adopting better agricultural practices to provide modern technologies. In addition to this, looking for appropriate ways to reduce woodcutting by using technologies to save energy or alternate types of energy such as solar energy, wind fan, and electricity generation and supply them for rural poor communities, management charcoal market by using aged serves tree and create new practical methods reforestation for lessening the adverse influence of wood cutting. On another hand, to compact poverty, it is necessary to support livelihoods for people who are more susceptible to land degradation areas for sustainable food production at the household level, including increasing incomes and find job opportunities, and providing, education, sanitation facilities, health care.

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THE SMART JUBRAKA: A SUSTAINABLE HOME GARDEN FOR FOOD SECURITY

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Abstract

Sudan has long-standing consequences of Structural Adjustment Programs (SAP), manifested in food security emergencies due to macroeconomic crises, with inflation rates reaching 412% by June 2021, depleting household purchasing power to spend up to 75% of their income on food. Numerous studies have shown that farmers' indigenous knowledge possesses sustainability in their practices, methods, and technology, but that heritage is under threat from modern farming approaches that gradually replace them without understanding the potential behind this heritage, less proper adoption, and hindrance in transferring technology. Women play an integral role in Sudan's traditional household farming system known as Jubraka (home gardens), which directly contributes to the food and nutrition security of the family. In this study, we present a multidisciplinary framework for Smart Jubraka in West Kordofan state to improve and increase the agriculture production of home gardens and empower rural women. Different elements in the framework promote plant diversity, farming practices, nutritional consumption patterns and contents, biological pest control, and optimized plant yields. A garden that is enhanced and upgraded may contribute to women's empowerment, reduce child malnutrition risks, increase food security, and strengthen community resilience to climate change.

Keywords: Smart Jubraka, Food Security, Sustainable Development.

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ELECTROCOAGULATION OF CATTLE MANURE WASTEWATER

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Abstract
As the annual global growth of livestock manure rapidly increases, more effective agricultural best management for manure management is needed to address turbidity and phosphorus (P) contamination in water bodies. Livestock lagoon wastewater and tile drainage water contain elevated P. When Manure spills occur on animal farms critical amounts of P are discharged into rivers. Manure pollution can lead to water quality impairment, death of aquatic organisms, and public health concerns. The purpose of this study was to determine the effectiveness of electrocoagulation in the reduction of turbidity and orthophosphate (OP) in cattle manure lagoon wastewater (CMLW) and tile drainage water. Electrocoagulation (EC) can mitigate pollutants such as turbidity and P from livestock wastewater and tile drainage effluent. Although electrocoagulation has been shown to effectively purify industrial wastewater, integrating this technique into agricultural best management practices is significantly understudied, especially for the control of CMLW and tile drain pollution. The electrocoagulation batch reactors were developed in the study using carbon steel (iron) electrodes to effectively reduce turbidity and OP in unprocessed, raw, undiluted CMLW, 50% diluted CMLW, 12% diluted CMLW, tile drain water, and synthetic P solution. Results showed undiluted CMLW demonstrated the highest reduction of both turbidity and OP by 96% when operating at 0.5 A for 15 h. Turbidity initially increased during electrocoagulation; then, after 2 h, a rapid decrease occurred, therefore suggesting iron anode dissolution into agricultural wastewater is necessary to obtain a more transparent solution with reduced OP and turbidity. The results from this study highlight the effectiveness of electrocoagulation technology to reduce turbidity and OP from agricultural wastewater.

Keywords: Electrocoagulation, Phosphorus, Cattle, Manure, Water.

INTRODUCTION

By the year 2030, livestock manure is projected to significantly contribute to the 5 billion Mg annually of human and animal waste expected to be produced on the planet at that time (Berendes, Yang, Lai, Hu, & Brown, 2018:679). Some countries, like the Netherlands, produce more cattle manure than they can legally apply. Meanwhile, China attempts to drastically reduce manure discharged into rivers (Central Bureau of Statistics, 2016; Central Bureau of Statistics, 2015; Statistics, 2010; Strokal, Ma, Bai, Luan, Kroeze, Oenema, Velthof & Zhang, 2016: 024014). Despite the scope of the problem, containment and safe use of animal fecal wastes have not been priorities in global sanitation policy (Berendes *et al.* 2018:679). The increase in manure from livestock production presents an opportunity to find new, innovative approaches to treating manure and recovering valuable resources, including nutrients, energy, and heavy metals (Uludag-Demirer, Olson, Ives, Nshimyimana, Rusinek, Rose, & Liao, 2020:2697).

Manure best management practices (BMPs) include spreading or crop irrigation, which is said to improve soil fertility and stimulate crop growth by providing organic nitrogen (N) and forms of soluble P, referred to as orthophosphate or phosphate (OP). However, repeated manure

applications beyond crop requirements increase the soil concentration of P and the degree of P saturation (Sims, Simard & Joern, 1998:277). Previous manure management techniques have proposed solutions for only small-scale or integrated crop and livestock farms (Hai, Schnitzer, van Thanh, Thao, & Braunegg, 2016: 274; Huong, Madsen, Xuan Anh, Thi Ngoc & Dalsgaard 2014:53; Nhan, Milstein, Verdegem, & Verreth, 2006:160; Roubík, Mazancová, Banout, & Verner, 2016:2784; Roubík, Mazancová, Phung, & Banout, 2018:362; Thien, Cuong, Hang, Chao, Anh, Trach, & Sommer, 2012:64; Vu, Tran, Nguyen, Chi Vu, Khanh Vu, Jensen, 2012:1). However, these solutions have not been mentioned for intensive farming systems such as contract farming (Huong, Takahashi, Nomura, Son, Kusudo& Yabe, 2020:136200).

When manure spills are discharged into rivers, this can present an excess in both N and P causing eutrophication. Nutrients discharged can affect the healthy background levels of N and P, typically governed by the Redfield ratio 106 C:16 N:1 P, where the limiting reagent is P. The Redfield ratio is widely used as an optimum for algal growth, although other factors, such as light or temperature, often also influence algal growth (Hecky, Campbell, & Hendzel, 1993:709; Redfield, 1960:205). As a result of continued eutrophication, aquatic life populates and grows rapidly consuming excess nutrients until dissolved oxygen is depleted. After the oxygen is consumed, algal outbreaks and hypoxia can occur. Therefore, to prevent excessive algae growth in freshwater, it is more effective to control the governing limiting reagent, P, as opposed to N (Daniel, Sharpley & Lemunyon, 1998:251). Monitoring P in manure discharge may prove to prevent eutrophication.

Several studies were completed using iron electrodes to prove the efficacy of electrochemistry to treat the non-point source and point-source wastewater (Asaithambi, Beyene, Aziz, & Alemayehu, 2018:1; Đuričić, Malinović & Bijelić, 2016:33; El-Shazly & Daous, 2013:184; Tian, He, Liang, Yang, Logan, & Ren, 2018:129). A limited number of studies analyzed EC concerning the reduction of phosphorus, turbidity, TDS, salinity, and conductivity of animal manure. Although successful studies of EC exist, there is limited agricultural literature that characterizes the cumulative energy consumption required to significantly reduce turbidity and OP in CMLW and tile drain water.

This research evaluated the feasibility of EC treatment using carbon steel iron electrodes (which will be referred to as “iron electrodes”) in a batch operating mode to reduce both turbidities, measured in NTU, and OP, with units of mg-PO4 L-1, in agricultural wastewater. The experiments involved a novel design of an EC prototype with a constant current design. Point-source agricultural pollution was represented by cattle manure lagoon wastewater (CMLW) samples and tile drainage water. Water quality parameters including OP, turbidity, TDS, conductivity, salinity, pH, and temperature were monitored during EC.

MATERIALS AND METHODS

Electrocoagulation batch reactor design

Two EC batch reactors with dimensions 41 x 13 x 10 cm were built from a 20 L plexiglass aquarium (Carolina Biological Supply Company, Burlington, NC). Located inside the two batch reactors were a plastic anode and cathode spacer. This electrode spacer always maintained a 2.5 cm spacing between the anode and cathode during experiments. The iron electrodes were inserted into the electrode spacer housed inside the two EC batch reactors.

To represent agricultural wastewater pollution, each batch reactor was filled with 4.0 L of CMLW samples. The cattle manure was obtained from a local dairy farm lagoon pit. Cattle

manure lagoon dilutions were expressed as the ratio of the volume of liquid manure per total volume (v/v) of the solution, multiplied by 100. Therefore, samples included undiluted CMLW, 50% CMLW, and 12% CMLW, with treatment time 15 h, 10 h, and 5 h, respectively. Tile water samples and synthetic PO_4 solution were treated for 5 h. To serve as a source of fertilizer water with low turbidity, water samples were obtained from a tile drain pond on the University of Illinois corn and soybean farm. The control used as a baseline for EC experiments was a synthetic PO_4 solution formulated with low turbidity to represent synthetic P from fertilizer and livestock waste.

Electrocoagulation batch reactor simulations

Electrocoagulation treatment of 4 L of cattle manure water in each batch reactor was initiated by pressing the run button in the MATLAB® graphical user interface. This action started the flow of 0.5 A of current from the anode, through the cattle manure wastewater or tile water, to the cathode. The synthetic orthophosphate solution operated at 0.1 A to represent the minimum current and baseline operating conditions. Initially, a 125 mL sample of the cattle manure water was obtained from the two EC batch reactors before initiating the electrical current between the anode, cattle manure water, and the cathode. After 1 h of constant 0.5 A of electrical current to treat cattle manure water, a 125 mL water sample was obtained every 1 h from each EC batch reactor.

For each hourly sample, the water quality parameters TDS, conductivity, salinity, temperature, pH, turbidity, and OP were measured. The gradual reduction in turbidity, OP, TDS, conductivity, and salinity was evidence the EC process was carried out properly. The TDS, conductivity, salinity, and temperature were measured using a waterproof multi-parameter pocket tester (Apera Instruments, Columbus, OH). The pH was measured using a pH probe obtained from Oakton pH 700 Benchtop Meter with National Institutes of Standards and Technology (NIST) traceable calibration (Oakton Instruments, Vernon Hills, IL). Turbidity, measured in Nephelometric turbidity units (NTU) and based on white light (400–680 nm) and 90° incident angle, was measured using an Environmental Protection Agency (EPA) certified and calibrated portable device (Hanna Instruments, Smithfield, RI).

To prepare samples for phosphate analysis, post-settling of flocculant particles in the 125 mL EC water samples were filtered using a 0.45 µm filter. An Astoria Autoanalyzer (Astoria-Pacific, Clackamas, OR) determined the OP concentration measured in mg-PO_4 L^{-1}. The 4500-P F-Automated Ascorbic Acid method was applied to the analyzer. To convert OP to units of P, multiply OP times 3, which gives mg P L^{-1}.

Removal efficiency equations

The turbidity removal efficiency (TRE) was determined using an adapted ***Equation 1*** below (Asaithamb *et al.* 2018:1):

$$TRE\ (\%) = \frac{([NTU_i]) - ([NTU_t])}{NTU_i} \times 100\% \quad (1)$$

where NTU_i is the initial turbidity of the sample before EC treatment measured in NTU, NTU_t is the final turbidity after EC treatment at time t for corresponding agricultural wastewater samples.

The equation to represent the OP removal during EC is shown in ***Equation 2*** (Đuričić *et al.* 2016:33):

$$E_U = \frac{\gamma_i - \gamma_f}{\gamma_i} \times 100\% \quad (2)$$

where E_U is the percent removal efficiency of OP as % PO_4, γ_i represents the initial concentration of OP, before EC treatment, expressed as mg-PO_4 L^{-1}, and γ_f is the final concentration of OP, after EC treatment, expressed as mg-PO_4 L^{-1}. Operational cost and energy consumption were determined in prior studies using industrial and domestic wastewater (Asaithamb *et al.* 2018:1; Tian *et al.* 2018:129) to assess the sustainability and economic feasibility of the process.

Statistical Analysis

Statistical analysis was done using descriptive statistics of data from duplicate time-series experiments following EC treatment. Mean values are represented by an average of two duplicate values. Error terms were estimated using the half-range formula, where the maximum data value minus the minimum data value is divided by 2.

RESULTS

Electrocoagulation effects on agricultural wastewater

The purification of cattle manure water was accomplished during EC batch reactor experiments. More specifically, this process measured the ability of electrolysis to reduce turbidity and OP, and the energy consumption required to obtain this reduction. Before EC of the cattle manure, lagoon wastewater samples were brown. After electrolysis, the samples were clear in color. All experiments displayed a trend towards increasing pH. Turbidity increased and then decreased during treatment, except for the tile drain water and synthetic phosphate water. For all other water quality parameters, including salinity, conductivity, and TDS, a reduction was observed. Variation in pH occurred for all experiments using agricultural wastewater; however, the range in pH for all experiments remained alkaline (pH of 5.43 to 10.03, n=128), with an average value of 8.56. An increase in pH values was observed in all EC treatments. The pH in all experiments increased independently of the amount of turbidity reduction.

Turbidity reduction

The duplicate EC batch reactors for undiluted, 50% diluted, and 12% diluted manure lagoon wastewater showed that turbidity initially increased, then, after additional EC treatment time turbidity was rapidly reduced. EC of tile drain, water and synthetic solution resulted in only an increase in turbidity in 5 h. Turbidity data was measured in NTU for each experiment and is demonstrated in **Figure 1**.

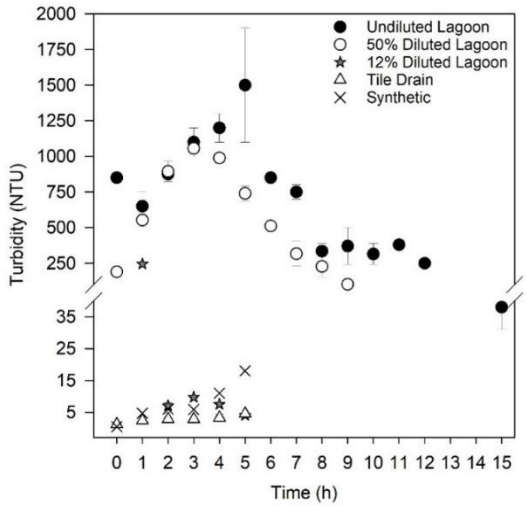

Figure 1: *Turbidity data.*

Duplicate hourly turbidity samples were taken during electrocoagulation experiments with EC time ranging from 5-15 h. All experiments ran at 0.5 A except for synthetic phosphate solution at 0.07 A. Undiluted manure lagoon wastewater sample had the highest turbidity removal at 95%, while the 50% diluted lagoon wastewater resulted in a 56% reduction, 12% diluted lagoon: 92%. No reduction of turbidity occurred for tile drain and synthetic P water. The error bars represent the half-range error.

It can be seen from ***Figure 1*** that using a constant current at 0.5 A, 12%, 50%, and 100% cattle lagoon wastewater samples presented turbidity reduction rates of 92% (55 NTU – 4 NTU) in 5 h there was a 56% reduction (190 NTU – 83 NTU) in 10 h and 95% (850 NTU – 31 NTU) in 15 h, respectively. By contrast, the experiments using tile water (1.25 NTU – 4.55 NTU) and synthetic phosphorus (0.5 NTU – 18 NTU) did not present removal in the 5 h experimental time compared to high turbidity samples; instead, an increase in turbidity was observed.

During the EC experiments for and for 12%, 50%, and 100% cattle manure lagoon wastewater, an increase initially in turbidity occurred, then after some time, the turbidity was reduced below the initial NTU value before EC treatment, except for tile drain and synthetic trials. However, water quality parameters such as pH, dissolved solids, and conductivity decreased over time. Except for turbidity, the removal rate of water quality parameters, including TDS, salinity, and conductivity, showed a linear relationship with time. The 100%, 50%, and 12% CMLW all presented similar turbidity trends, signifying that the dissolution of iron d is not linear.

Orthophosphate removal

Each treatment showed an initial maximum decrease in OP during all EC batch reactor experiments among the five different agricultural water types tested in under 3 h. All experiments resulted in OP concentrations of less than 1 mg PO_4 L^{-1}. The phosphate concentrations observed over time for each experiment are demonstrated in ***Figure 2***.

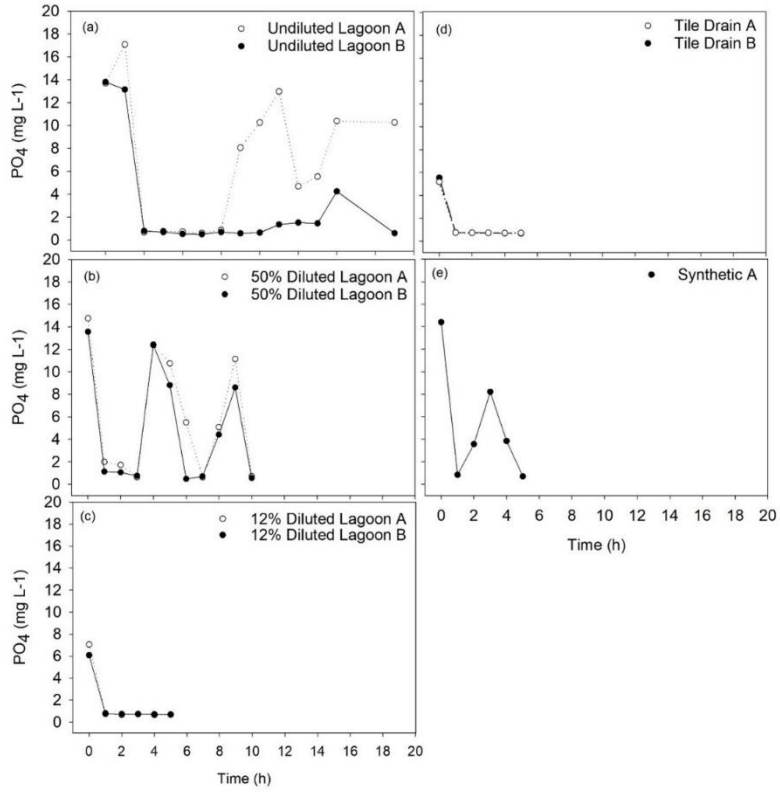

Figure 2: *Phosphate concentrations.*

Hourly orthophosphate (mg-PO_4 L^{-1}) samples during electrocoagulation were analyzed for (a) undiluted lagoon wastewater (95% reduction at 2 h); (b) 50% diluted lagoon wastewater (95% reduction at 3 h); (c) 12% diluted lagoon wastewater (88% reduction at 1 h); (d) tile water (86% reduction at 1 h); (e) synthetic solution (94% reduction at 1 h). Initial operating condition used 0.5 A and 0.07 A for synthetic water.

In 2 h of EC treatment of undiluted manure, the lagoon wastewater samples showed an increase in turbidity while orthophosphate concentration was decreased by 95% (initial PO_4 concentration: 13.7 mg L^{-1}; final PO_4 concentration: 0.73 mg L^{-1}). In the 50% diluted manure lagoon wastewater experiments, a 95% reduction in phosphate occurred in 3 h (initial PO_4 concentration: 14.2 mg L^{-1}; final PO_4-P concentration: 0.69 mg L^{-1}). In the treatment of the 12% diluted manure lagoon samples, a rapid reduction of 86% phosphate was observed in 1 h (initial PO_4 concentration: 6.6 mg L^{-1}; final PO_4 concentration: 0.75 mg L^{-1}). The 12% diluted manure lagoon experiment showed an early decrease in turbidity starting at 1 h until the completion of the EC treatment (5 h) compared to all the other experiments, this was the only trial where at 2 h, the turbidity decreased as OP decreased.

Orthophosphate removal in low-turbidity waters

During the tile drain water experiments, at 2 h OP's initial concentration decreased by 86% reduction of phosphate was recorded (initial PO_4 concentration: 5.4 mg L^{-1}; final PO_4 concentration of 0.74 mg L^{-1}). Turbidity was reduced by 87% in 2 h from an initial NTU of 55 to a final NTU of 7. The performance of the EC using low turbidity synthetic water resulted in an increase from the initial turbidity of 0.5 NTU to 4.7 NTU as opposed to a maximum reduction of OP at 1 h, reduced by 94% (initial PO_4 concentration: 14 mg L^{-1}; final PO_4 concentration: 0.8 mg L^{-1}). The agricultural pollution samples, including undiluted CLMW, 50% diluted CLMW, and synthetic phosphate water, had a higher initial OP concentration than the 12% diluted CLMW and the tile drain water, which resulted in a larger cumulative OP removal compared to the low orthophosphate concentration samples.

DISCUSSION

Despite the effects of sludge build-up on the electrodes, a novel EC reactor powered by a constant-current circuit showed proof of concept in reporting the relationship between time and energy consumption required to reduce turbidity and OP using different types of agricultural pollution: unprocessed livestock waste, tile drainage water, and synthetic OP solution. No additives were used in this study to enhance the electrolyte efficiency for better EC results, nor were the agricultural samples adjusted for pH. This investigation was designed to treat agricultural pollution on an industrial in-field level without additional treatment or the addition of chemicals.

Turbidity removal efficiency compared to prior studies

A comparison of prior EC studies treating different types of wastewater using carbon steel electrodes is shown in ***Table 1***. Although EC treatment determined OP removal, the turbidity reduction for dairy lagoon effluent, dairy manure, and synthetic wastewater was not evaluated (Mukhtar *et al.* 2009; Zhang *et al.* 2016:57960; Đuričić *et al.* 2016:33). The energy consumption was also not reported for the scaled-up EC unit onsite of a dairy farm with 700 lactating cattle (Mukhtar *et al.* 2009). In previous experiments, the turbidity and OP removal efficiency achieved over 90% and 60%, respectively. Nasution, Yaakob, Ali, Tasirin & Abdullah (2011:1332) reported that in an 8 h EC treatment on palm oil mill effluent, a gradual

reduction of turbidity at 62%, was visualized with respect to time. Another study determined a 70% color reduction in landfill leachate with pH 7.83 and electrodes 2.5 cm apart, with energy consumption of 0.27-2.18 kJ L^{-1} (Asaithamb *et al.* 2018:1).

Polluted Water Sources	Initial Experimental Conditions	Turbidity Removal Efficiency	Electrical Energy Consumption	OP Removal Efficiency	Energy Required for OP Reduction	Ref.
*Dairy lagoon effluent	PO_4: 17 mg L^{-1} pH: 7.8 Scale: Field	-	-	99.6%	-	(Mukhtar *et al.* 2009)
Dairy manure	Current: 0.6 A PO_4: 67.5 mg L^{-1} pH: 7.4 Time: 100 min Scale: Batch Volume: 0.8 L	-	-	96.7%	875 kJ g^{-1}- PO_4	(Zhang *et al.* 2016:57960)
Synthetic wastewater	Current: 5 A PO_4: 25 mg L^{-1} pH: 3 Time: 40 min Scale: Batch Volume: 0.2 L	-	-	63.4%	115 kJ g^{-1}-PO_4	(Đuričić *et al.* 2016:33)
Anaerobic Digestion Effluent (Mixed food and municipal sludge)	Current: 2 A pH: 7-8 Turbidity: 4663 PO_4: 29 mg-PO_4 L^{-1} Time: 10 min Scale: Batch Volume: 60 L	90%	-	99.2%	1,954 kJ g^{-1}-PO_4	(Uludag-Demirer *et al.* 2020:2697)
Cattle Manure Lagoon Wastewater	Current: 0.5 A PO_4: 6.6-14 mg-PO_4 L^{-1} Turbidity: 50-850 NTU pH: 7.74-9.08 Time: 15 h Volume: 4.0 L	56-95%	178 to 226 kJ	94-96%	422 kJ g^{-1}-PO_4 [a] 745 kJ g^{-1}-PO_4 [b] 3,113 kJ g^{-1}-PO_4 [c]	This Study
Tile Drain Water	Current: 0.5 A PO_4: 5.4 mg-PO_4 L^{-1} Turbidity: 1.3 NTU pH: 7.74 Time: 10 h Volume: 4.0 L	No Reduction	183 kJ	86%	4,134 kJ g^{-1}-PO_4	This Study
Synthetic P	Current: 0.07 A PO_4: 14 mg-PO_4 L^{-1} Turbidity: 0.5 NTU pH: 6.13 Time: 5 h Volume: 4.0 L	No Reduction	25 kJ	94%	94 kJ g^{-1}-PO_4	This Study

[a]Undiluted lagoon, [b]50% diluted lagoon, [c]12% diluted lagoon
*Economic cost to treat dairy lagoon effluent was $0.12 per liter or $30 per 1000 liters.
Table 1: *Turbidity and OP removal efficiency of different wastewater by EC.*

In this current study, the EC treatments showed an initial increase in turbidity, in contrast to what was reported in prior studies shown in ***Table 1***. This phenomenon can be described as the dissolution of iron, a required mechanism for successful EC treatments. The dissolution mechanism supports the major finding in this study that turbidity is initially increased during experiments, reaches a critical value, then reduces significantly as the precipitation of particles begins to settle. A similar study observed similar results, where negative consequences of the sacrificial anode contributed to the emergence of undesirable color and an increase in the proportion of dissolved solids in the treated effluent (Valente, Mendonça & Pereira, 2012:1713).

Orthophosphate and turbidity removal efficiency compared to prior studies

In the current study, removal of OP observed during EC experiments saw an initial decrease in cumulative OP removal in 2 h. In contrast to the OP reduction, an increase in turbidity was observed, resulting in an inverse relationship between OP and turbidity. For instance, prior studies reported that turbidity does not increase but decreases over the entire time series of the experiment (Đuričić *et al.* 2018:33; Uludag-Demirer *et al.* 2020:2697; Asaithamb *et al.* 2018:1; Nasution *et al.* 2011:1332). Iron electrodes passing 5 A through synthetic wastewater, in a previous batch study, showed 50.2% turbidity reduction with 30% OP reduction from an initial 100 mg-PO_4 L^{-1}, salinity 250 mg L^{-1}, in 10 min of treatment time (Đuričić *et al.* 2016) compared to the current study which saw a range of 28-96% OP reduction.

Initial OP concentrations for prior studies were almost twice as high as the values in the current study. The energy consumption is also higher in previous studies, even though the EC treatment time was significantly lower. However, the tile drain water resulted in higher energy consumption than synthetic wastewater and anaerobic digestion trials. Significant reduction of OP can occur during long or short treatment times with a current over 0.07A, however, turbidity removal efficiency requires at least 0.5 A with initial turbidity of at least 50 NTU and treatment time over 5 h. Therefore, wastewater with larger OP concentrations required a higher energy consumption for the mass of P removed during EC treatment.

CONCLUSION

The study documented in this paper achieved significant removal of turbidity and OP using iron electrodes during the EC batch reactor investigation. This research addressed shortcomings of agricultural best management practices and prior studies by focusing on reducing turbidity and OP for tile drain and CMLW. Therefore, the EC prototype designed in the study demonstrated the potential to purify point source animal wastewater by removing turbidity and OP significantly, using a low operating current and energy consumption. After the initial maximum cumulative reduction in OP, fluctuations in OP concentration were observed until the completion of the experiment. Further investigation on strategies to inhibit the increase in OP concentration after initial reduction should be further investigated. Future applications and broad impacts of the study require that EC technology is scaled to field level and then tested to address the sustainability of using electrolysis systems on farms. More testing is required on diverse animal manure lagoon samples, including swine, poultry, and equine, to determine the overall effectiveness of the proposed technology in removing OP from cattle wastewater. For nutrient management by farmers, electrolysis could be used as a candidate for best management practice for OP pollution prevention.

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EFFICACY OF CONSTRUCTED WETLAND IN THE IMPROVEMENT OF EFFLUENT FROM SOBA STABILIZATION PONDS, KHARTOUM, SUDAN 2021

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Abstract

Background: *Wetland is one of the natural treatment systems, where contaminants are removed via a range of natural processes mediated by complex interaction between water, plant, microorganisms, soil/gravel media and atmosphere. While utilizing the power of nature and energy from the sun, polluted water can be cleaned in sustainable way, with minimum operation and maintenance cost. **C**onstructed wetlands (CWs) are planned systems designed and constructed to employ wetland vegetation to assist in treating wastewater in a more controlled environment than occurs in natural wetlands.*

Methods: *This is a descriptive study carried out in Khartoum state. Aimed to assess the role of constructed wetland in improvement of effluent characteristics from Soba stabilization ponds in Khartoum – Sudan.*

A small prototype of a constructed wetland was constructed in an open area in Khartoum. The treatment is done by passing wastewater through substrate media that rely on physical, chemical, and biological processes for removal of contaminants. These are removed via a range of natural processes mediated by complex interaction between water, plant, microorganisms, soil/gravel media and atmosphere. The used prototype with dimensions (1.5×3) m, depth (0.8) m, (1) % slope, daily flow (0.257) m3/d, and with retention time 14 days. Samples were systematically collected from the inlet and outlet of prototype during the whole month. Subsequently, samples were subjected to analysis in the laboratory.

Results: *The study reached good results in effluent characteristics such as Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Suspended Solids (TSS), and Pathogens, which were removed by 85.4%, 95%, 98%, and 95%, respectively. And the performance is moderate in removing of Metal, Nitrogen, Phosphor, and Ions.*

Conclusion: *The system is most cost effective and sustainable.*

This study recommended Stop discharge effluent of Soba Stabilization ponds directly into White Nile River, applying constructed wetland technique in treatment of wastewater in Sudan due to availability of wild lands, good climatic conditions that fit to the plant growth requirements, and also availability of plant species to be used in these systems (reed is recommended).

Keywords: Natural Treatment Systems, Wastewater, Constructed Wetland.

INTRODUCTION

Most aquatic ecosystems around the world, especially rivers, lakes and reservoirs, have been polluted by untreated domestic sewage/wastewater, mining waste, industrial wastewater, agricultural waste, and other pollutants (von,*et al*., 2005). Sewage is the wastewater generated by a community, namely; domestic wastewater, from bathrooms, toilets, kitchens, etc., raw or treated industrial wastewater discharged in the sewerage system, and sometimes rain-water and urban runoff. Domestic wastewater is the main component of sewage, and it is often taken as a synonym. Wastewater contains a number of pollutants and contaminants, including plant nutrients (nitrogen, phosphorus, potassium), pathogenic microorganisms (viruses, bacteria,

protozoa and helminthes), heavy metals (e.g., cadmium, chromium, copper, mercury, nickel, lead and zinc), organic pollutants (e.g., polychlorinated biphenyls, polyaromatic hydrocarbons, pesticides), and biodegradable organics (BOD, COD), and micro-pollutants (e.g., medicines, cosmetics, cleaning agents). All of these can cause health and environmental problems and can have economic/financial impacts (e.g., increased treatment costs to make water usable for certain purposes) when improperly or untreated wastewater is released into the environment; nutrient contamination and microbial water quality issues are considered (Brears, 2018).

The concept of sanitation on the other hand, includes wastewater collection and treatment systems that become a matter of concern in order to protect public health and the environment, especially the sources of drinking water (Feigin, *et al*., 2012). Sewage treatment is the process of removing contaminants from wastewater, primarily from household sewage. It includes physical, chemical, and biological processes to remove these contaminants and produce environmentally safe treated wastewater (Bressani, 2019).

Today, a wide range of treatment technologies are available for use in our efforts to restore and maintain the chemical, physical, and biological integrity of the nation's waters. During the past 20 years, considerable interest has been expressed in the potential use of a variety of natural biological systems to help purify water in a controlled manner (Mitsch, *et al*., 2003). One of the natural treatment systems is wetland, where contaminants are removed via a range of natural processes mediated by complex interaction between water, plant, microorganisms, soil/gravel media and atmosphere. While utilizing the power of nature and energy from the sun, polluted water can be cleaned in sustainable way, with minimum operation and maintenance cost. **C**onstructed wetlands (CWs) are planned systems designed and constructed to employ wetland vegetation to assist in treating wastewater in a more controlled environment than occurs in natural wetlands.

Hammer (1990) defines constructed wetlands as a designed, manmade complex of saturated substrate, emergent and submerged vegetation, animal life, and water that simulate wetlands for human uses and benefits. CWs are “eco-friendly” alternatives for secondary and tertiary municipal and industrial wastewater treatment. The pollutants removed by CW’s include organic materials, suspended solids, nutrients, pathogens, heavy metals and other toxic or hazardous pollutants. In municipal applications, they can follow traditional sewage treatment processes**.** The objective of using CWs is to remove organic matter, suspended solids, pathogenic organisms, and nutrients such as ammonia and other forms of nitrogen and phosphorus. The growing interest in wetland system is due in part to recognition that natural systems offer advantages over conventional activated sludge and trickling filter systems. When the same biochemical and physical processes occur in a more natural environment, instead of reactor tanks and basins, the resulting system often consumes less energy, is more reliable, requires less operation and maintenance and, as a result costs less. They also are used for removing heavy metals and toxic compounds (Stefanakis, *et al*., 2014).

Constructed wetlands for wastewater treatment can be categorized as either Free Water Surface (FWS) or Subsurface Flow (SSF) systems. In FWS systems, the flow of water is above the ground, and plants are rooted in the sediment layer at the base of water column. In SSF systems, water flows through a porous media such as gravels or aggregates, in which the plants are, rooted (Tatum, 2015). FWS systems are very appropriate for polishing secondary and tertiary effluents, and for providing habitat. The environment in the FWS systems is generally aerobic at, and near, the surface, tending toward anoxic conditions near the bottom sediment. The microbial film grows on all available plant surfaces, and is the main mechanism of pollutant removal. FWS usually exhibits more biodiversity than does SSF systems.

On the contrast, SSF systems are most appropriate for treating primary wastewater, because there is no direct contact between the water column and the atmosphere. There is no opportunity for vermin to breed, and the system is safer from a public health perspective. The system is particularly useful for treating septic tank effluent or grey water, landfill leach ate and other wastes that require removal of high concentrations organic materials, suspended solids, nitrate, pathogens and other pollutants. The environment within the SSF bed is mostly either anoxic or anaerobic. Oxygen is supplied by the roots of the emergent plants and is used up in the Bio film growing directly on the roots and rhizomes, being unlikely to penetrate very far into the water column itself. SSF systems are good for nitrate removal (denitrification), but not for ammonia oxidation (nitrification), since oxygen availability is the limiting step in nitrification (Tatum, 2015).

The advantages of Constructed wetlands are:

(1) Relatively inexpensive to construct and operate.
(2) Easy to maintain.
(3) provide effective and reliable wastewater treatment.
(4) Relatively tolerant of fluctuating hydrologic and contaminant loading rates (optimal size for anticipated waste load), and
(5) Provide indirect benefits such as green space, wildlife habitats and recreational and educational areas (Davis, 1995).

Even though the potential for application of wetland technology in the developing world is enormous, the rate of adoption of wetlands technology for wastewater treatment in those countries has been slow. It has been identified that the current limitations to wide spread adoption of CW technology for wastewater treatment in developing countries is due to the fact that they have limited knowledge and experience with CW design and management (Zhang *et al*.,2015). The Constructed Wetland is assumed to be a suitable system for Sudan due to availability of wild lands; the system is most cost effective and sustainable. Also, good climate condition of Sudan that fit to the plant growth requirement (moderate high Temperature, Relative Humidity, long summer, clear sky less smoke), and also availability of plant species to be used in these systems. Constructed wetland technology is environmentally friendly and less expensive than other physical–chemical methods, because it involves natural processes resulting in the efficient conversion of hazardous compounds (Fakhru, *et al*., 2009).

Justification

- The characteristics of wastewater effluent from Soba treatment plant are not satisfying the national and international standards for discharge into surface water but they are satisfying standards for unregistered irrigation due to the high values BOD_5^{20} 38.5 mg/l, COD 74 mg/l, TSS 70 mg/l, and total coliform $1.9x10^{10}$ CFU/ml (Mohamed, 2011).
- With regard to water quality improvement and best treatment of the sewage water, constructed wetlands (CWs) have a great potential for the treatment of wastewater. These systems consist of beds or channels which have been planted with helophytes (water loving plants, that are available and naturally grow in Sudan), which rely upon physical, chemical and biological processes to remove contaminants from wastewater. All types of the constructed wetlands are capable of removing nitrogen, phosphorus, biochemical oxygen demand, chemical oxygen demand, total suspended solids, metals and pathogens from different types of domestic and industrial wastewater (Choudhary, *et. al*., 2011).
- Treatment wetlands provide cost-effective and sustainable alternative to treat sewage water.

Expected Outcome
This system is expected to have Aesthetics and enhances the landscape, through provision of acceptable quality of treated wastewater for irrigation of recreational areas, good and cheap alternative of treatment systems that operated by unskilled workers with less cost compared to the other more costly systems

Use of Outcomes
Results of this study are expected to be useful for different governmental institutions such as ministry of urban planning and ministry of health.

Objectives:
The general objective of the study is to assess the role of constructed wetland in improvement of effluent characteristics from Soba stabilization ponds in Khartoum – Sudan, and the specific objectives are:

- To measure the efficacy of the constructed wetland in the reducing BOD and TSS.
- To measure the efficacy of the system in the reduction of organic and inorganic matter.
- To determine the efficacy of the system to reduce the pathogenic bacteria.
- To identify efficacy of the system in the reduction of heavy metals and soluble ions.

MATERIALS AND METHODS

Study Design: This is a descriptive study.
Study Area:
A small prototype of a constructed wetland was constructed in an open controlled area in Khartoum which bordered White and Blue Nile. The main climatic conditions of Greater Khartoum are conditioned by its location on the southern fringes of the Sahara. The city experiences four climatic seasons, winter season extends from mid-November to March, cool and dry air from the north-east, a minimum temperature ranging between 8ºC to 10ºC which falls to 5ºC during night, and maximum temperatures varying from 23ºC to 25ºC, relative humidity sometime be as low as 20%. The hot, dry summer season is well in place by the end of March. The maximum temperatures may exceed 45ºC by the end of May. Weather instability is indicated by the recurrence of dust storms. The rainy season covers the period from July to September, with August being the rainiest month, generally annual rainfall ranges between 110 and 200 mm, A short hot (about 40ºC) transitional season occurs between mid-September and the beginning of winter. This changeover season from south-westerly to north-easterly winds is accompanied by dust storms. Where the system will be operated under ambient air conditions of temperature (2o – 30), relative humidity 20 %.

Designing criteria of the system:
The prototype:

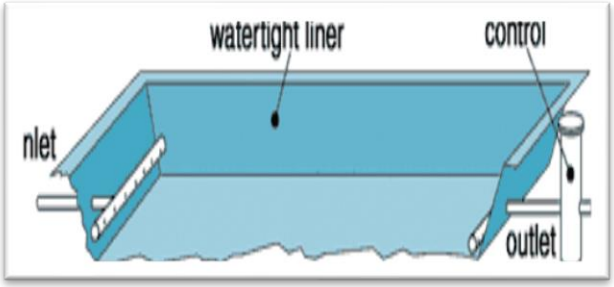

Figure 1: *Inlet and Outlet pipe.*

A pipe of 3-inch diameter at both inlet and outlet of prototype with nozzles fixed to ensure optimum distribution in the inlet zone, and optimum collection in the outlet zone. Filters media of gravel put into the inlet and outlet zones with the size of 15 cm of prototype, then the remaining area of prototype filled out with sand, fine gravel and soil for normal setup.

Vegetation:
Common Reeds (Phragmites australis) as local wetland species were used in this study.
Reeds are tall annual grasses with an extensive perennial rhizome. Reeds have been used in Europe in the root-zone method and are the most widespread emergent aquatic plant. Systems utilizing reeds may be more effective in the transfer of oxygen because the rhizomes penetrate vertically, and more deeply than cattails (Crites, 1988).

Planting techniques:
Seedlings should be planted as (8 pieces /m^2).

Study population:
Samples of treated wastewater (effluent) were collected by jerry cans from the final stage of the treatment at Soba wastewater treatment plant, and samples of final effluent from the constructed wetland prototype.

Sampling techniques:
Samples were systematically collected from the inlet and outlet of prototype during the whole month due to suitability of the weather conditions to the plant growth. Two samples (one from the inlet and one from outlet) were collected each 14 days that results in approximately 4 samples (4 weeks) in addition to three blank samples for quality control. Subsequently, samples were subjected to analysis in the laboratory.

Methods of data collection:
Running of the experiment and quality control:
- The operation and management were checked on a regular basis.
- Water levels, water quality, habitat, flora and fauna, structures and embankments, and other parameters were reported and documented regularly, with possible immediate repair of damage to the structures and control weeds.

Data collection and Laboratory analysis of the samples:
Data were collected over a period of 4 weeks on a bi-weekly basis from the outdoor pilot prototype treatment system.Method of analysis used is procedure described in the Standard Methods for the Examination of Water and Wastewater. (APHA, 23RD edition 2015).

RESULTS AND FINDINGS

Samples	BOD5
1st sample influent	550 mg/l
2nd sample effluent 1	190 mg/l
3rd sample effluent 2	80 mg/l
BOD5 Removal	65.4% - 85.4%

Table 1: *BOD_5 Removal.*

Samples	COD
1st sample influent	720 mg/l
2nd sample effluent 1	42.6 mg/l
3rd sample effluent 2	30 mg/l
COD Removal	94% - 95%

Table 2: *COD Removal.*

Samples	TSS
1st sample influent	5258 mg/l
2nd sample effluent 1	70 mg/l
3rd sample effluent 2	74 mg/l
TSS Removal	98%

Table 3: *TSS Removal.*

Samples Metals	1st sample influent	2nd sample effluent 1	3rd sample effluent 2	Removal percent
Fe	0.14 mg/l	0.11 mg/l	0.04 mg/l	21.4%-71.4%
Cr	0.16 mg/l	0.07 mg/l	0.07 mg/l	56.2%
Mg	22 mg/l	0 mg/l	12 mg/l	45.4%-100%
Mn	0.003 mg/l	0.001 mg/l	0.002 mg/l	33.4%-66.7%
Cu	0.08 mg/l	0.02 mg/l	0.04 mg/l	50% - 75%

Table 4: *Heavy metals Removal.*

Samples	Plate count
1st sample influent	3 *106 cfu
2nd sample effluent 1	275 * 102 cfu
3rd sample effluent 2	150 * 102 cfu
Bacterial removal	99% - 95%

Table 5: *Bacterial Removal.*

Samples	Nitrate No3	Nitrogen	Nitrite No2	Nitrogen
1st sample influent	4.470 mg/l	1.010 mg/l	0.132 mg/l	0.040 mg/l
2nd sample effluent 1	2.390 mg/l	0.540 mg/l	0.086 mg/l	0.026 mg/l
3rd sample effluent 2	3.115 mg/l	0.705 mg/l	0.102 mg/l	0.030 mg/l
Removal percent	30.3% - 46.5%	30.1% - 46.5%	22.7% - 34.8%	25% - 35%

Table 6: *Nitrogen Removal.*

Samples	Po4	P
1st sample influent	204.8 mg/l	67.6 mg/l
2nd sample effluent 1	148.8 mg/l	49.2 mg/l
3rd sample effluent 2	160.5 mg/l	55.4 mg/l
Removal percent	21.6% - 27.3%	18 % - 27.2%

Table 7: *Phosphate Removal.*

Samples Ions	1st sample effluent	2nd sample influent 1	3rd sample influent 2	Removal percent
K	53 mg/l	11.5 mg/l	8.3 mg/l	78.3%-84.3%
Cl	175 mg/l	10.4 mg/l	0.9 mg/l	94% - 99.4%

Table 8: *Ions Removal.*

DISCUSSION

This study's results demonstrated efficacies for constructed wetland in BOD_5 reduction ranging from 65.4 to 85.4 %, as shown in Table 1. This result agrees with Khazaleh and Gopalan (2018) who found in their study of constructed wetlands BOD removal of 77%.

Sudanese Standards Metrology Organization has set the standard for BOD_5 mean concentration in effluent discharged into surface waters at 15 mg/l and for irrigation uses at 50 mg/l. It is thus seen that the study plant prototype does not satisfies the standards for discharge into surface waters but it almost satisfies the standards for irrigation uses.

This study showed that the efficacy of the constructed wetland in COD removal ranged from 94 to 95%, as shown in Table 2. Sudanese Standards Metrology Organization has set the standard for COD mean concentration in effluent discharged into surface waters at 75 mg/l and

for irrigation uses at 150 mg/l, it is seen that the study plant prototype does satisfy the standards for discharge into surface waters and also satisfy the standards for irrigation uses.

Sudanese Standards Metrology Organization has set the standard for TSS mean concentration in effluent discharged into surface waters at 30 mg/l and for irrigation purposes at 50 mg/l, observed that the study plant prototype does not satisfies the standards for discharge into surface waters but it is near to satisfies the standards for environmental and irrigation uses. In this study the efficacy of constructed wetland in TSS removal is 98% as shown in Table 3. This result agrees with UN HABITAT Constructed wetlands Manual (2008) as it reported as 95% that mean the performance of constructed wetland in TSS removal is better.

The study showed that the efficacy of CW_S in reducing of heavy metals 60.7 as shown in Table 4, this result agrees with Mthembu (2013), who found in his study the treatment efficiency of vegetated beds in removal of metals is 26% to 76%. These results do satisfy the Sudanese Standards for heavy metal concentration to be discharge into surface water and irrigation uses. From the plate count test, the study shows that the efficacy of CW_S in pathogenic removal is 99 to 99.5% as shown in Table 5, this result agrees with Vymazal (2001), who found in his study the treatment efficiency of vegetated beds in removal of pathogens is 92%. Standards set by Sudanese Standards Metrology Organization for mean total coliform concentration in effluent discharged into surface waters are 500/100 ml and for irrigation uses are 1000/100 ml, it is seen that the study plant prototype do satisfies the standards for discharge into surface waters and satisfies the standards for irrigation uses.

The study showed that the efficacy of CW_S in nitrogen removal is 34.6 as shown in Table 6. this result agrees with Vymazal (2001), who found in his study the treatment efficiency of vegetated beds in removal of Nitrogen is about 35%. These results do satisfy the Sudanese Standards for nitrogen concentration to be discharge into surface water and irrigation uses.

The study also shows the efficacy of CW_S in phosphate removal 22.6 as shown in Table 7. this result agrees with Okurut (2000), who found in his study the treatment efficiency of vegetated beds in removal of Phosphor is an average of 24% in tropical aeries. These results do not satisfy the Sudanese Standards for phosphor concentration to be discharge into surface water and irrigation uses.

CONCLUSION

This study was carried out in Khartoum state, aimed at measuring the efficacy of sub surface constructed wetland for the improvement of the final effluent from Soba Stabilization Ponds in Khartoum, Sudan. From the result of these investigations, we can conclude that:
Constructed wetlands have great potential to improve the characteristics of wastewater. Moreover, the Constructed wetland is cost effective in terms of maintenance, and simple in terms of operation.
The performance of constructed wetland is high in removing BOD_5, COD, TSS, and Pathogens, with efficiencies of 85.4%, 95%, 98%, and 95% respectively. However, the performance of constructed wetlands is moderate in removing Metal, Nitrogen, Phosphor, and Ions.
The results of this study clearly recommended the application of constructed wetlands for the treatment of wastewater in Sudan due to availability of wild lands, good climatic conditions that fit to the plant growth requirements, and also availability of plant species to be used in these systems.

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DESIGNING A PORTABLE TREATMENT SYSTEM FOR EQUIDS IN RURAL SOUTH AFRICA IN A POSTHUMAN-CENTRED DESIGN FRAMEWORK

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Abstract
This Industrial Design Honours research project laid the foundation for a bridge between two very different worlds – industrial design as a progressive, technologically advanced driving force, and the wild coast of South Africa's Eastern Cape as its rural, lingering counterpart. Veterinary resources in this part of the country are incredibly difficult to access. When they are accessible, they are often under equipped to deal with the issues encountered by animals in such a rural and informal setting. This presents an opportunity for the needs the community to be met by designing for context appropriate manufacture and implementation alongside the experts in the field. In designing this portable equine treatment system (known as a crush), it is revealed how important it is to introduce more technologically advanced manufacturing methods and products into rural areas. The system which stemmed from this research project holds equids in place while they receive treatment so that the animals and the people treating them are safe and calm. Given that the issues in this field are so varied and challenging to address this became a passion project. Since the community was somewhat difficult to engage with, data collection relied heavily on observatory field work and engagement with limited experts to design something that can be used by the community but does not necessarily need to be adopted by individuals within the community. Of course, these innovations may be met with some scepticism at first, but therein lies the importance and opportunity of community engagement. Products and solutions may be more difficult to implement in such a rural setting, but that does not mean that these settings should not be designed for. The value of this research project lies in the opportunities for growth in the relationship between rural community engagement and the introduction of innovative technologies.

Keywords: Animal Welfare, Posthuman-centred Design**.**

INTRODUCTION

Over the last hill between inland and ocean, a rural village spans from one hillside to the next in the Eastern Cape of South Africa. Stray and domestic animals roam the dirt roads, foraging and challenging the occasional car. This is Hole in the Wall (known in isiXhosa as izi Khaleni which translates to 'place of thunder'). In this village donkeys, mules, ponies, and horses (collectively: equids) are the preferred means of transport for people and their supplies. Without their animals, many of the inhabitants would not have access to necessities or be able to participate in common cultural practices. Equids here are not only pets or working animals, they are often also a status symbol. De Klerk, Quan and Grewar (2020) explain that the use of working horses has an impact on the lives of their owners and the community at large. The work that these equids undertake has a direct (often negative) impact on their health and welfare (usually due to ill-equipped owners). In these same rural communities, access to proper horse care is also often limited, either because it is too far away or too expensive. Many of the issues identified in literature can be alleviated with the design and implementation of appropriate solutions. The ripple effect created by the wellbeing (or lack thereof) of the animals for welfare organisations, animals, and their owners, is at the centre of this study's concerns. Gaining a deeper understanding into the issues faced by the community on which this study is focused

creates an opportunity to design a solution to help the equids, the welfare organisations caring for them, and thereby the community at large.

Figure 1: *The Hole in the Wall village, Hole in the Wall, 2021 (photograph by author).*

The aim of this study is to examine existing issues in the rural horse community of Hole in the Wall, with the goal of understanding where these issues stem from and potential ways that they can be solved or alleviated from an industrial design standpoint. The objective of this study is to use the understanding gained through field research and interviews to design and implement a viable, contextually appropriate solution to one of the issues identified in the chosen setting.

RELATED STUDIES

There is little information available on existing issues of equine welfare in the rural South African context. Where information is available, it is mainly in articles focused on the show and racing horse industry, and issues of deliberate neglect or abuse in these situations. There are quite a few organisations in rural, urban, and peri-urban areas who look after the welfare of working horses in these communities. One of these organisations is the Hole in the Wall Horse Project, which cares for the equids in this study's chosen setting. On two known occasions the welfare of South African equids and its impact on their owners has been examined from an academic and design perspective. These 'case study' like tasks were focussed on specific issues in specific contexts, much like the current study of the Hole in the Wall Horse Project.

The first is an ICSID Interdesign study in 2005, where the theme of Sustainable Rural Transport was addressed in Rustenburg. ICSID Interdesign (2005) explains that transport is an issue that is dealt with every day in rural, peri-urban, and urban communities. Removing the ability to transport people and goods leaves people stuck in a poverty cycle, lacking access to basic goods and services and unable to uplift themselves in any meaningful economic way (ICSID Interdesign 2005). This study focussed on Rustenburg in the North-West province because there is a lack of infrastructure and access to transport in the chosen communities (ICSID Interdesign 2005). Community participation was a large contributor to the success of the study (ICSID Interdesign 2005). Popescu, Borda, Oros, Sandru, Spinu, Giupina, and Diugan (2016) explain that the lack of a good relationship between human and animal amongst working horses showed a significant increase in behavioural issues, although this is not necessarily something that can be solved within the scope of this study. It may be worth considering this information from an educational perspective in further study or intervention on welfare.

The second is a 2020 study of the socio-economic impacts of working horses in the Cape Flats. Both instances were largely concerned with animal-drawn carts which are used for the transport of people and goods in these communities. These studies examined the welfare of the animal as well as the human within this context of horse-drawn cart transportation in rural settings. It became clear through both studies (presented in 3.2.2) that the wellbeing of the equid and its owner are intricately connected. De Klerk, Quan and Grewar (2020) reveal in their study that there is indeed a concept of 'Health in Social-Ecological Systems' at work in the setting of the Cape Flats, as horse and human health are closely interwoven. This study also examines the economic impacts of working equids, stating that 89% of their participants identified horse-related work as their source of income (De Klerk, Quan & Grewar 2020). This study was also largely and specifically focussed on horse-drawn carts, with the impact clearly being documented: when the horses cannot work, the owners and all their dependants are suffering. This highlights the importance in the current study in taking care of the welfare of the animals to ensure a ripple effect of welfare for their owners and the community at large.

Charlotte Burn, Tania Dennison and Helen Whay (2009) examine the environmental and demographic risk factors for working horses, donkeys, and mules in developing countries (Afghanistan, Egypt, Ethiopia, Guatemala, India, Jordan, Kenya, Pakistan, and Gambia). They postulate that over 85% of equids live in developing countries, and the majority of them are working animals – drawing carts, being ridden, or used for agriculture or ceremonial practices (Burn, Dennison & Whay 2009). They also explain that a lot of this work is prolonged and strenuous and takes place in harsh environments, leading to the animals being overworked, malnourished, and easily wounded (Burn, Dennison & Whay 2009); pointing out that there is actually very little known about the distribution of different problems and how they can be helped by different charities and welfare organisations. This is especially true in the South African context, where there is little awareness (apart from in the specific context of horse-drawn carts) of which issues occur, how frequently, and where.

In *Improving Animal Welfare: A Practical Approach* (2010) by Dr. Temple Grandin there is a chapter dedicated to 'Practical methods for improving the welfare of horses, donkeys, and other working draught animals in developing areas.' Grandin is renowned for her work examining the more humane slaughtering of livestock, as well as her expertise on animal behaviour. In this chapter she emphasises the importance of equestrian labour, especially in rural communities in developing parts of the world (Grandin 2010:439). Much of Grandin's (2010) further writing on the matter has to do with improper tack and husbandry, and she also goes on to write about the importance of parasite control and wound treatment. However, there are no suggestions as to how to best go about administering these proactive and reactive treatments in a rural setting. There is little information available on the best way to keep the animal and human safe while it is receiving any of the recommended treatments, or appropriate technologies for implementing said treatments.

METHODOLOGY

This study made use of a qualitative, autoethnographic approach to data collection. According to David Silverman (2021:3) qualitative research focusses on understanding people's experiences, and values deeper meanings and implications over objective facts. To obtain fruitful, meaningful information, Silverman (2021:8) recommends that the researcher finds a setting and asks themselves "What is going on here?" A qualitative approach has therefore been chosen for its potential to provide a much wider context appropriate framework for

understanding the data and meeting the aims of the study. Within the context of this study, understanding the experiences of the human and animal participants will be crucial to designing a well-considered solution. Carolyn Ellis, Tony Adams, and Arthur Bochner (2011) explain that autoethnographic research "seeks to describe and systematically analyse (graphy) personal experience (auto) in order to understand cultural experience (ethno)." Taking an autoethnographic approach allows for submersion in the chosen context, allowing the study to combine observation, interaction, and personal experience in a meaningful way. Using a qualitative approach will provide insight into all the participants' experiences and perceptions. This combination of methodologies will yield comprehensive, valuable results within the frameworks of human- and posthuman-centred design and design for sustainable technology.

Human-centred design (HCD) was first presented by IDEO in 2015 as a framework for designers to follow to reach resolved, human-centred outcomes; that is – outcomes which take each *person* the design impacts along its journey into consideration. The idea of 'posthuman-centred design', or designing with non-human factors in mind, moves beyond the technoscientific context typically associated with posthumanism (Reisenbichler 2019) to incorporate elements of nature and even animals. Laura Forlano (2017:17) suggests that considerations of the 'non-human' in posthuman design need to include who or what is involved (humans and equids); how, and in what ways they are involved (horizontally rather than hierarchically); what new knowledge, partnerships, or stakeholders are needed (community engagement appropriate to the context); and finally, how ethics are embedded throughout the process. Keeping only the western idea of a 'human' at the centre of the design process re-enforces capitalist, colonial structures in which there is a clear hierarchy of 'ideal human' over all other (non-human or less-human) participants (Reisenbichler 2019). This does not take away from the value of a human-centred design approach. Within the context of this study, a mindset change incorporating a more varied subject than just 'man' positions the HCD process to consider a wider range of participants within a broader posthuman framework.

Data collection for this study comprised a combination of interviews, group discussions, and rigorous observatory and participatory field work. Participation was voluntary and adhered to strict ethical guidelines. Participants ranged from equid owners to welfare workers, to veterinarians and their nurses, assistants, and technicians, to manufacturers specialising in steel design and manufacture. These people were all chosen based on their experience in and knowledge of the use, care, and treatment of animals – especially in a rural context. The data gathered came from semi-structured interviews and participatory fieldwork and observation. Given the importance of the fieldwork, the immersion in the community included animal outreach, volunteer work, and community engagement. The equids around which the posthuman-centred part of this study revolves were only observed in the field, and only interacted with adhering to strict safety guidelines and under the supervision of the animal's owners.

RESULTS & DISCUSSION

People who earn little to no money are unlikely to spend money taking care of their animals. Since there is no veterinarian within less than a three-hour drive from this rural part of South Africa, the Hole in the Wall Horse Project (which runs solely off of donations and has been operational for 16 years) provides what assistance they can to the animals and their owners. Over this time the biggest issues identified were parasites, inappropriate tack, and trying to hold animals still while treating their wounds or other issues. It became clear that almost all

the treatments associated with equids require them to be held still in some way. Usually this entails the owner holding them by their harness, but sometimes more force must be used.

Observing the animals along with the clinic workers and the owners assisted in identifying the most prominent issues for which there may be a design solution. Many people come to the clinic from very far away (an hour or more on horseback). The people arriving at the clinic are mostly children, and often they arrive with animals that do not even belong to their family – they are just doing someone a favour. The animals are treated for all kinds of ailments, with confiscation or euthanasia only being considered as a very last resort in extreme cases. Tack is often confiscated and where possible, replaced with donated tack. All the treatments, from deworming to wound cleaning to dipping, require the equid to be held in place. This is no small task, especially since many of these animals do not have a relationship of trust with humans at all. They are rather easily spooked and can easily inflict serious harm on the person treating them. When an equid is hurt or afraid, or the wound is in a difficult area to reach, treatment becomes even more difficult. This often requires the use of a 'twitch' (shown in figure 2) which is meant to calm the horse down much like holding a cat by the nape of its neck, releasing endorphins for about 10 to 15 minutes. It pinches the animal's lips in a steel clasp, making it easier to control them – but not doing anything to improve the human-animal relationship. This can obviously not be done if the equid has injuries around its mouth. The only alternative if the owner cannot control the animal with a harness or a twitch is to 'cast' it (pull it to the ground using ropes). Casting equids to the ground (figure 3) is very stressful for the animal and requires a lot of manpower. Not only does this break down the human-animal relationship even further, but if big animals lie on their side on an unpadded surface for too long, they can get pressure necrosis where there is a lack of blood flow, and they can become lame and experience permanent nerve damage.

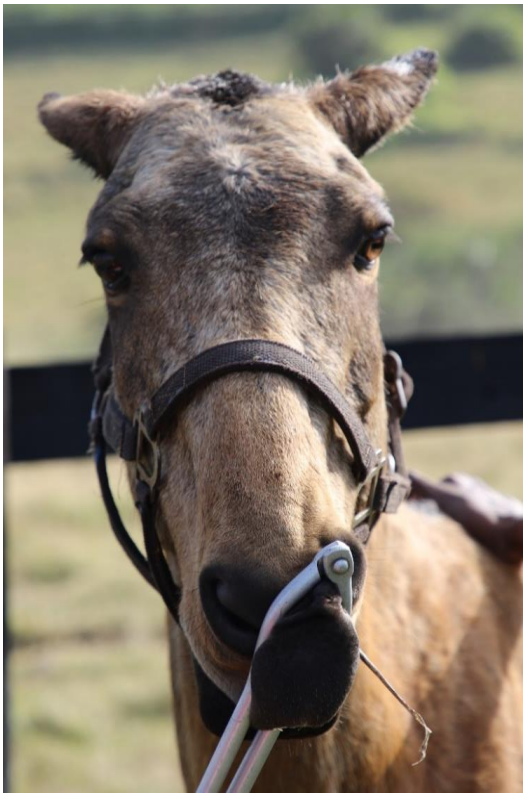

***Figure 2**: Twitch being used on a Basotho pony, Hole in the Wall, 2021 (photograph by author).*

***Figure 3:** Marlene Els (photographer), Equids being cast for treatment, Hole in the Wall, 2018.*

One of the leading problems with equids in this area is that of parasites. Many of the sores, wounds, and even deformities seen over the years are caused by internal and external pests which often cause a lot of damage before they are seen and treated. This damage can easily be avoided with preventative measures, early detection, and appropriate treatment. Figures 4 and 5 show a few of the many parasite infestations that have been encountered at the clinic over the years – these could have been avoided with frequent dipping and internal parasite controls – both of which require the animal to be held in place.

Figure 4: *Marlene Els (photographer), Parasite infestation in a cast horse, Hole in the Wall, 2019.*

Figure 5: *Marlene Els (photographer), Parasite infestation in a cast horse, Hole in the Wall, 2019.*

There is a clear gap in literature when it comes to the research of general equid welfare in rural South Africa, and a lack of recommendations and design strategies for improving their overall welfare. Interviews and field work have revealed many areas where there is room for improvement. It has been shown how vital it is to hold an animal still while it receives reactive or preventative treatment for any one of the ailments it may encounter, as well as how crucial parasite control is. This information is accentuated by the literature on the important role of these equids in their communities. Given the socio-economic impact of equid wellbeing on the community which relies on them for income and the transport of goods and people, broadening the possible treatment area of these animals by making the treatment system mobile will yield a host of benefits.

Within the scope of this study, the most important issue that was addressed is the physical and emotional wellbeing of an animal and its caretakers while it is being treated. The design outcome will take the form of a 'crush' (a kind of passage an animal is walked into and held still in to receive treatment) which can be disassembled and moved to a new location. There is also room for this same system to assist in the treatment of external parasites. This modular versatility can and should be introduced into the design of the system to ensure that it is scalable and can adapt to the needs of the community. The human-centred and posthuman-centred frameworks allowed participant input and animal needs to guide the process and lead to the chosen direction of a portable equid treatment system. The fact that it must be an appropriate technology for the area is underscored by interactions with the community as well as literature on working equids and their owners in developing countries.

DESIGN CRITERIA

Holding animals still for a variety of treatments is very important for the safety and wellbeing of the animals, their owners, and the people treating them. For this reason, the system must be able to safely and comfortably hold animals of various sizes in place. External parasite control (in the form of dipping) is critical for the overall health of the animal (and thereby for the benefit of the owner). Therefore, a dipping mechanism is incorporated into this equid treatment system. A portable system is a very helpful tool for the community and the Hole in the Wall Horse Project to have to help the animals and by extension the community. The system should be small, light, and simple enough to be collapsed and moved to a new location.

Rather than a standalone crush, this design should be approached as a horse treatment system. The system should be scalable in some way – additional features should be able to be added as necessary. The outcome should be scalable in that it must allow for modularity, adaptability, and growth. It must be portable and easy to maintain and repair within the context. Cost is a very important factor in such a low-income community. There should also be aesthetic considerations to make it somewhat of an attraction, uplifting the community and encouraging engagement with the system.

CONCLUSIONS

Veterinary care plays an important role in the welfare of equids (and by effect, their owners) and although there is not much to be done from a design perspective in terms of the lack of access to veterinary care in this setting, the available care can be improved upon. One way of doing this is to create an environment where the animal is safer, calmer, and kept still to receive

the treatments that are available. The best way to do this is by placing the animal in a crush which acts as the basis of an equestrian treatment system. Preventative care which does not require a veterinarian such as deworming, hoof trimming, dipping, and wound treatment, are all provided for free at the Hole in The Wall Horse project. This goes a long way in helping the animals to live a longer, healthier life, free of needless suffering. Incorporating an easier way to dip the animals into this crush allows for it to serve an even greater purpose than just holding the animal still for treatments, as they can be dipped faster, with less waste and less stress, and in a way which is safer for the animal and the human treating them. Synthesising the available literature with the input from participants, the final design outcome is determined to be a portable equestrian treatment system comprised primarily of a crush and a dipping system, with additional recommended elements that could be added on as and when they are needed. Renders of the equestrian treatment system can be seen in figure 6, and photographs of the functional prototype can be seen in figure 7.

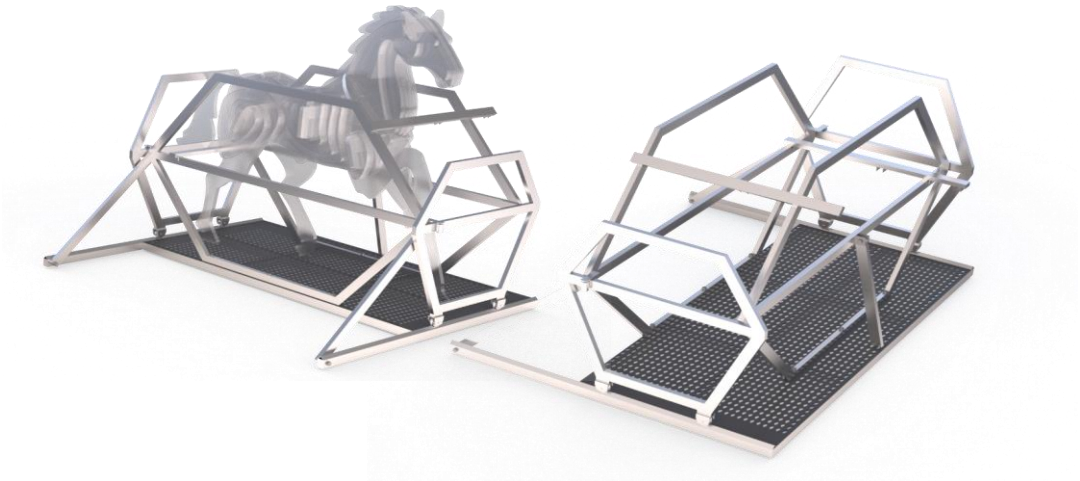

Figure 6: *Design by author, Renders of the treatment system, Coffee Bay, 2021 (renders by author).*

Figure 7: *Design and manufacture by author, treatment system prototype, Hole in the Wall, 2021 (photographs by author).*

The central component of this horse treatment system is the crush itself. The crush is portable because of its size, light in weight and material usage because of its shape, and safe and user friendly for animals and humans alike. It can be taken apart into 7 smaller pieces for ease of transport but when assembled it is heavy enough to be stable. This breakdown is crucial to allow organisations to cover a wider treatment area and travel to the animals, rather than expecting the sick or wounded animals to travel to them. These pieces are assembled with galvanised nuts and bolts for corrosion resistance. The gates and their locking mechanisms are safe and easy to use. Rather than a conventional swinging gate, theses gates slide so that the person treating the animal is not at risk if the animal kicks the gate. The gates are two different heights so that you can walk animals of different heights into the crush from either side depending on their height requirements. One wall is fixed, and the other is adjustable, allowing the user to adjust the width to either 850mm (for the average thoroughbred), 680mm (for the average Basotho pony or mule), or 450mm (for the average donkey) depending on the size of the animal. The standard length is 2m, but this can be adjusted incrementally in front of and behind the animal using the easy support bars. It is highly unlikely that an equid of more than 2m in length will need to be treated in this system. It is made of mild steel and the simple design and forgiving material makes it easy for the average 'handy man' in the area to repair if something should break.

The floor of the crush is made of expanded mesh for drainage purposes, and covered with injection moulded rubber, anti-fatigue, noise cancelling drainage mats. This will make the experience more comfortable for the animal and allow for easy cleaning, which is very important for limiting disease transmission. The structure is painted in a hammered silver finish, allowing it to stay cool to the touch in the sun while preventing it from being too reflective so as not to spook the animals. Important moving components such as the gate rollers and wheels are held in place with nuts and bolts rather than welded, so that they are easy to replace. This crush will allow many of the health and wellbeing issues that arose in the primary and secondary research phases to be addressed in a safer, less stressful way. From the research we know that healthy animals have the ability to uplift the entire community, so this system has a further reaching effect than just the few humans and animals who have contact with it.

The final design also includes a dipping system which comprises standard components (a portable shower pump, flexible hoses, and a trigger nozzle) to make the dipping process faster, easier, and less stressful for the animal. The trigger on the nozzle makes this additive system very easy to use and allows for good control over the water pressure. The pump is also very quiet. The equid can now feel safe and calm inside of the crush while it is being dipped. It also speeds up the dipping process and reduces wasted dip significantly, allowing more animals to receive treatment in a shorter amount of time. Once an equid walks into the system the back gate is closed and secured to prevent it from reversing out. The front gate is then closed and secured. Thereafter, the support bar (or bars if necessary) can be positioned in the most optimum positions depending on the size of the animal and which areas need to be accessed. Figure 8 shows an exceptionally big Boerperd crossed with a Basotho pony in the system after having her hooves trimmed. Figure 9 shows a Basotho pony being groomed and dipped after being dewormed and given a vitamin booster. This Basotho pony almost fell asleep after his treatment, resting his chin on top of the gate. All of these animals were much calmer inside of the crush than they were being tied to a pole or held by their owners, and certainly calmer and safer than they would have been if they had to be cast to the ground.

It will be very important to include a social side into this study for its prolonged success. The community needs to be educated on the importance of the welfare of their animals and

encouraging them to interact with the crush and lead their animals in themselves will strengthen the bond between them and ignite a sense of pride. Educating and upskilling some members of the community on the use of the system can only do good, which will hopefully be underscored by the good that the treatment system will bring.

Figure 8: *Design by author, Boerperd cross Basotho pony in the system after a hoof trimming, Hole in the Wall, 2021 (photograph by author).*

Figure 9: *Design by author, Basotho pony being dipped and relaxing after treatment, Hole in the Wall, 2021 (photographs by author).*

This study unveiled that many of the issues faced by equids and their owners arise because of a lack of access to proper care, fiscal support, and education. There are limited veterinary resources on the rural wild coast in the Eastern Cape of South Africa, and the Hole in the Wall Horse project runs solely off donations. People are not always educated on the best ways to care for their animals. In this context, an appropriate solution is easily reparable, portable, uses simple mechanisms, and is also functional, durable, and serves its purpose. It should also not be too expensive to acquire, make, or maintain. The design outcome of this project not only meets but exceeds these criteria, as has been shown by its successful prototyping and prototype implementation in the field. For far too long design has focussed heavily on human-centric approaches, but this paper shows how far designing for appropriate technology from a posthuman-centred point of view can go to provide a multitude of benefits for and beyond the human. How a system like this one may be received is always somewhat difficult to predict, but previous engagement with the community made them much more open to trusting the research and design process and adopting the new, human- and posthuman-centred, appropriate design-oriented technology.

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HEALTH

PAPERS

SIGN LANGUAGE GLOVES (ARABIC SIGN LANGUAGE)

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Abstract
Communication beween people is one of the most important things that society is built on and we cannot live without it. It connects people together whatever the means used for it. We are trying to tear down the communication barrier between any spoken language users and sign language users by making a device that translate from Arabic Sign Language (ARsL) to Arabic language. It is found that ARsL is just developing as a standard sign language and only a third of the population of the Middle East that uses sign languages know it. The communication problem here is that people don't understand sign language, and the communication process cannot be completed without all the involved parties being able to understand each other. Our Sign Language Glove utilizes the power of software-aided-hardware to translate ARsL widely used in Sudan into written letters first. Then the letters are added together as a series of letters. The hardware uses the sensory data fed from flex sensors and an accelerometer for converting input so the corresponding letter to the sign just done by the user is output to the display. The output is chosen from the verity of our database of the ARsL letters. This database was collected and formulated based on interviews done with some mute parties and was optimum to the different stages in letter signing. The display method we are using is the Serial monitor in Visual Studio Cade as an output receiver to display Arabic language letters and symbols.

Keywords: ArSL, Flex Sensors, Accelerometer, Translation, Visual Studio Cade.

INTRODUCTION

Living in the 21st century, everyone can connect to everyone through more than one - maybe uncountable - ways, from the apps on internet to post mails. This is true no matter the country in which you live. However, every rule has an exception to it, and here it is the minority of people who use Sign language. As mentioned, it is those who needed a branch of language that is specially used by them, as made for the use of people who have an inability to hear or talk. The language is used also by normal people and evidence of this can be seen in schools that teach Sign language and also in some news channels that sometimes include an interpreter for those that use sign language.

For being a part of the languages that can have multiple branches it comes in every form. Meaning that each country has a Sign language of its own that is considered as their standard of the language. Take for example Britain, United States of America, Brazil and Russia; they all have their versions of Sign language and each is abbreviated as BSL, ASL, BCSL and RSL respectively.

The Sign language is something of old times. The recorded history of sign language in Western societies starts in the 17th century, but one of the earliest written records of a sign language found is from the fifth century BC, in Plato's Cratylus. Socrates argues that if one had no voice to use, he would use other ways to be understood like moving hands or the head and other body

parts. In the Middle Ages, Socrates was used in a number of religious orders but are not considered as a sign language, just as communication gestures (Bauman & Dirksen, 2008). Vows of total silence are among the origins of the gestural communication. It was in the 17th century, that the rule of St. Benedict forbade conversation during certain times in the day. (Anon, 2021)

Until the 19th century, the language was limited to the manual alphabets (fingerspelling systems) that were invented to facilitate transfer of words from an oral to a sign language, rather than documentation of the sign language itself. Many sign languages have developed independently throughout the world, and no first sign language can be identified. Both signed systems and manual alphabets were found worldwide, and, the majority of it seem to occur in Europe in the 17th century. (Anon, 2021)

Therefore, the objectives of this project are: to reduce the communication gap between deaf people and others; to build a glove device to detect Arabic sign language; and to establish serial communication between the glove and the computer.

RELATED STUDIES

Khan and Mehdi (2002) examined the possibility of recognizing sign language gestures using sensor gloves. Previously, sensor gloves were used in games or in applications with custom gestures. Their paper explores use of Sign Language recognition done by implementing what is called “Talking Hands”, and observing the results. Their project utilized a sensor glove to capture the signs of ArSL performed by a user and translated into sentences of English. Artificial neural networks were used to recognize the sensor values coming from the sensor glove. These values were matched to one of 24 alphabets of the English language and two punctuation marks formulated by the author. Hence, mute people could then write complete sentences using this application.

The system is aimed at maximum recognition of gestures without any training. However, it has potential to be used widely as there is need for long training sessions. The speed of gesture capturing and recognition can be adjusted in the application to incorporate both the slow and fast performers of ArSL. Since a glove can only capture the shape of the hand and not the shape or motion of other parts of the body, e.g. arms, elbows, face, etc. from that we know that only postures are taken in this project. Signs for letters ‘j’ and ‘z’ are ignored as they involve moving gestures. Two custom signs have been added to the input set. One is for space to separate between words and the other is for full stop. These are not part of sign language, but have been added to facilitate in writing the English equivalent of the sentence being performed.

The Results show that the accuracy rate of the software is 88%. This figure is low because the training was done on people not already familiar with sign language; instead, they were given a handout to perform the signs by reading from it. Since there was a wide variation in the samples, some even gave incorrect readings for the sensors. The tests were done on people who were using this glove for the same alphabet. The problem was that some of the letters involved dynamic gestures. As mentioned above, these gestures were not in the scope of the project. Also, some gestures require use of both hands, which would require two sensor gloves.

A wearable wireless gesture decoder module has been developed (Shaheer, et al., n.d.) that can translate the fundamental set of ArSL gestures into corresponding alphabets and words and it

utilizes a glove that houses a series of flex sensors on the metacarpal and inter-phalangeal joints of the fingers to detect the bending of fingers, through the piezo resistive effect. The project has the following advantages: Portability, compactness, cost-effectiveness and a user-friendly android application gives this system an edge. Research done on the international sign languages yields that there is no universal sign language in the world. The database of alphabets and words, embedded with various sensors can be used by using only the formal part of the ARLS, consisting of 15 words and 26 letters. Recognition happens in 3 phases: recognizing sensors' values, processing and displaying/listening the sign. Sensors include one flex sensor for thumb and pinkie, and a pair for rest of the fingers of the hand. The primary input to Arduino Leonard is the values of flex sensors and accelerometer.

Sadek, et al. (2017) made a device to translate from sign language to a spoken/written language that can translate all of the Arabic sign language. It is intended to try illuminating the law-wise, religious-wise and social-wise problems that the sign language users suffer from. They mention that the sign language relies on sight and has 3 major sections: letter, word and expression level. They then speak about the types of gloves that have the translate ability needed. For each type, they describe its components, accuracy measures and the price of the devise. According to the research, two approaches are done statistically. One being the classification of words in accordance to movements phases of each hand, the other is the shape of the hand and the fingers movement way. And choose the later one to make the device. It is notable that the final project of the researchers was only 5% of the cost of the compared ones. In their sending point, they used a 7-frame massage to send the data of the sensors. Yet the glove made do not translate the full Arabic sign language with the same high accuracy and could provide translating of other sign languages.

METHODOLOGY

The project has two components in order to perform correctly. The Hardware side, which represent the component that convert ArSL to letters, and the Software side, which provides the instructions and Database to the Hardware (microcontroller). Fig.1 depicts a flow chart that represents the steps to perform the project. After preforming the two side (software, hardware) of the project we made some tests to make sure of project performance, then we conducted an optimization to enhance the performance of the project.

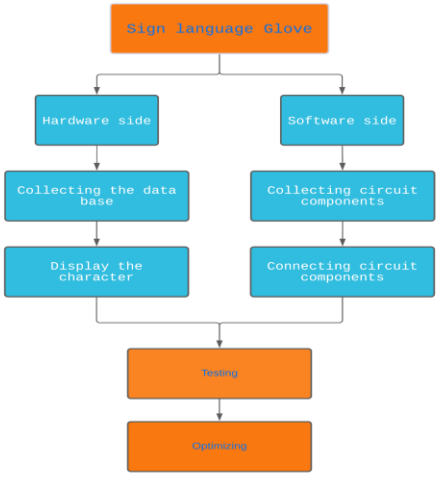

***Figure 1**: Simple workflow.*

Collecting the components required for the hardware part of the project is the first step. The project's circuitry consists of resistors, flex sensors, wires, an accelerometer and an Arduino Uno. This combination of hardware however was selected from a variety of schemes and circuitries that were all read about in researches done by others, some of which are found in Related Work section. One of the main reasons to select them is to reduce the complexity level of the hardware while maintaining a sustainable level of accuracy.

For our first step, the flex sensor is connected to the bread board. This is done by connecting the negative pin of the flex sensor to a resistor and then to the ground (GND pin of the Arduino), and connecting the positive pin of the flex sensor to either a power source of 5 volts or the 5V pin of the Arduino. We connected the accelerometer chip to our Arduino. It was first done to make sure the chip itself is good and running and the other connection incident took place in order to put together the different part of the system. Nevertheless, both incidents have the same connection wiring to the Arduino as follows: wire SCL of the chip to Arduino's A5 pin, SDA from the chip to A4 of the Arduino, VCC of the chip to 5V of the Arduino and lastly the GND of the chip to the GND of the Arduino.

What we did was to put together five flex sensors with the Arduino and to test their readability the same way we did with one flex sensor. Using the same connection layout with difference in the part that each one has it is own unique pin of output data to the Arduino, the final hardware looked as follows in Fig. 2.

***Figure 2**: The Hardware: Glove.*

With the hardware set, we then wrote a program to enter the value we want to represent. Fig. 3 is a flow chart to illustrate the process of data collection.

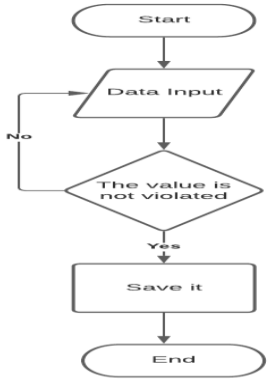

***Figure 3:** Data collection flow chart.*

We included the values into the spread sheet (Microsoft Excel) and performed a statistic representation of the values with the exclusion of the anomalous results and their representation in graphs. Fig. 4 illustrates one of the spread sheet graphs.

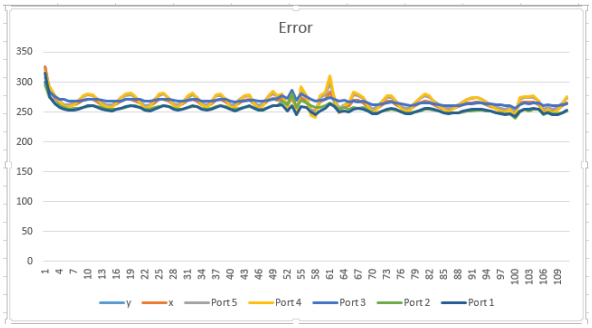

***Figure 4**: Spreadsheet representation the error rang.*

We then entered the results into a program that we wrote in order to display the letters translated from the ArSL. Fig. 5 is a flowchart representing it.

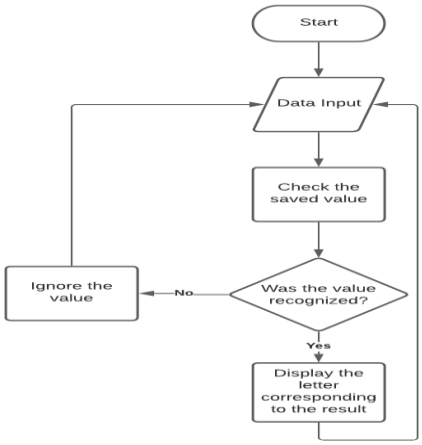

***Figure 5**: Project's flow chart.*

How it works:
The Accelerometer is used to measure the tilt of the palm. Five flex-sensors are fixed onto the surface of the glove, one for each finger. The sensors measure bend in the fingers and palm and according to the bend angle value the Arduino Uno understands which set of values represent which symbol and transfer the appropriate output value to the user interface which displays and speaks the symbol generated.

RESULTS AND DISCUSSIONS

Similarity in shape but difference in gesture:
As the alphabets are listed in our language database, there are some similarities between some letters. For example, the alphabet (س) and (ش) are taken in this case, shown in Fig. 6, and utilized as an example to demonstrate the methods we use to overcome the possible duplication and confusion.

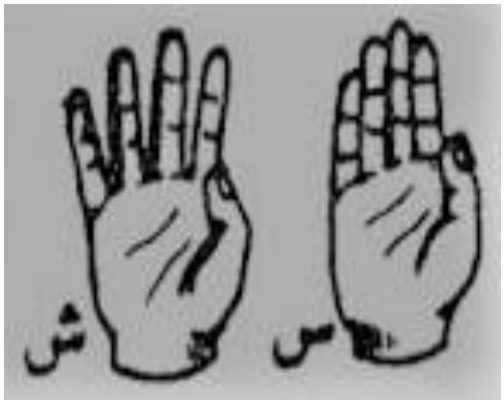

Figure 6: *Handshape of* (س) *and* (ش).

It is commonly known that in any sign language, no matter the language difference, there are some similarities between assigned hand shape of different letters of the language. As an example (I) and (J) of the German sign language, (S) and (T) of the Mexican sign language or (R) and (RR) of the Spanish sign language. Almost in all parts of the language, written language, the two letters differ very much in their written shape. As when we process listening-wise the letters can be distinguished from each other seamlessly as they are produced by each when spoken are different.

When it comes to sign language, it is sometimes hard to tell them apart without having to focus on the gesture or the shape of the hand. Our system aims to lower down how much focus you need to put-up in order to tell them apart. Here we take the possibility of the same hand shape but with a gesture involved. The two letters are exact but are told apart by using a movement along with the shape of the hand. The accelerometer is used here to sense the movement of the hand, it can tell the difference of the hand position in the X- axis and the Y-axis and is available as one of the inputs that the Arduino Uno processes to give the corresponding output.

Letters that are similar in their values:

There are some letters that are alike in the inputs, meaning the inputs that the processor receives to make the program outputs of the associated letter have a high similarity. To not make the processor use allocated data to output the wrong letter, we beat this issue by calculating an error range to differ between similar inputs of different letters by means of mathematical methods.

If a certain letter lays in the error range the output shall not be passed to our output phase. The only way the output is determined is if our mathematical algorithm rules out this letter from the suspected letter area and moves it closer to the correct letter’s area.

Words separations:

The proposed system translates sign language in a letter-by-letter progression, to form any word we spell it by sign language, as sign language only support signs of letters and very few count of words. The reason behind this is that there are simply too many words to figure then assign a sign for. So, in the process of letter signing, we spell the words you tend to say. To seize the problem at hand we would have to introduce our system with a new sign that isn’t already used or perhaps assigned in our database either in the ArSL. This new sign would serve as an identification proposed as to tell the device: a word has ended and another is being signed. Our system holds the ability to write the signed letters together and when it receives a signal

indicating that a word separation sign, it automatically inserts a space after the last letter it received a sign of.

Displaying output (method choosing):
The output methods we took into considerations and then used are two distinguishable methods. One is thought as a hardware approach and the other is the software approach. Regarding the hardware approach, we are using an LCD as our way of display. This has the advantage of being an ease-of-use to both parties using the project. However, it will add to the overall cost of making the project, together as a unit or if it was made on an industrial scale. Using the software approach the way of doing it was using Microsoft's Visual Studio Code. The application provides you with much power throughout coding or using extensions. A helpful extension that is used here is the Serial Monitor provided by the Arduino extension. The extension provides ArduinoC language support and can compile as if it was an Arduino IDE. Through this the extensions serves to display letters translated by the project and then display it on screen. The reason behind taking the initiative to move from the Arduino IDE to Visual Studio Code, is the support of UTF-8 encoding that is available in Microsoft's Visual Studio Code is more extensive.

CONCLUSION

One might also note that there have been some alterations from the original plan, like changing the database to match our language of choice (Arabic language) or changing the Arduino we are using from Nano to Uno, noted throughout the documentation presented here.

All sensory data is being fed to the Arduino. This works as the mind of the device and utilizes all its code along with the database to translate the Arabic Sign language to written Arabic language that is then displayed on the computer screen.

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APPLICABLE INDUSTRY 4.0 - TECHNOLOGIES IN HEALTH 4.0: A REVIEW

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Abstract
Industry 4.0 emerging technologies have been considered to provide new digital solutions in the manufacturing sector. As a result, the application of Industry 4.0 enabling technologies has spread beyond the manufacturing sector and most sectors. Amongst these sectors, the Healthcare sector and other sectors have realized that the concept of Industry 4.0 and its enabling technologies will be of enormous benefit to their business operations. The concept of Industry 4.0 and its enabling technologies has sparked interest in the healthcare sector such that Health 4.0 was derived and tailored to meet the needs of healthcare. The application and adoption of Industry 4.0 enabling technologies should not be thought of as a "one size fits all" across sectors, but each sector should consider identifying applicable technologies to its business operations. Therefore, the purpose of this paper is to highlight the key technologies introduced by Industry 4.0 that are applicable and can be adopted by the healthcare sector in support of Health 4.0.

Keywords: Health 4.0; Industry 4.0 Technologies; Internet of Things; Electronic Health Records.

INTRODUCTION

Industry 4.0 and its enabling technologies are centred on the capabilities of the 1st, 2nd, and 3rd industrial revolutions, specifically on the digital capabilities of the third industrial revolution (Schwab and Davis, 2018). However, Industry 4.0 should not be solely defined as a technology-driven revolution but rather as a concept that promotes organizational digital transformation (Lu, 2017). Industry 4.0 is a system that aims to construct customized models of production, products, and digital services that can provide real-time interactions among users, products, and devices at the time of a production process (Schwab and Davis, 2018 and Zhou et al, 2015). The concept of Industry 4.0 comprises two systems; embedded production system technologies and intelligent production processes (Zhong et al., (2017), these two systems are integrated holistically at both the horizontal and vertical dimensions within an organization's systems offering operational flexibility. Pessl et al, (2017) define Industry 4.0 as "an intelligent and transdisciplinary world in which smart factories represent the connection between digital and physical production networks". The concept of Industry 4.0 and its enabling technologies aims to promote an environment where there will be minimal interventions of human inputs in operations, where the integration of both digital and physical systems can make decisions without major interferences from humans.

The concept of Industry 4.0 was particularly formulated for the manufacturing sector with the objectives of continuous maximization of profits, minimization of operational costs and rapidly responding to customer demands in a digital business environment. The concept of Industry 4.0 is pioneered by the manufacturing sector. The application of Industry 4.0 has sparked interest in other sectors and disciplines forcing them to understand that this concept will

enormously affect their contemporary business operations. As a result, most sectors and disciplines have begun adopting the Industry 4.0 concept and tailoring the concept to meet their specific needs. Amongst these sectors is the healthcare sector, which has begun adopting the Industry 4.0 concept which has led to the formulation of Health 4.0 that is tailored to meet the healthcare needs. The concept of Industry 4.0 applies to the healthcare sector and is regarded as the reference point that led to deriving Health 4.0 to support the health systems in devising a strategic concept within the sector (Stankovic et al, 2017, Thuemmler et al, 2017 and Maisiri and van Dyk, 2018).

The concept of Industry 4.0 has enabling technologies that are regarded as pillars that support the application of Industry 4.0. The purpose of the Industry 4.0 pillars is to ensure that the entire system of an organization is linked and synchronized to other individual systems such that it can operate as a single unit that can be securely accessed internally and externally by its users. Its key focus in healthcare is to provide integration of real-time monitoring, and diagnoses enabled by artificial intelligent support (Chanchaichujit et al, 2019). In support of these purposes, there are underpinning enabling technologies known as the pillars of Industry 4.0 which include, autonomous robots, simulation, big data and analytics, system integration, internet of things (IoT), cyber security and cyber-physical systems, the cloud, additive manufacturing, augmented reality (Vaidya et al, 2018). Already these technologies have been adopted and absorbed by the healthcare systems. Both Industry 4.0 and Health 4.0 have been built on their respective preceding foundations. There is a linkage between the Industry 4.0 and Health 4.0 technologies, however, the preceding technologies previously applied by the manufacturing sector (1st, 2nd, and 3rd) and the healthcare sector (H1, H2, and H3) do not show a significant link as compared to the present technologies provided by Industry 4.0 (Maisiri and van Dyk, 2018).

The identified enabling technologies of Industry 4.0 are applicable to Health 4.0 since there is a direct linkage between Industry 4.0 and Health 4.0 technologies, healthcare has begun adopting and implementing these technologies in solving current problems and fixing the dysfunctional healthcare system (Latif et al, 2017). Therefore, this paper aims to review the literature on applicable technologies in Industry 4.0 that are applicable and have been adopted by Health 4.0.

LITERATURE REVIEW

Industry 4.0 Enabling Technologies

The technologies used in the concept of Industry 4.0 will influence the contemporary methods used to produce products as well as shift the customer perceptions toward value-added products demand. Any sector like healthcare, aspiring to adopt the concept of Industry 4.0 must understand the underlying technologies that support this concept. This section presents the enabling technologies that support the concept of Industry 4.0 Table I presents the pillars of Industry 4.0 employed by the manufacturing sector.

Enabling technologies	Description of technologies
Big Data and Analytics	Data that has been generated from various data sources such as sensors, devices, processes, actuators, web applications, social media platforms, etc., has become valuable to organizations. Because of the enormous data received from these sources organizations are forced into creating value from the data received. Big Data is characterized by volume, variety, velocity (the rate at which the collected data is generated), value and veracity (Demchenko et al, 2013). However, these

Enabling technologies	Description of technologies
	characteristics cannot be achieved without analytics, therefore Big Data analytics technologies must be employed in analyzing and interpreting the data from various sources into meaningful information.
Simulation	In simulation, physical experimentation can be performed in a virtual setting using real-time data, the real world can include business processes and operations analyzed in a virtual model to gain insight into the current business processes and operations to further create different scenarios that can be used for the analysis of future events.
Cloud computing	According to the National Institute of Standards and Technology (NIST), cloud computing is defined as; "a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications and services) that can be readily provisioned and released with minimal management effort or service provider interaction."
Cyber-Physical Systems	In CPS, the physical and virtual environments are closely linked by objects and software which allows different components to function autonomously and collaboratively in a myriad of ways with the objective of exchanging information.
Cyber Security	In the advent of digitalization, cyber security is important for organizations in guarding business information software, information technology hardware, and other systems used for storing data from theft and unauthorized access from users that might abuse the organization's data.
Systems integration (horizontal and vertical)	Systems integration is supported by horizontal integration and vertical integration; where horizontal integration focuses on the integration of IT systems where they are implemented in various stages of the organization's operations and are not limited to internal functions only but other external value chains within the network. Vertical integration aims to integrate the existing IT systems at different hierarchical levels, from sensors and actuators to the entire business levels of the organization.
Autonomous Industrial Robots and Artificial Intelligence (AI)	Autonomous industrial robots are designed and built to function autonomously possessing the abilities to be flexible and self-configuring to easily adjust and adapt to newly introduced environments with minimal reliance on humans. Their formulated intelligent attributes, allows them to interact with their counterparts in the production system by providing and receiving feedback through the use of the Internet of Things. Artificial Intelligence (AI) plays a major role in these robots by providing intelligent attributes based on machine intelligence (Skilton and Hovsepian, 2017).
Internet of Things (IoT)	Additive Manufacturing is classified under the domain of advanced manufacturing, it employs the principle of adding material layer by layer of the product construction rather than subtracting material as previously done in milling, turning, and drilling operations, the design of the product is constructed and saved in a specific file format using CAD software. The file format is then fed into the printer or machine and the material of choice is selected to produce the final product.
Additive Manufacturing	Additive Manufacturing is classified under the domain of advanced manufacturing, it employs the principle of adding material layer by layer of the product construction rather than subtracting material as previously done in milling, turning, and drilling operations, the design of the product is constructed and saved in a specific file format using CAD software. The file format is then fed into the printer or machine and the material of choice is selected to produce the final product.
Augmented and virtual reality (AR and VR)	The idea employed in augmented reality is that it combines the physical reality and virtual elements through the use of intelligent devices (head-mounted gear, smartphones apps, smart wearable glasses .etc.), where the users can be in contact with the physical world while interacting with the virtual elements around them. The virtual elements are placed in the user's physical environment augmenting them to enable the user to be partially immersed while open-minded about the physical environment (Dodevska & Mihić, 2018). Whereas, virtual reality technology allows the user experience to be fully immersed in the 3D virtual environment. The real environment or imaginary environment is simulated in 3D images using a set of technologies (computer and electronic devices) to allow the user to interact in the virtual environment (Khan et al, 2011 and Mittal et al, 2019).

***Table I**. Industry 4.0 enabling technologies.*

Adopted Industry 4.0 Technologies Applicable to Health 4.0

In as much as some technologies identified in Industry 4.0 are already adopted and implemented in healthcare, some still need further research as to whether they apply to healthcare. This section highlights the application of the adopted technologies in Health 4.0.

Cyber-Physical System (CPS) and Medical Cyber-Physical System (MCPS)

Cyber-Physical Systems have been adopted in the health domain and are employed in smart pharmaceuticals particularly to manage diseases utilizing autoregulatory feedback loops employing various accessories like smart mobile phones (Thuemmler and Bai, 2017). The usage of Cyber-Physical Systems inspired the discovery of Medical Cyber-Physical Systems, although presently these systems are complex and have not reached maturity yet as compared to contemporary systems. Using MCPS can improve the care for patients as it uses specific treatment-based sensors and modeling (Khelassi et al, 2019). MCPS is made up of interconnected smart medical devices, cloud servers, big data applications, and Electronic Health Records (EHR) that are linked together to assist health practitioners and patients to access the hospital services remotely. MCPS depends on remote networking supplied by the cloud computing technology, the usage of MCPS in the diseases control department can help health practitioners to collect and monitor real-time data to assist in the prevention of spreadable diseases (Qiu et al, 2020).

Internet of Things (IoT), Cloud Computing and Medical Internet of Things (mIoT)

In any operational setup, both the technology of the Internet of Things and cloud computing complement each other, as the Internet of Things might not be applicable without cloud computing (Botta et al, 2016). Cloud resources can enormously benefit the Internet of Things significantly in its limited technology capabilities which include storage, processing, and communication (Botta et al., 2016). The discovery of the Medical Internet of Things in healthcare was stimulated by the concept of the Internet of Things, such that it has proven to significantly increase in adoption across the healthcare industry. The architecture of the Medical Internet of Things is similar to that of the traditional Internet of Things in that it also provides a connecting platform that links smart medical devices, technologies, and health systems together for enabling the collection and exchange of data for better health service delivery to the end-user and the service provider. The supply of drugs, authentication of medicine, resource scheduling to cater to patient's needs, patients' health continuously monitored using devices, efficiently managing operations, rapid decision-making assisted to assess changing healthcare conditions and how they can be dealt with timely, the mentioned factors can be achieved through the use of Medical Internet of Things in healthcare (Latif et al., 2017 and Khelassi et al, 2019).

Big Data, Analytics and Cyber Security

The proliferation of data received by the healthcare systems from different data sources such as the EHRs and other medical devices connected to the system requires that the healthcare industry makes use of this data effectively to better understand the continuous changing needs of patients and that of the organization itself. The use of the technology of Big Data and Analytics in healthcare has served the purpose of interpreting the collected data into useful information. The use of big data and analytics in healthcare can significantly contribute to areas such as genomic analysis, evidence-based medicine, analysis of patients' profiles, and analyzing fraud (Aceto et al, 2020). However, cyber security should be strengthened to avoid a data breach. Because once the patients are insecure in sharing their data, the effect will affect the collection of critical data from patients resulting in less informative data being collected, thus influencing the analytics in providing accurate results as the data received not being

sufficient enough to provide a true reflection of the patients' medical history. Once the cyber security is strengthened, there will be trust in exchanging data between the patient and the healthcare system, this will encourage the sharing of information and provide the big data analytics technology to have a true reflection of the patients' health records and informed decisions can be reached by the health practitioners.

Medical Robots

The use of medical robots in healthcare is inspired by autonomous robots that have significantly improved manufacturing setups. In healthcare, medical robots are beginning to gain momentum, so far these robots have assisted health practitioners in many ways which include, safety improvement, reduction of morbidities, reducing the risk of contact that can be incurred when treating infected patients as well as improving the operational efficiency of surgeons when treating patients and conducting surgery operations (Latif et al., 2017 and Javaid et al, 2020).

Augmented Reality (AR), Virtual Reality (VR), and Simulation

The healthcare industry has benefited from the use of augmented reality, virtual reality, and simulation technologies allowing it to harness knowledge from the virtual and real spaces at the same time. The healthcare industry has adopted intelligent devices to improve the implementation of virtual reality and augmented reality. Augmented reality provides the opportunity of a simulated environment for training, where practitioners can excel from partial-task training to realistic full-task training that mainly reaches both interaction and complex spatial orientation in the areas of neurosurgery and echocardiography (Barsom et al, 2016). Simulation can now be used by surgeons to assist them to generate data from a simulated environmental set up to improve the efficiency of surgical operations and planning. The application of virtual reality simulation has improved the training processes that were traditionally undertaken by medical practitioners, such that they are now provided with basic skill training where the supervision of seniors is no longer needed in a controlled environment and also lessens the pressure experienced when operating patients (Yiannakopoulou et al, 2015 and Li et al, 2017). Also, Javaid and Haleem (2019) mention that doctors and patients can provide useful information to each other through the use of virtual reality.

Additive Manufacturing

The adoption of additive manufacturing in healthcare is rapidly increasing due to its ability to create complex geometries and reduction in lead-time to fabricate customized products that meet patients' requirements. In healthcare, the technology of additive manufacturing is considered multidisciplinary, in that collaborations are critical from different disciples (surgery, engineering, rehabilitation, radiography, etc.) in achieving successful results (Tuomi et al, 2014). The application of additive manufacturing in healthcare is classified into five major fields; (i) medical models (additive manufacturing is supported by data from medical images to manufacture models that are used for training to perform surgical simulation, planning for operations and educating students), (ii) medical aids, orthoses, splints and prostheses (addictive manufacturing technology enables the fabrication of personalized devices that are used for improving healing on patients experiencing trauma, abnormality or defect), (iii) surgical tools (additive manufacturing is used to fabricate tools and hardware that can be used for medical devices that are used to improve medical procedure efficiency), (v) inert implants (tissue replacement implants that rely on medical imaging and 3D that are employed in surgical operations are made using additive manufacturing) and (v) biomanufacturing (technologies of additive manufacturing are used to manufacture tissues and organs using micropatterning technology) (Tuomi et al., 2014). The area of additive manufacturing is not

only limited to these categories but can also be used in operations such as pharmaceuticals, surgery, bio-printing, medical imaging, prosthetics, medical devices, and finance for effective cost management (Ramola et al, 2019).

Artificial Intelligence

In healthcare, the continuous increase of big data available from various sources and the analytical methods performed has been made possible by AI techniques. The AI techniques have been adopted mostly in digital health domains because of their capabilities of learning and reasoning (Jayaraman et al, 2020). AI can extract hidden knowledge from the large volume of health data that is rapidly flowing in from different ubiquitous devices. Also, the analyzed enormous healthcare data (i.e., structured, and unstructured) using AI algorithms have made it possible to support physicians to gain better insights into a particular condition so they can make informed clinical decisions (Jiang et al, 2017 and Jayaraman et al., 2020).

DISCUSSION AND CONCLUSION

In reviewing the literature, the study has indicated a significant relationship between Industry 4.0 and Health 4.0 technologies. This supports the findings that have been observed previously that the concept of Health 4.0 has been derived from the concept of Industry 4.0, hence the adoption of technologies. There are similarities between the Industry 4.0 and Health 4.0 technologies, although their application setup varies with industry but their characteristics are built on the same principles. Areas that were “no go zones” previously in healthcare due to insufficient technologies are now areas of exploration and advancement with the Health 4.0 technologies, benefitting the healthcare systems as well as their patients.

In as much as there are many benefits from these technologies, the application of other technologies within this cluster such as medical robots, cyber security, big data, and analytics have gained momentum in healthcare, but they have not matured like other technologies since they are still at an introductory phase, and this has posed uncertainties of reliability both from the health practitioners and the patients. Therefore, resources should be invested in research for these technologies to ensure that much knowledge is gained so that there can be a full scale of adoption and application of these technologies. This is an important issue for future research, as to what challenges the healthcare systems have faced or are facing in adopting the Industry 4.0 technologies.

In conclusion, the Industry 4.0 technologies are significantly applicable to healthcare without any hesitation and the system itself has benefitted enormously from these technologies. It would be advisable for healthcare to consider that as innovation progresses and the operational environment changes so will the needs of patients, therefore, the usage of Health 4.0 technologies should be continuously monitored to ensure that they still serve the purpose as intended initially and are improved as times change.

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USING DATA ANALYTICS TO PREDICT COVID-19 CASES IN SUDAN

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Abstract

As the number of COVID-19 cases increases in unpredictable ways, healthcare workers find difficulties in handling the growth of this infectious disease due to the delay in the lengthy process of Polymerase Chain Reaction (PCR) test and diagnosing the disease accompanied by the lack of medical resources and facilities. To deal with this situation, non-medical therapeutic techniques are urgently needed to cope with the fast outbreak of the pandemic and to curb the spread by fast and accurate diagnosis. This paper aims to build a model for predicting COVID-19 cases in Sudan by studying the pattern of its symptoms, and their significance in causing illness along with other factors by using data mining and machine learning techniques. Classification predictive methods are used to predict cases based on historical categorical data. These methods help to give a better understanding of COVID-19 behaviour, by studying their association and influences on disease prediction and diagnosis. An artificial neural network (ANN) model was designed to give high accuracy in predicting positive COVID-19 cases in Sudan based on observed symptoms such as cough, shortness of breath, sore throat, pneumonia, and headache with an overall accuracy of 67.35%. Symptoms were added in an incremental way to improve the prediction accuracy rate. The research aims are to avail a dynamic model that is self-adaptive as the accuracy of the data increases and more simple symptoms are added which will provide a fast reliable diagnosis utilizing affordable techniques.

Keywords: COVID-19, Machine learning, Artificial Neural Network.

INTRODUCTION

The COVID-19 pandemic was first reported in Wuhan, China, and has spread in more than 50 countries. The international organization, the "World Health Organization" (WHO), declared COVID-19 to be a Public Health Emergency of International Concern (PHEIC) on 30th January 2020. Increasing infectious disease, of course, causes rapid spread and endangers the health of many people and therefore requires immediate action to prevent disease at the national level. Beginning from December 2020 till April 2021 COVID-19 has spread over 209 territories or countries affected around 1,771,514 persons with about 108,503 death cases (Tagebe Tsega, Nit meghalaya, 2020). In the absence of availability of adequate medicine or vaccine, currently, the best way and the most widely-used strategy for the mitigation and control of the pandemic is social distancing, self-quarantine, wearing a face mask, and the use of sanitizers. Millions of people are forced by their governments to stay in difficult conditions and self-isolation (Ian Cooper,Argha Mondal,Chris G.Antonopoulos, 2020). The COVID-19 symptoms differ from individual to another depending on the individual immunity system and other factors. The most common symptoms are fever, cough, fatigue, sore throat, headache, runny nose, chest pain, nausea, vomiting, diarrhoea, the loss of taste or smell, and conjunctivitis. In Sudan, the number of cases is increasing continuously and thousands of cases are daily reported. The COVID-19 test resources are limited and are not available in most of the hospitals. As a result, these tests become expensive. Another issue is the lengthy process of Polymerase Chain Reaction (PCR) test and the lack of medical resources and facilities. Thus, the rate of growth in COVID-19 cases and the limited testing resources are inversely proportional. Also, Symptoms of COVID-19 are also similar to symptoms of other respiratory diseases as they can lead to an incorrect diagnosis. To achieve this, there is an urgent need for non-medical therapeutic techniques to

early diagnose the cases to prevent further outbreaks of the COVID-19 pandemic, to curb the spread by fast and accurate diagnosis. The aim of this paper is to build a model for predicting COVID-19 cases in Sudan by studying the pattern of its symptoms, and their significance in causing illness along with other factors by using machine learning techniques.

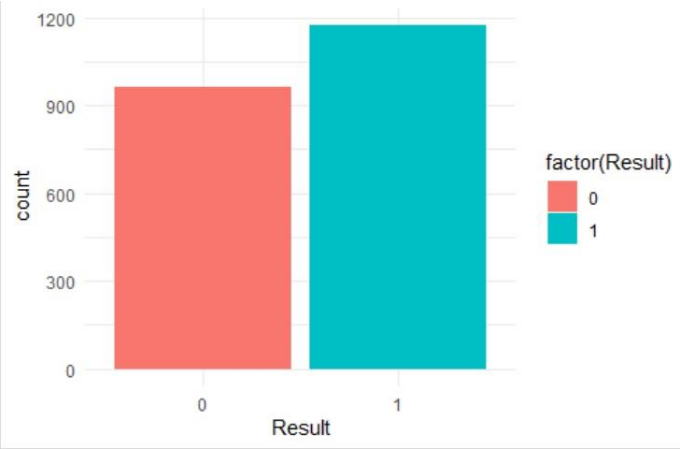

Figure 1: *Dataset Positive-Negative COVID-19 Cases.*

Figure 1: *Shows the number of positive-negative COVID-19 cases: positive cases: 1176; negative cases: 1013; Overall 2189 cases.*

RELATED STUDIES

Various papers have been published based on previous studies of data mining techniques related to COVID-19. So, in the previous study presented the outbreak of a virus called the Middle East Respiratory Syndrome Coronavirus (MERS-CoV) it has arisen in Saudi Arabia. The novel virus belongs to the coronavirus family. The MERS-CoV symptoms include cough, fever, nose congestion, breath shortness, and sometimes diarrhea. In this study they applied two data mining techniques: Naive Bayes classifier and J48 decision tree for building models to better understand the stability and the possibility of recovery from MERS-CoV infections. Their dataset was obtained from Saudi Ministry of Health and the data of MERS-CoV reported between 2013 and 2015.The data was separated in three categories: new cases, recoveries and deaths. All categories of patient information included the following attributes: gender, age, nationality, city and whether the patient is a healthcare personnel or not. The first group combined recovery and death records and the second group included the new case records to predict the stability of the infection based on the current status. After they built models to predict the stability and recovery of MERS-CoV infections by using algorithms, the decision tree recovery model indicated that patients who are healthcare personnel are more likely to survive if their age was found to be in predicting the stability. So, patients between 66 and 87 suffer more from critical complications; moreover, the performance of all the models was compared and evaluated by using the measures: accuracy, precision and re-call. In their result, the accuracy of the models was found between 53.6% and 71.58%. So, the performance of the prediction models can be increased significantly by including more data collected on patients with MERS-CoV infections (Isra Al-Turaiki , Mona Alshahrani, Tahani Almutairi, 2016). Also, in a separate study presented, the logistic regression model along with the clinical judgment were found to identify predictions of COVID-19 positivity. Selected classifiers were assessed for prediction performance, such as the change of smell or taste sense, presence of fever and body aches, and absence of shortness of breath and sore throat. The study used an

anonymous electronic survey posted on social media for those whom tested or quarantined for COVID-19 in the United States. The results showed that 145 participants were declared positive COVID-19 testing and 157 with negative results. Smell or taste change along with fever and body ache were associated with COVID-19 positivity but shortness and sore throat were associated with the negativity of results. The model used in this study had a predictive ability with an accuracy of 82%. An anonymous electronic survey was used in the study; so it relied on the respondent's self-reporting leading to the high possibility of entries duplication, and erroneous responses. It was also affected by the selection bias of the respondents. Moreover, testing locations and specifics regarding testing procedures that were considered COVID-19 test performance factors for prediction were not assessed in this study (Lauren T. Roland, 2020).

Additionally, the previous study proposed a machine-learning model in which it represents high accuracy prediction of COVID-19 test results by featuring a dataset containing eight binary factors: gender, age greater than or equal to 60, known contact with an infected individual, and the appearance of five initial clinical symptoms (cough, fever, sore throat, shortness of breath, headache). In addition to the test date and results on daily basis, the baseline model predicted a positive SARS-CoV-2 infection in an RT-PCR test by asking eight basic questions. The model predicted correctly (TRUE-Positive) 95% of the cases. Fever and cough were found keys to predicting COVID-19. The model also showed that male gender and contact with infected individuals were considered COVID-19 predictors. While the model can be implemented globally resulting an effective screening and prioritization of testing for the virus in the general population, the data that were reported by the Israeli Ministry of Health were quite conflicting, symptoms can be mislabelled, which arose by the underestimation and under-reporting issues. Also, the erroneous and missing of the basic features on the dataset resulting in decreasing the accuracy of data being modelled (Zoabi, 2021).

In another study presented a model for diagnosing the disease using data mining algorithms based on a hybrid model. They used the electronic and clinical information of patients with suspected or confirmed COVID -19 in Emam-Reza hospital in Mashhad city in Iran to diagnose the COVID -19. The proposed method uses hybrid classifiers where the general model can be used to provide diagnoses with higher precision rather than classifiers. To execute the proposed model, they used data mining tools including Rapid Miner 9.7 and Python 3.7. This study used stacking classifiers of basic algorithms including a simple base, decision tree, and K-nearest neighborhood backup vector machine. In this cross-sectional study, they investigated and compared basic algorithms and Hybrid algorithms in terms of accuracy, precision, recall, and measure benchmarks. Moreover, they also evaluated the results using the cross-validation method. Rapid Miner version 9.7 was used for pre-processing and experimenting with other algorithms. This study uses binary classifiers and basic and hybrid algorithms to improve the performance and more accurate diagnosis of COVID -19. The results had shown that the stacking algorithms diagnoses patients were 85.6% accuracy so might improve the model's performance by increasing the data of the COVID -19 dataset and using other models like a neural network, Genetic Algorithm, and Logistics Regression (Morteza Nikooghadam,Adel Ghazikhani,Mohammad Saeedi, 2021).

METHODOLOGY

Dataset Description and Pre-processing

As mentioned earlier, our dataset was obtained from a test laboratory in Port Sudan state. The type of dataset studied is qualitative data. It contains 36 attributes as follows: Nationality, gender, age, age group, country of arrival, entry point, contact condition, state, locality, address, reporting date, arrival date, symptoms appearance date, hospital entry date, isolation entry date, week, isolation center, symptoms (fever, cough, sore throat, shortness of breath, running nose, pneumonia, renal failure, chest pain, headache), temperature, other diseases, sample type, result, result date, exit date, city. The researchers used the statistical programming language R as the primary tool for pre-processing and data preparation, beginning with data cleaning because of the lack of quality in the health care systems, and the absence of a centralized clean COVID-19 database in Sudan, it was difficult to extract any knowledge from it. Also, data integration has a role to handle data redundancy that is found in the dataset (Morteza Nikooghadam,Adel Ghazikhani,Mohammad Saeedi, 2021). Data reduction focuses on the symptom's characteristics and their associations with each other towards an accurate diagnosis and reducing dataset volumes without affecting dataset integrity. Additionally, data transformation helps to facilitate the analysis of COVID-19 symptoms and their weights by using type conversion or labeling for some data mining purposes and models.

Data analysis

The researchers started their analysis by exploring the relationships among the attributes. Descriptive statistics were carried out on the COVID-19 cases to understand their nature. Data analytics is one of the important tools in discovering the relationships and other useful information existing in a body of data (Abdelrahman E. E. Eltoukhy,Ibrahim Abdelfadeel Shaban,Felix T. S. Chan,Mohammad A. M. Abdel-Aal, 2020). The researchers will describe and will use the following data analytics:

Correlation Analysis

Correlation analysis is a measurement of what way two variables are related to each other under a linear relationship assumption to detect if these variables are related to each other, positively or negatively, or not correlated at all. The importance of this type of analysis is to study the relationships between every variable in the COVID-19 dataset with the patient's test results, and see if they are related to each other, positively or negatively, or not correlated at all. The correlation can be conducted using the chi-square test to study the relationship between two categorical variables

It was found that cough, sore throat, shortness of breath, pneumonia, and headache have significant impact because their p-values are less than 0.05. Whereas chest pain, fever, and other factors such as age, and contact condition had p-values greater than 0.05, and were rejected.

Features Selection

As the research focuses on the symptoms' characteristics and their associations with each other towards an accurate diagnosis, some dimensions (attributes) are irrelevant to the symptoms' nature, such as isolation canters and the patient's localities are needed to be reduced. Feature selection methods are used to implement features engineering to reduce dataset dimensionality features that are not related to the problem under study with the lowest significance among the others without affecting dataset integrity and to reduce processing complexity and time required to track the disease pattern. It must be systematically conducted because the output

features will be used to train diagnostic models to yield accurate results and performance models.

The stepwise logistic regression model was performed to test and find which symptoms relate to COVID-19. This gave the right prediction in diagnosis and confirm the indication of COVID-19 disease existence. Thus, all the symptoms (cough, sore throat, shortness of breath, pneumonia, fever, chest pain, and headache) and affected factors like age, gender, and contact condition are added to the initial model.

After that, the researchers used the "boot.stepAIC" function to identify which symptoms and factors to depend on our final model. The result was the LR model dropped fever, age, gender, contact condition, and chest pain because they had low significant values, but other symptoms showed higher significant values. The final model featured cough, sore throat, shortness of breath, pneumonia, and headache as the five significant symptoms.

Data Visualization

Data visualization is a dynamic method, and one of the interactive ways that lead to new data discovery, which facilitates the processing of a large amount of data (Parul Gandhi , Jyoti Pruthi, 2021). It was used in this study to convert the raw data of COVID-19 cases into meaningful form to extract the disease growth rate, and to highlight the growth affection on the limited medical testing resources in Port Sudan. Thus, the technique that is to be used to present data in a bar chart.

Association Analysis

Association rules are the most data mining technique process used to find hidden interesting relationships in large datasets, by studying the association strength between the dataset variables, the frequency of variable sets, and measurement of how variables are related to each other. The importance of association analysis in this study is about highlighting the pattern of symptoms relationships in indicating whether the patient result is positive or negative to present accurate diagnoses, which do not clearly appear in the dataset. The exploration of the hidden relationship takes from the frequent items set by collecting the set of symptoms that frequently occurs together with association rules by addressing the strength of the relationship between COVID-19 symptoms. The evaluation strength of association rules is based on support, confidence, and lift.

Table 1 shows the rules of support above 0.2, and the confidence if it is greater than or equal to 1, reflects the number of times a given rule of symptoms to be true in the practice.

Additionally, the lift measurement greater than 1 reflects a correlation between the symptoms in the rules.

Also found that the occurrence of cough, shortness of breath, and sore throat are strongly associated with all the occurrences of the other symptoms, while the occurrence of headache and pneumonia is not associated with each other.

Rules	Support	Confidence	Coverage	Lift	Count
{Pneumonia} => {Shortness of breath}	0.2617766	1.0000000	0.2617766	2.354992	389
Pneumonia => {cough}	0.2617766	1.0000000	0.2617766	2.354992	389
Pneumonia => {Sore throat}	0.2617766	1.0000000	0.2617766	1.163665	389

Rules	Support	Confidence	Coverage	Lift	Count
Cough => {Pneumonia}	0.2617766	0.6164818	0.4246299	2.354992	389
Cough => Shortness of breath	0.4179004	0.9841521	0.4246299	2.317670	621
Cough => Headache	0.2321669	0.5467512	0.4246299	2.036271	345
Cough => {Sore throat}	0.4205922	0.9904913	0.4246299	1.152600	625
Shortness of breath => {Pneumonia}	0.2617766	0.6164818	0.4246299	2.354992	389
Shortness of breath => {Cough}	0.4179004	0.9841521	0.4246299	2.317670	621
Shortness of breath => {headache}	0.2335128	0.5499208	0.4246299	2.048076	347
Shortness of breath => {Core throat}	0.4185734	0.9857369	0.4246299	1.147067	622
Headache => {shortness of breath}	0.2335128	0.8696742	0.2685061	2.048076	347
Headache => {Cough}	0.2321669	0.8646617	0.2685061	2.036271	345
Headache=> {Sore throat}	0.2409152	0.8972431	0.2685061	1.044090	358
{Cough, Shortness of breath} => {Pneumonia}	0.2617766	0.6264090	0.4179004	2.392915	389
{Cough, Sore throat} => {Pneumonia}	0.2617766	0.6224000	0.4205922	2.377600	389
{Cough, headache} => {Shortness of breath}	0.2321669	1.0000000	0.2321669	2.354992	345
{Cough, Pneumonia} => {Shortness of breath}	0.2617766	1.0000000	0.2617766	2.354992	389
{Cough, Sore throat} => {Shortness of breath}	0.4179004	0.9936000	0.4205922	2.339920	621
{Cough, Shortness of breath} => {Headache}	0.2321669	0.5555556	0.4179004	2.069062	345
{Cough, Sore throat} => {Headache}	0.2321669	0.5520000	0.4205922	2.055820	345
{Cough, Headache} => {Sore throat}	0.2321669	1.0000000	0.2321669	1.163665	345
{Cough, Pneumonia} => {Sore throat}	0.2617766	1.0000000	0.2617766	1.163665	389
{Cough, Shortness of breath} => {Sore throat}	0.4179004	1.0000000	0.4179004	1.163665	621
{Cough, Headache} => {Sore throat}	0.2321669	1.0000000	0.2321669	1.163665	345
{Sore throat, Shortness of breath} =>{Pneumonia}	0.2617766	0.6254019	0.4185734	2.389068	389
{Sore throat, Pneumonia} => {Shortness of breath}	0.2617766	1.0000000	0.2617766	2.354992	389
{Sore throat, Pneumonia} => {Cough}	0.2617766	1.0000000	0.2617766	2.354992	389
{Sore throat, Shortness of breath} => {Cough}	0.4179004	0.9983923	0.4185734	2.351206	621
{Sore throat, Headache} => {Cough}	0.2321669	0.9636872	0.2409152	2.269476	345
{Sore throat, Shortness of breath} => {Headache}	0.2328398	0.5562701	0.4185734	2.071723	346
{Sore throat, Headache} => {Shortness of breath}	0.2328398	0.9664804	0.2409152	2.276054	346

Rules	Support	Confidence	Coverage	Lift	Count
{Shortness of breath, Pneumonia} => {Cough}	0.2617766	1.0000000	0.2617766	2.354992	389
{Shortness of breath, Pneumonia} => {Sore throat}	0.2617766	1.0000000	0.2617766	1.163665	389
{Shortness of breath, Headache} => {Cough}	0.2321669	0.9942363	0.2335128	2.341419	345
{Shortness of breath, Headache} => {Sore throat}	0.2328398	0.9971182	0.2335128	1.160311	346
{Cough, Sore throat, Shortness of breath} => {Pneumonia}	0.2617766	0.6264090	0.4179004	2.392915	389
{Cough, Sore throat, Headache} => {Shortness of breath}	0.2321669	1.0000000	0.2321669	2.354992	345
{Sore throat, Shortness of breath, Pneumonia} => {Cough}	0.2617766	1.0000000	0.2617766	2.354992	389
{Cough, Sore throat, Pneumonia} => {Shortness of breath}	0.2617766	1.0000000	0.2617766	2.354992	389
{Sore throat, Shortness of breath, Headache => {Cough}	0.2321669	0.9971098	0.2328398	2.348186	345
{Cough, Sore throat, Shortness of breath} => {Headache}	0.2321669	0.5555556	0.4179004	2.069062	345
{Cough, Shortness of breath, Headache} => {Sore throat}	0.2321669	1.0000000	0.2321669	1.163665	345
{Cough, Shortness of breath, pneumonia} => {Sore throat}	0.2617766	1.0000000	0.2617766	1.163665	389

Table 1: *Association Analysis Result.*

Data Modelling

The classification method is considered one of the most powerful and effective predictive methods that are suitable for medical purposes, especially disease diagnosis. It is applied to a large volume of data, to train the model about the behavior of COVID-19, toward accurate prediction and diagnosis of COVID-19 results as much as it can. The researchers need to use a model that is: first, a self-adaptable model that will improve its COVID-19 diagnostic performance based on symptoms with increased reliability in the data. Second, flexible to accept more data with a reasonable processing capacity increase. Third, can be used as a standalone model after it is trained.

Decision Tree

Decision tree is the most powerful and popular tool for classification and prediction. A Decision tree is a flowchart-like tree structure, where each internal node denotes a test on an attribute, each branch represents an outcome of the test, and each leaf node (terminal node) holds a class label. The model can handle non-linear datasets such as categorical datasets which dataset that is provided in this research is categorical data. Also, it features an understandable representation and it can perform classification without requiring much computation. (GeeksforGeeks, 2021)

Despite the advantages that are mentioned above, the decision tree model might be quite challenging to be fitted the dataset. First of all, we mentioned that to perform high diagnostic

performance, the self-adaptive model is needed to fit the dataset, but in the case of the decision tree, it can be less adaptive in training the model, because of the need of sorting down the instances from the root every time the dataset is increased or changed. In result, it decreases the flexibility of accepting new cases and lowers the ability to perform as a standalone model after it's being trained. With increasing cases over time, the model's ability to fit the dataset is decreasing, which lowers the prediction accuracy.

Artificial Neural Network

The Artificial Neural Network model is basically a mimic of the human brain neurons' layers on functioning phenomena. It is a structure of three types of layers: input, hidden, and output. These layers contain units called neurons interconnected by directed edges with a weight representing its synaptic strength. These neurons receive one or more inputs and apply some functions, to produce an output, that is to be passed to the next layer as an input (might combine with other inputs) to produce another output, proceeding until the terminal neurons produce the final output for the model (Sonali. B. Maind , Priyanka Wankar, 2014). In the matter of COVID-19 disease complexity, this model is used because of its learning adaptability, because it can handle this complexity by training itself on the behavior of the symptoms, adapting to the changes whenever the disease develops itself in less time.

RESULTS AND DISCUSSION

In this study, an artificial neural network prediction model has been conducted for diagnosing COVID-19 cases in Sudan (Port Sudan) medical test laboratory by using R tool. Although the model prediction score is not highly accurate, it gives a glimpse into what symptoms represent high significance in COVID -19 diagnosis.

There are several metrics used to evaluate the model prediction performance, and the results are accuracy 67.35%, error rate, sensitivity 73.74%, specificity 60.89%, precision 73.7%, and F1 score 73.7%.

The most significant part of the results is the ease of use of the model especially if it can be ported to a mobile device. The new approach is ML establishes a model on a computer and trains the model to port it to a mobile which can then be used as an expert tool to classify cases in the field.

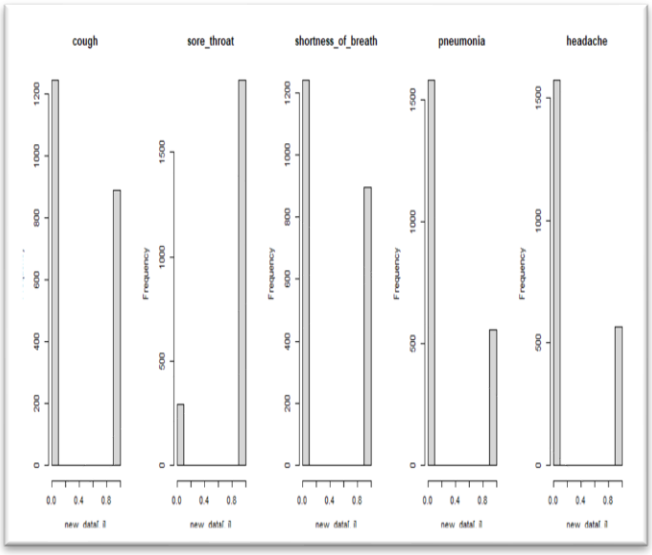

Figure 2: *COVID-19 Significant Symptoms.*

Figure 2 shows the visualization of the number of the significant symptoms in the cases: cough (yes=1299, no=890), sore throat (yes=1845, no=344), shortness of breath (yes=895, no=1294),

Variable	Result	Fever	Cough	Pneumonia	Headache	Shortness of breath	Sore Throat	Chest pain
Result	1.00000000	0.027704302	0.29673016	0.24398740	0.11132564	0.27884594	0.24691123	0.03445555
Fever	0.02770430	1.000000000	0.02588987	0.01817046	0.01834725	0.02601479	0.07708210	0.00210058
Cough	0.29673016	0.025889872	1.00000000	0.70183659	0.53844247	0.97402019	0.31372360	0.08113537
Pneumonia	0.24398740	0.018170459	0.70183659	1.00000000	0.45780907	0.69846662	0.23572865	0.11560436
Headache	0.11132564	0.018347252	0.53844247	0.45780907	1.00000000	0.54163304	0.04914781	0.08337175
Shortness of breath	0.27884594	0.026014758	0.97402019	0.69846662	0.54163304	1.00000000	0.30152853	0.08074587
Sore Throat	0.24691123	0.077082099	0.31372360	0.23572865	0.04914781	0.30152853	1.00000000	0.02725126
Chest Pain	0.03445555	0.002100584	0.08113537	0.11560436	0.08337175	0.08074587	0.02725126	1.00000000

pneumonia (yes=1633, no=556), headache (yes=1625, no=564).

Table 2: *The Correlation between Symptoms.*

Table 2 shows the correlation results between the symptoms: fever, cough, pneumonia, headache, shortness of breath, sore throat, chest pain, and with the test results. It shows that fever and chest pain are neither correlated with other symptoms nor with the result. And it highlights the existence of correlation of cough, pneumonia, headache, sore throat, and shortness of breath.

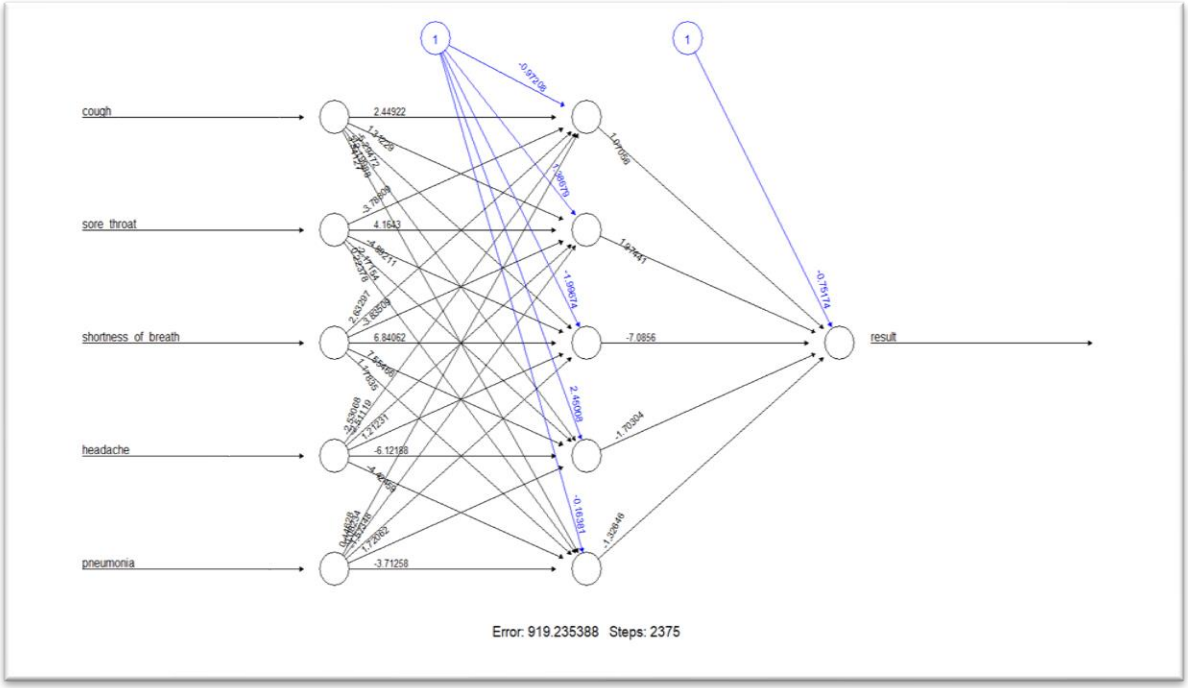

Figure 3*: Neural Network Design.*

Figure 3 shows the artificial neural network model that is conducted to predict COVID-19 cases based on symptoms.

CONCLUSIONS

On a final note, the research focused on tracking COVID-19 symptoms appearance that causes the disease, in contemplation of decreasing its growth rate by adopting an ANN model as a solution for a more reliable diagnosis without the need for testing. The model was conducted on a real dataset brought from a test laboratory in Port Sudan. The analysis of the dataset pattern has found that the highest significant COVID-19 symptoms are: cough, sore throat, shortness of breath, pneumonia, and headache, while fever didn't show significance in causing illness. Additionally, neither age nor gender showed significance in causing illness. Moving forward, the dataset was used to train an ANN model with the highest significant COVID-19 symptoms. Unfortunately, the model prediction performance does not live up to expectations, or any level of satisfaction. The correct predicted cases were relatively low, causing some inaccurate results. By taking further investigation, the model was trained by another dataset outside Sudan, by taking the same sample size of the research primary dataset, the model prediction performance was phenomenal, resulting in overall highly accurate results. In essence, the dataset that was provided in this research was unreliable to be used, because of the lack of real-world aspects that the primary dataset represents.

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UNIVERSITY TO INDUSTRY: THE COMMERCIALISATION OF APPROPRIATE MEDICAL DEVICES IN THE SOUTH AFRICAN CONTEXT

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Abstract

Medical devices need to be appropriate for the context in which they are used. There is a need for increased local commercialisation of medical devices to achieve this. Navigating the commercialisation of medical devices is a complex undertaking. For any innovation to be successfully commercialised, a clear understanding of the specific processes and policies in place is essential. Although various commercialisation and medical device design models exist, none provide a comprehensive description of how to commercialise a medical device, specifically an Emergency Medical Service (EMS) device, from a South African university. This paper presents an overview of a 2-year Industrial Design Master's study which documented the process of taking a university project to a fully commercialised medical device in the South African context.

Framed in the pragmatic paradigm, this study aimed to define the process of commercialising a medical device from within a university to industry. The researcher conducted an in-depth review of existing commercialisation and medical device design process models and literature and synthesised this information into a Journey Map. Thereafter, the researcher participated in and documented the practical process of commercialising a university-born medical device and capturing this process in a process model. Finally, this process was analysed and compared to that depicted in the literature, and synthesised information was presented in a final process model. The purpose of this paper is to provide an overview of the findings of this study and the resultant process model which serves as a guide for the development and commercialisation of appropriate medical devices for the South African medical industry.

Keywords: Medical Device Design, Commercialisation, Appropriate, South Africa.

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PEACE, SECURITY, AND ETHICS

PAPERS

KNOWLEDGE NETWORKING FOR EAST AFRICA CSO NETWORK FOR PEACEBUILDING AND CONFLICT PREVENTION (ECONET)

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Abstract

Peacebuilding practices in Africa are characterized by short-term interventions, low effectiveness, elite's dialogues, and state-centric top-down approaches. They lack systematic efforts at the permanent dismantling of conflict-pro structures (political, socio-economic, environmental, and community) that generate and exacerbate conflicts. Despite the prevailing discourse on the importance of local ownership, many peacebuilding programs do not accommodate local context and ignore indigenous practices for conflict resolution and resource governance. Civil society organizations play an intermediate role between states, international actors, and communities (citizens). This role can empower local communities to become more resilient and take the lead on peacebuilding and conflict prevention. WANEP (West Africa Network for Peacebuilding) is an African success story of mobilizing CSOs into a large peacebuilding network and inspired east Africa's newly established ECONET. Using Sudan as a case study, this research attempts to develop an optimum design of East Africa's Knowledge Networking for peacebuilding by defining the network's structure, governance, collaboration links and patterns, capacity building, and knowledge diffusion, in a way that ensures the sustainability and effectiveness of peacebuilding interventions. The network pursues knowledge sharing and exchange of information, best practices, and experiential knowledge, as well as early conflict warning signals and insights. Through this collaborative platform, grassroots communities and various stakeholders will examine existing interventions, prevention policies, strategies, and practices to determine impact, efficiency, and effectiveness in developing innovative approaches. We argue that besides grassroots participation, incorporating indigenous knowledge and resource governance; fostering knowledge networking values of scalability, collaboration, and knowledge creation; and utilizing community-based appropriate technologies, can expose and dismantle many conflict-pro structures and advance sustainable peacebuilding.

Keywords: Knowledge Networking; Peacebuilding; Conflict-pro Structures.

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REGIONAL SPATIAL STRATEGY AS A TECHNICAL TOOL FOR PEACE CONSOLIDATION IN SUDAN

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Abstract
In spite of the veteran concerted efforts in appropriate technology in Sudan, but these efforts remain as sectorial isolated projects. One of the objectives of this paper is to incorporate these efforts in the policy making domain, and to consider appropriate technology one of the principal pillars of the developmental strategies in Sudan. Peace consolidation is the absent obligatory in Sudan. Consequently, both the series of national strategies and the myriad peace agreements had never achieved their designed objectives. Low regional economic performance and pervasive rural poverty geared by the societal technical underdevelopment are evidently proved to instigate relapsing into war after peace agreement was achieved. Given the heterogeneous socio-economic and spatial diversity of the conflicting zones in Sudan, it is one of the challenges of this paper to provide a spatial context to the pillars of peace consolidation that could provide for technology transfer and adoption of appropriate technology. The paper called for the Regional Spatial Strategy concept, as a powerful systematic tool, to localize appropriate technology at the regional sectoral economy. A grounded approach helps analyzing the Livelihood modes, level of productivity and rural poverty. The analysis recommends designing a robust conceptual techno-economic framework, however based on technical packages relevant for each economic sector in its corresponding spatial context. To safeguard against recurrence of violence, this framework recommends aggregating the regional spatial strategies vertically into a national spatial strategy; hence guarantee a grass root methodology, and pledge for peace consolidation to be included in the national context.

Keywords: Regional Spatial Strategy, Techno-Economic Development Framework, Appropriate Technology, Peace Consolidation.

INTRODUCTION

In spite of the huge economic opportunities in Sudan, but Sudan is now one of the poorest LDCs, with over 40% of its citizens living below the poverty line (ADB, 2021). Poverty in Sudan results from a combination of factors ranging from the malfunctioning of the macro and regional economies, climate change impacts, and internal civil tensions and wars (Osman, 2013). The Sudanese economy shrunk significantly by 2.3% in 2018, and the economic growth remains negative between -2.5% and -1.5% in the last three years (IMF 2019). The Sudan's real GDP is registered by the African Development Bank to shrink by 8.4% in 2020 (ADB, 2021). The UNESCO (2022) estimated the adult literacy rate at 60.7% of the total population in 2018 with a significant variation between regions. The UNDP (2022) ranks Sudan at the bottom strata of the Human Development Index (HDI), stating that the scoring of the country averaged 0.43 in the era 1980 - 2020 (international average is 0.724 points); hence ranks at 167 out of 185 countries. The World Bank (2020) averaged the political stability indicator for Sudan from 1996 to 2020 at a value of -2.17 points; with a minimum of -2.67 points in 2010 and a maximum of -1.55 points in 2004, (Political Stability Index scaled weak status as -2.5; and the strong status as +2.5).

This gloomy picture on the economic malfunctioning is not without a history. It is a result of a cumulative failure of successive national and strategic developmental planning. A quantitative-objective approach was adopted in the 10-year Plan of Economic Development 1961/62-1970/71, then in the 5-year plan 1970-75, and in the successive three 6-year plans beginning from 1976 to 1994. A shift towards a qualitative-approach began by the National Comprehensive Plan 1992-2002; and the Quarter-Century Plan 2007 - 2031, which was structured around five 5-year action plans. However, and in spite of that, the World Bank (2020:211) confesses the non-achievement of the targeted developmental objectives all over the period after Independence (1956). One of the causes of this failure is discussed to criticize the top-down approach, and the nonexistence or non-efficiency of a technical body that could technically and spatially bridge between the national and the local levels.

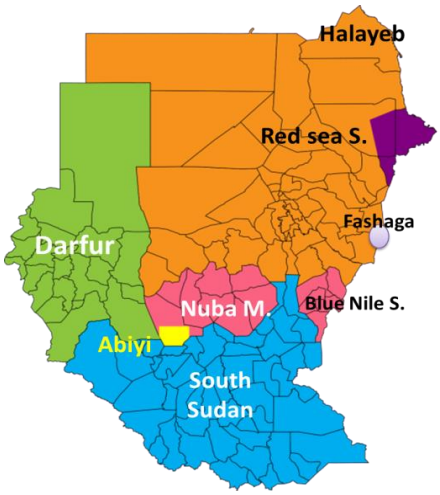

***Figure 1**: conflicting areas in Sudan.*

On the other hand, Sudan practices all types of civil wars and social tensions since 1954 up to date. Civil wars in **South Sudan** began before independence (1956) and ended by signing the Comprehensive Peace Agreement *CPA* 2005; however, resulted the secession of South Sudan into an independent state. Nevertheless, border issues are yet solved, and cross border tensions are still registered. In spite of this comprehensive settlement, but the three bordering areas of **Abiyi, Nuba Mountains** and south **Blue Nile** state are still churning.

Social tensions in **Darfur** began in the mid-seventies impacted by the drought and desertification phenomena, and turned to civil conflict as from 2003. Again, several peace agreements were signed aimed to resolve the conflict such as Abuja peace agreement (2006), Doha peace agreement (2011) and lately the Juba Agreement (2020). Still violence is triggered in the region. A recent official report of HAC (no. 50/A/1 dated 23.11.2021) stated twelve villages were burned, 1003 houses were destroyed and tens of women were raped and similar number of men killed in Jabal Moon accidents in November 2021.

Tensions in the **Eastern Sudan** began politically in 1986 as a tribal conflict between Bija and Bani AAmir, before spreading all over the region and expanded to intersect some neighbouring countries' interests. It is still burning today in spite of the efforts exerted and the several peace agreements signed, such as Asmara (2006) agreement. The situation in Eastern Sudan culminated in blocking the whole region in September 2021 by Juba-peace opposing parties, hence isolating all the Sudan's Red Sea ports from the rest of the country.

The World Bank (2011) attributed the conflicts in Sudan mainly to two factors, one to climate change impacts, which results in high competition on natural and scarce resources. The other to the chain effect of the low economic achievements attributed to the pervasive societal technical underdevelopment, which inherit low productivity and perpetuate rural poverty. (Interpreted in figure 2).

Figure 2: *interpreting World Bank's (2011) view to causes of conflicts in Sudan.*

The resultant of this situation is a severe deterioration of the regional economy in all the affected states (Osman (2013), high rate of rural-urban migration (stated by the World Bank (2020) as 3.3% in 2020 up from 2.5% in 2010), and a vicious circle of malfunctioning and failures, flagrant conflict, peace agreement and a new cycle of war. About 2.5 million are discussed by Global Economy Organization to be displaced since 2010, and a new 4.9 million people in need of humanitarian assistance in 2021 in Kordofan, Darfur, and the Blue Nile states.

The above discussion concludes a set of hypothesis and assumptions. A tacit assumption emerged that there exist some linkages between the macro-economic malfunctioning, the failure of peace agreements and the non-achievement of objectives of the national developmental strategies. None of these three domains could register success without the positive performance of the other two. This notion entails the methodology of this paper to handle the concept of peace, and virtually, peace consolidation, at a wider transdisciplinary context. The other hypothesis reads that peace consolidation is the easier to be achieved than the other two parameters, since needs no major restructuring. Then breaking the vicious circle of the interlinked failures by consolidating peace at the affected areas will refresh the regional economy and will stabilize the social and economic parameters both at the regional and the national levels. Another hypothesis reads that, while peace-making (peace agreements) is a political issue, but peace consolidation is a technical issue, which should be handled through investigating the socio-economic parameters, as well as the technical and technological aspects of productivity, capacity development and sustainability. These hypotheses reveal a binary research problem. Another hypothesis is summarized around the fact that the objectives of the national strategic planning would never be achieved without a stabilized rural population, which in turn could not be realized without an intensive spread of peace. Any hesitation in this solid relationship would evidently lead to the collapse of either of them. It goes to state that peace consolidation will never be achieved solely by signing a peace agreement, however robust it is; unless root causes of conflict and strategic visions are included. On the other hand, lessons learnt from the cumulative failures of the national developmental strategies ensure that

developmental objectives could never be achieved without incorporating peace consolidation key factors within the axiom of the strategy.

The above discussion needs preparing an arena wherein socio-economic parameters, technical issues and spatial domains could act together. Moreover, and to solve the dilemma of the above interlinked circles, vicious or innocuous, this research calls upon the concept of the **Regional Spatial Strategy (RSS)** to work as a technical tool to achieve the above objectives. The RSS is famous of its peculiarity in mediating the spatial and technical domains. On the other hand, the historical failure of the national and the top-down approaches in Sudan necessitate adopting a method that could enable a lower level of handling.

The RSS concept is revived by the British Planning and Compulsory Purchase Act 2004, to bridge the gap between the local planning policy and national planning policy. Despite the fact that the RSS was abolished in England by the Localism Act 2010, after been condemned to be "too top down", but all its basic justifications are now applicable in Sudan. It well serves the social and the socio-economic diversity of rural Sudan, and could easily be synchronized with the prevailing federal administrative system inherited from the Regional Governance Act 1980. It could allow planning to establish a tailored approach for regions to better utilize their diverse opportunities, and best address the causes of local problems, especially urban and rural poverty. It is the lucubration of utilizing the planning system to affect local socio-spatial development, and mediate to link it with the national development strategy. RSS is a suitable tool to aggregate issues of technology by giving each region its fit-for-purpose dose that respects its socio-cultural capacity.

FOCUS

Based on the World Bank's (2011) notions interpreted in figure 2, this paper draws a hypothetical definition that **Technical Underdevelopment** in the Sudanese context could be defined as the lack of qualified personnel and technical infrastructure, that ends with the use of crude methods of production; wherein man's effort, simple tools and animal capability composes the maximum production capacity. While **Technology Development Process**, is "the directed process at developing new knowledge, skills and artefacts that in turn facilitates platform development, which leads in product/ process development" (Aristodemou et. al. 2019:2).

Hawthorne (1971) defined **Technology** as the "application of science to the solving of well-defined problems"; while Schlie (*et al.* 1987) defined technology as "the knowledge and means to do something"; but Goulet (1977) defined it as "the systematic application of collective human rationality to the solution of problem by asserting control over nature and over processes of all kinds". In line with this notion, **Technology Gap** could be derived to represent the difference between what has been really practiced (or is known) at the production sector of the economy, relative to what is needed in order to achieve goals, or strategic objectives. Then, and for the purpose of this paper, **Appropriate Technology** could be defined as the fit-for-purpose small-scale technology that local people can manage and use. This definition is supported by Sharif (1988), that appropriateness of technology is derived from the context and the objectives needed to be achieved by technology; and appropriate technology should cater for the social variations, cultural and place-and-time of operation. The technology is deemed to be "appropriate" when it is compatible with local, cultural, socio-economic, and political institutions of the society in which it is used.

The way out to bridge the technology gap between the available level and the appropriate level is discussed by Aristodemou (*et. al.* 2019:2) to be via technology transfer that works to developing new knowledge, skills and opportunities that would enhance productivity and economic performance. Rodrik (2021) ensures that this technology gap is widened, geared by the indicators of poverty and education level of the society.

Then **Technology Transfer** is an accompanied terminology with appropriate technology; it could be handled as the process of diffusion or transforming technology from an entity to another, and in successful cases of transfer the recipients have to understand and utilize the transferred technology effectively. Chungu (1996:7) assures that to succeed in transferring technology or utilizing appropriate technology seven factors should occur, on top of them is the local and the macro transferee contexts (or environment, in his words). The local transferee context in regional Sudan is determined by and large by the socio-cultural status and the consolidation of peace in the area; while the macro context depends to a great extent on whether the region is conducive, and whether the inter-regional strategy (the national strategy) is thriving to activate a linking mechanism balancing technology adaptation between the different regions of Sudan. A failure to guarantee a regional positive context for technology transfer could finally lead to inappropriate technologies being transferred to either of the regions.

The nub of this discussion goes towards ensuring that peace consolidation in Sudan could not be attained without concealing the pervasive societal technological underdevelopment, and bridging the technology gap at the production sector. Regional spatial strategy and appropriate technology are called to formulate the main pillars of this process.

FORMULATION OF THE RESEARCH PROBLEM

Thinking of peace as a socio-political contract that should include developmental strategies, well emerged in technical and technological parameters, allow asking a new set of research questions touching the livelihood and rights of all the conflicting parties versus the sustainable utilization of resources and opportunities. It also allows suggesting a grounded constructivist methodology investigating the principal causes of conflicts, and touches the attempts bridging the technological gap at its grass root level, by adopting appropriate technology suitable for each area or local society in the conflicting zones.

Sudan has a deep experience in research and adoption of appropriate technology; Fernando (*et.al.* 2008) stated the efforts of Khartoum State in utilizing appropriate technology for housing the urban poor; Elkhalifa and Balila (2010) investigated the efforts of the National Fund for Housing and Rehabilitation in search for adequate and affordable housing based on appropriate local building materials and technologies. The UNDP (2022) has a thumping effort in all the states of Sudan, focused on the critical aspects of stabilization, peace, and institutional reform. Successful projects of appropriate technology were implemented such as creating safe animal routes in North Darfur; erection of Sudan's first wind turbine in 2021; the continuous project of enhancing community stabilization through innovative value chain partnerships in Darfur, wherein appropriate technology is utilized to approach an innovative value chain partnership between farmers, UNDP and manufacturing companies in Darfur; and not the least is the technological capacity development projects for youth and women in local sorceries. Another appreciated effort is exerted by the Agricultural Technology Transfer Society (ATTS, 2022) in Sudan, focusing on technology transfer and increasing agriculture productivity. The stated vision of ATTS is cited as "attainment of food security in Sudan through availing appropriate

technologies". These efforts are unique in adaptation of appropriate technology for empowering livelihood modes in livestock and agroforestry activities, alternative energy, capacity development for women and workers and the like.

The main research problem is polarized around the fact that there is a huge effort done by the government and the stakeholders to adapt appropriate technology in Sudan, both at the academic and the professional sectors. But these efforts are without a unified vision or framework that could stream them towards definite objectives. Priorities are also not kept to maximize chain effects of these efforts.

It is one of the objectives of this paper to develop a framework that could curb the heterogeneous efforts into a well-defined visionary strategic context. Again, the research attempts to handle the issue of appropriate technology within a wider socio-spatial context, leading to strategic objectives such as peace consolidation and eradication of rural poverty.

CAUSES AND IMPACTS OF TERRITORIAL VIOLENCE IN SUDAN

The history of conflicts in Sudan is deeply rooted even before Independence, and is terrifically affecting its economy and stability. To scrutinize the root causes and impacts of conflicts and territorial violence in Sudan, this paper tends to categorize conflicts regionally into four categories: South Sudan, Darfur, Eastern Sudan and the three areas.

South Sudan Civil War

Conflicts began in South Sudan a year before Independence, Pike (2011) attributed the sparking of the first war to the closed administrative system applied by the British rule, and its failure to create favorable conditions between north and south when preparing the deal for independence in 1955. This situation led to a mutiny by separatist southerners who began a low-profile civil war led by the armed *Anyanya* movement, who flagged the mottos of self-determination of the southern region and for equitable development and infrastructures.

The Addis Ababa Peace Agreement 1972 (AAPA) came to end this civil war by granting regional autonomy to the south, and acknowledged them a defined share in wealth and authority in the North. The lack of economic development in the region, and the failure to fulfill most of the non-political agenda of the AAPA, led to the collapse of the AAPA; and in 1983 the second civil war flared. The second civil war continued the same slogans and agenda, and lasted in 2005 by signing the Comprehensive Peace Agreement CPA 2005 in Nivasha, Kenya; which decided a referendum after a six-year interim period, and the referendum led to the secession of South Sudan into an independent state in 2011.

Assal (2016:4) argues that the negotiation of the CPA spanned three years, but with a clear absence of the civil society; also, strategic developmental agenda were not emphasized, and women participation is neglected; women by the CPA negotiators are conceived as passive victims of war, not a principal player in the Southern society. The Frontline World (2005) estimated about two million have died from the two parties in this war; more than four million Southerners have been displaced, with 1.5 million living in settled areas and 707,000 in camps in Khartoum area. Ali (2013) calculated the average annual military expenditure in Sudan in this war period to be US$ 845 million; meaning an expenditure of US$ 33.8 billion for the run of the war. That is 2.3 million dollar every morning for forty years.

Darfur Conflict

Darfur, the deep western region in Sudan, of an area about 493,180 km^2, populated by 9.4 million people in 2018 (CBS, 2018), comprising more than 160 tribes and ethnicities (UN-Habitat, 2020:15). It is important to mention that livelihood modes in Darfur depend mainly on agriculture and grazing; these two modes are practiced at the tribe scale, where a complete tribe or ethnicity practices either of the two modes. Osman (2013) stated that the conflicts in Darfur began when the region was pervaded by severe waves of drought and desertification in the seventies. Consequently, agricultural areas shrink, grazing ranges declined, and water resources seized in narrow pockets. Conflicts began by the competition of herders and farmers on water resources, animal routs and land ownership. Soon the conflict turned to tribal tensions, and then to armed confrontations as from 2003.

Several peace agreements were signed between the government and the armed movements; all of them concentrate on the division of wealth and power. Ali (2013) calculated the government of Sudan incurred costs of US$14.1 billion in Darfur just for direct military expenses and infrastructure damages in the era 2004-2011, (about US$1.8 billion annually); and the UN spent US$10.9 billion for Darfur peace-keeping in the same era. About 3380 villages burned or destroyed, and hundred thousand lost their lives. Recent estimates points that this war (2003-2020) has cost Sudan about US$ 28.8 billion; and the international community about US$19.9 billion, total is US$48.7 and is still escalating.

The Three Areas

This terminology is coined by the negotiation parties of the CPA 2005, to refer to three border areas, viz: the southern Blue Nile State, Nuba Mountains and Abiyei area. The CPA admitted the 2010 km border line of 1956 between northern and southern Sudan, but failed to resolve the social interactions, reciprocal movements and common livelihood imposed by the legacy of socio-ethnic groups living there. Some 81 tribes and ethnicities share living cross this border line (Aldood Jubara, 2010). The three-areas-track of Juba 2020 negotiation raised problems of land ownership, land uses, grazing rights and the distribution of ethnic groups along the border line. The conflict over the oil-rich Abiyei region is drawn according to the ethnical geographical distribution of the Misseriya tribes of the north and the Dinka Ngok tribes of the south. The CPA 2005 left the three areas to the vague phrase of “the popular consultancy”, without determining who is entitled to participate in this euphemistic referendum. However, it could be concluded that while the CPA 2005 succeeded in ending the war in the South, but it instigated the conflict of Darfur and seeded a potential conflict in the three areas.

Eastern Sudan Tensions

The Eastern Region, sometimes described as the forgotten region, composed of three states: Kassala, Gadarif and Red Sea; has an area of 326,703 km2, populated with 6.2 million in 2018 (CBS, 2008) . The Central Bureau of Statistics (2018) states that poverty rate in this region reached 54%, while the national score is 36%. The ICARDA (2012) classified the three states of the region as the poorest states in Sudan. The region turned to a site of armed conflict since the 1990s, when groups took up arms citing political and administrative marginalization, economic impoverishment and low pace of development. With a mediation of the Eritrean government, and the momentum of the CPA 2005, the government signed the Eastern Sudan Peace Agreement (ESPA 2006) in October 2006 with the Eastern Front; albeit with low profile international clout and support. Conflict erupted again in 2011. Lately a peace agreement was signed within the Eastern-track of Juba 2020 agreement, but instead of spreading peace in the region, riots and confrontations returned worst. In October 2020 protestors blocked the main highway connecting Sudan sea ports to the rest of the country, raising mottos that “they are not

against peace, but are looking for just peace that addresses the root causes of the marginalization of the region, lift poverty, and provide basic services and development" (Amin, 2020). It is interesting to record that all the states within the above four areas of conflict in Sudan are classified by ICARDA (2012) either within the human poor states or the income poor states; meaning that rural poverty is either one of the significant instigators of war in these areas or is the eventual impact of conflict.

To curb the above discussion, it is in table (1) below, that the main four causes of conflict are ranked for each region.

South Sudan	○ Uneven development patterns & lack of basic infrastructure. ○ Human rights for minorities and ethnical groups; mal-functioning of administrations. ○ Poverty & slender modes of production ○ International conflicts of interest.	**Darfur**	○ Climate change, desertification & aridness. ○ Conflicts between farmers & herders on natural resources, animal routs & land ownership. ○ Poverty and mal-managing of resources. ○ Uneven development patterns & lack of basic services.
Eastern Sudan	○ Poverty and marginalization. ○ Uneven development patterns & open eastern country borders. ○ Lack of basic services. ○ Impacts of climate change on livelihood modes & productivity.	**The Three Areas**	○ Poverty and primitive means of production. ○ Lack of infrastructure & basic services. ○ Tribal & ethnical tangles. ○ Political miss-interpretations. And international conflicts of interest.

Table 1: *Indicative ranking of the main four causes of conflict in Sudan - per regions (Source: interpreted by author from local literature).*

It could be asserted that the root causes of conflict in Sudan vary from region to region but rural poverty is attending across the regions. On the other hand, a scanning over the different peace agreements concludes that the above causes of conflict in the different regions of Sudan, and in best cases, were not thoroughly handled. Table (2) below summarizes the six typical pillars handled in the basic peace agreements for the different regions:

Pillars	**CPA 2005- Nivasha**	**DPA 2006 – Aboja** (Darfur)	**ESPA 2006- Asmara** (Eastern R.)	**Juba Agreement JPA 2020**
Power sharing method	Self-determination, autonomous rule	Transitional Darfur Regional Authority (TDRA).	Eastern Sudan States' Co-ordination Council (ESSCC)	Concept of regionalism. Darfur as autonomous ruled region.
peace implementation body	Unity Support Fund (USF)	Darfur Reconstruction & Development Fund (DRDF)	Eastern Sudan Reconstruction & Development Fund (ESRDF)	Darfur Development & Reconstruction Legation.
Public participation	Referendum on independence	Referendum on some of Darfur states	Consultative Conference on Eastern Sudan development	Not exist
Sharing the rule & power	VP from SPLM + 28% of national congress, 28% of national ministers.	The 4th. National hierarchical position + 3 posts of Cabinet Minister + 3 posts of State Minister from Darfur	2 posts of Cabinet Minister + one post of State Minister + 6 in National Assembly to be held by Eastern Sudanese.	20% of posts in every administrative level or cabinet or institutions to be reserved to Darfur people.
Funding peace	50% of oil and non-oil revenues to south	$ 300 M seed capital 2006 + $200 M for 2 years.	$100 M seed capital 2006+ $125 M for 4 years.	40% of mineral returns + $700 M annual fund to Darfur
Armed forces inclusion	Joint Integrated Units JIU	DDR program JAM	DDR program JMCR	DDR program

Table 2: *Major pillars of peace agreements in Sudan (Source: interpreted by author from peace agreement documents).*

What could be concluded from the above discussion is that the larger share of the county's income is exhausted in civil wars. Violence continues to have a significant impact on the economic performance of Sudan. It incurred a proportion of economic cost equivalent to 18% of the GDP in 2020, for expenditure reached $33.5 billion, with a total economic impact of $54.4 billion (IEP, 2021:89). Again, almost all the peace agreements did neither include the basic causes of conflict nor do they include strategic and developmental domains. Peace agreements concentrates on division of wealth and power, but not the human welfare or capacity building in the conflicting regions. Failure to sustain peace is inevitable then.

PEACE INDICATORS FOR SUDAN

The Institute for Economic and Peace (IEP, 2021) issued its 15th edition concerning the ranking of 163 countries around the world, upon their level of peace achievement, its economic value and impacts on socio-economic development. Twenty-three qualitative and quantitative indicators were worked out to end up with the Global Peace Index (GPI). Sudan scores 2.936 points (max=4), keeping its same last year's rank of 153 out of the 163 countries (IEP, 2021:10). Sudan ranks 156 and 157 in 2015 and 2010 respectively. On the Fragile indicator, Sudan scores 105.2 points (max=120) and ranked the 8th out of the 179 countries surveyed; getting better than the 108.7 points scored in 2018 (ranked 7th). In 2007 Sudan scored 113.9 points as one of the most fragile states in the world.

The Global Economy.com worked out the Security Threat Index as a unified indicator of a maximum of 10 points, by ranking 200 countries against twelve indicators covering five domains of: cohesion, economic, political, social and cross cutting domains. Table (3) below shows that in 2006 Sudan ranked first as the most threated country around the world by scoring 9.9 points; before getting better in 2021 to rank the eighth around the world by scoring at 8.1 points. The average value for Sudan in the era 2007 – 2021 is 9.28 index points. For comparison, the world average in 2021 is 5.29 index points.

Table (3) depicts that the performance in the field represented in the five domains for the last fifteen years (2006-2021) is almost the worst around the world, wherein, about 94% of the sixty fields scored over 80%. This gloomy picture of peace and its socio-economic context in Sudan reveals that the final achievements and impacts of the thumping efforts on peace from the government and the international society end with a prominent failure.

Year	Rank	Total	Cohesion Indicators			Economic Indicators			Political Indicators			Social Indicators		
			C1: Security Apparatus	C2: Factionalized Elites	C3: Group Grievance	E1: Economy	E2: Economic Inequality	E3: Human Flight & Brain Drain	P1: State Legitimacy	P2: Public Services	P3: Human Rights	S1: Demographic Pressures	S2: Refugees & IDPs	X1: External Intervention
2006	1st	112.3	9.8	9.1	9.7	7.5	9.2	9.1	9.5	9.5	9.8	9.6	9.7	9.8
2010	3rd	111.8	9.8	9.9	9.9	6.7	9.5	8.7	9.9	9.3	9.9	8.8	9.8	9.6
2015	4th	110.8	9.5	9.8	9.7	8.6	7.9	8.8	9.6	8.8	9.6	8.7	10.0	9.8
2020	8th	104.8	8.4	9.4	9.4	8.1	8.0	8.0	9.3	8.3	8.9	9.1	9.3	8.6
2021	8th	105.2	8.1	9.1	9.5	9.1	8.3	7.7	8.8	8.8	8.6	9.1	9.4	8.7

Table 3: *Sudan scores on the Security Threat Index 2006 -2021 (Source: The Global Economy.com).*

A CONCEPTUAL FRAMEWORK FOR TECHNO-ECONOMIC RSS

While table (1) ensures that the root causes of conflict in Sudan vary from region to region, but it verify the hypothetical preposition of figure (2) that rural poverty, low productivity and low economic performance did emanate from the societal technical underdevelopment. The way forward to design a model that sustain peace and achieve the objectives of the regional developmental strategies is designed simply by turning the negative factors of the World Bank's interpretation into positive factors, as in figure (3). This is reached by building the model around a "techno-economic developmental framework" rather than on the societal technical underdevelopment.

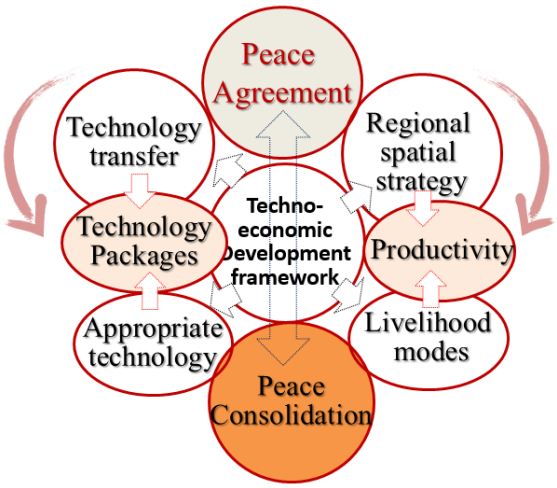

Figure 3: *Techno-Economic RSS Framework*

In this framework, the gap defined between peace making (agreement stage) and peace consolidation as a transitional target, is proposed to be bridged via the concept of the techno-economic development framework. This framework summarizes the efforts exerted by stakeholders and regional governments to conceal the situation of technical underdevelopment, basically accused by the World Bank as the main cause of conflict in Sudan, and the instigator for rural poverty and relapsing into war. Technology transfer and appropriate technology formulate the backbone of the model. Technology packages (TP) are the appropriate package of knowledge, capacity development and skills needed to be transferred to the specific region. On the other hand, enhancing productivity is the principal targeted objective of the RSS that will positively affect the livelihood modes and the economic performance of the specific sector. However, the design of the techno-economic RSS framework is achieved through three steps, as follows.

Composition of the techno-economic RSS framework

To furnish the floor for a bottom-up techno-economic RSS process, it is of importance to put the low literacy rate and the concepts of rural poverty eradication as continuous targets. These two targets should be handled through a context highly sensitive to technology transfer and appropriate technology. FEWSNET (2011) stated that agriculture provides livelihood for more than 80% of Sudan's population, and the average per capita income for rural agriculture is calculated to be US$1.08, while the average cost of the food basket is computed to US$ 1.1 (ICARDA, 2012: 28), with significant variation between regions. However, ICARDA (2012) provides a sound synthesis classifying rural poverty into income poverty and human capital poverty.

The design of the model begins by linking the poorest states in Sudan with the poverty level and the main livelihood activities in each of these states. It is not a chance that the poorest states are typically the states hosting the social tensions and civil war. The second step includes running a sectoral analysis, handling the thematic livelihood activities (e.g., agriculture, horticulture, grazing etc.) in each economic sector, within a comprehensive RSS concept. The final step is reached by synthesizing the previous two outputs in a way that could facilitate designing a suitable Technology Package (TP) relevant to each sector of the economy in its corresponding spatial and regional context.

However, and since the dynamic concept of technological appropriateness depends mainly on the use to which technology will be utilized and where, then framing for the techno-economic regional spatial strategy leads to propose seven packages of technologies, each accosting a specific economic sector and addressing a specific region (table 4).

Table 4: *composition of the Techno-economic RSS framework*

	State	Per capita A/I US$	Poverty level	Thematic Livelihood Activities			
Agriculture (as the main livelihood activity)	South Darfur	0.74	High IP High HP	Livestock	millet, sesame	fruits	vegetables
	Red Sea	0.61	High IP Medium HP	Livestock	cotton	-	vegetables
	Kassala	0.68	High IP Medium HP	-	Sorghum, wheat	fruits	vegetables
	North Kordofan	0.72	High IP Medium HP	livestock	millet, Sesame	-	vegetables
	North Darfur	0.78	High IP Medium HP	Livestock	millet, sesame	-	vegetables
	Gedarif	0.95	High IP Medium HP	livestock	Sorghum, sesame	-	-
	South Kordofan	1.37	Low IP High HP	Livestock	millet, sesame	fruits	vegetables
	West Darfur	1.49	Low IP High HP	Livestock	-	fruits	vegetables
	Blue Nile	2.56	Low IP High HP	-	Sesame, cotton	fruits	-
	Gezira	0.76	High IP Low HP	Livestock	-	fruits	vegetables
				TP 1	TP 2	TP 3	TP 4	TP 5	TP 6

Note: A/I= Agriculture income/ D IP = Income Poverty ; HP = Human Poverty TP= Technology Package

source: Researcher , + after ICARDA, 2012: 60

Designing the technology packages for the framework

It is imperative that in order to design a balanced techno-economic RSS, competent technology packages have to be identified and posted in each strategic sector and for the relevant corresponding region. The design of the package should be based on the comparative advantage of the specific region, but could be pragmatic and effective under the notion of "import-some and develop-some".

The framework will be mature when each technology package is corresponded to its relevant region. The vertical handling of the different regional spatial strategies could be aggregated into a national spatial strategy, by defining and strengthening the leading and strategic sectors. This model will guarantee a grass root methodology, and pledge for peace consolidation to be included in the national context. (Figure 4).

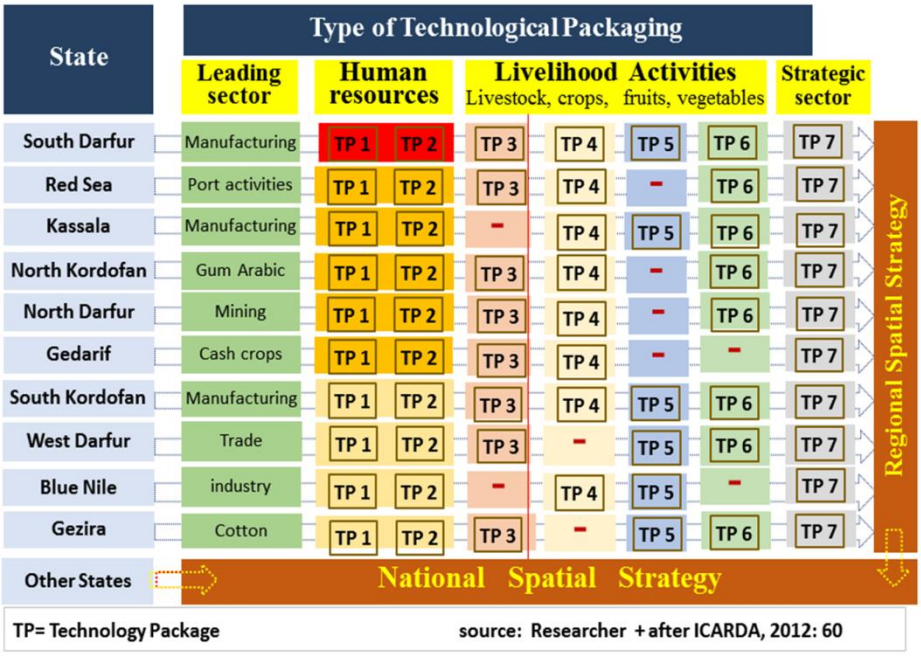

Figure 4: *Technology Packages for RSS*

Designing the techno-Economic RSS Matrix

The final step of designing the framework is complete by checking the workability of the model. The workability of the techno-economic development framework depends on nesting a horizontal network between the different technology packages, in a way that the whole packages would work a unifying system. A try to design such a framework for the RSS to work in Sudan is proposed by this paper in figure (5) in appendix (1). Each technology package has its specific stabilization indicators, stabilization domains and consolidation factors. This structure will ensure the package to include both the peace consolidation factors and the developmental strategic agenda.

CONCLUSION

Peace, whatever costs, is cheaper than war. Evidences in Sudan show a prominent failure in achieving objectives of both the series of the national developmental strategies and the myriad number of peace agreements. A vicious circle between economic malfunctioning, rural poverty and relapse of war is traced among the conflicting zones in Sudan. To break this vicious circle, this paper called for the concept of the Regional Spatial Strategy to positively affect the on-ground techno-spatial domain of achievements. A techno-economic framework, based on technical packages of appropriate technologies, is designed to hinge the required transformation of the local communities in the conflicting zones. Then peace agreement in Sudan should read a socio-economic contract bonded to strategic developmental objectives accompanied with technical capacity building and technology transfer. The regional spatial strategy is handled then as a systematic tool able to comprehend the grounded causes of conflicts and socio-economic degradation, and at the same time able to strategically adopt developmental objectives, through appropriate technology packages. To safeguard against recurrence of violence and to sustain peace within the regional spatial strategy, it is recommended for further studies to bind their objectives with Goal 16 of the SDGs, which stimulates “Promotion of peaceful and inclusive societies for sustainable development, provide access to justice for all, and build effective, accountable, and inclusive institutions at all levels”.

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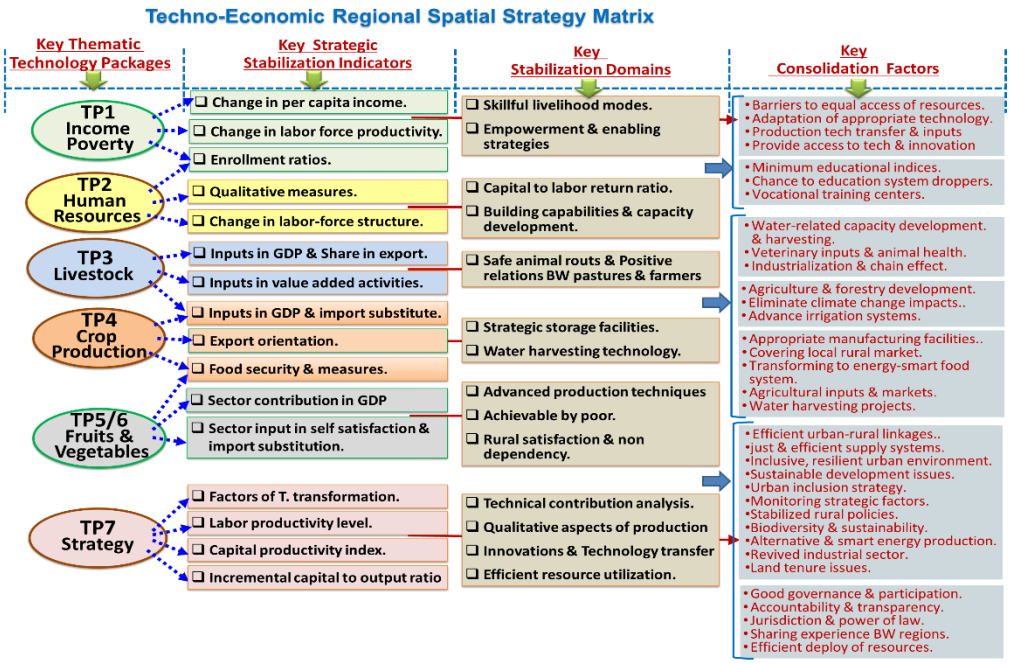
Appendix 1*: Figure 5: *Techno-Economic Regional Spatial Strategy Matrix



DECENT HOME DESIGN FOR RESETTLEMENT OF WAR DISPLACED IN DARFUR, SUDAN

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Abstract
Interior design is an art and science of enhancing the interior space of a building so that it meets the materialistic, spiritual, and social needs of its occupants. The goal of decent interior can reflect cultural identity and provide decent housing for displaced taking into account the social changes and the challenges of resettlement and the search for solutions to overcome them. The study area is north Darfur. The study uses participatory descriptive analytic methods to analyze the modern functions of interior design within the context of cultural heritage. The expected outcome of the study will be "a decent home design" that meets the needs of the local community and provides a sense of cultural identity of the interior spaces. As a result of applying the culture of the Darfur community, refugees may feel a stronger sense of cultural identity, while also preserving the cultural heritage, local knowledge systems, and parents' and grandparents' experiences that were destroyed by the war.

Keywords: Interior Design, Welfare Promotion, Adequate Housing, Resettlement.

INTRODUCTION

In principle, interior design is an attempt to solve life's problems related to the interior spaces of buildings. The variables that must be solved in the interior design are related to physical and immaterial problems. Physical problems relate to the conditions of the space that consists of the elements of floors, walls, ceilings, furniture and facilities. Non-physical problems are related to human factors such as psychological, social and cultural conditions that shape perceptions and feelings towards the atmosphere of a particular space.

This research is a comprehensive paper focusing on the role of interior design in addressing adequate housing for displaced persons and displaced persons by learning about the relationship between interior design and other disciplines. In particular, the vast majority of environmental and human psychology, while identifying some of the resettlement challenges through the use of traditional methods and how to work with internal design to create a healthy environment that can help displaced persons overcome some of the psychological effects of war, displacement and loss of identity. By using internal design elements, with the help of a new approach to psychology to help resettle the displaced, which is to promote well-being. One of the most important objectives of the United Nations Sustainable Development Goal 2030 is to seek solutions to reverse the negative psychological effects of displaced persons and displaced persons and to use them to create a positive energy to create a sense of well-being in order to achieve psycho-social peace that promotes a sense of satisfaction and justice.

Research Problem

The research problem is summarized in finding practical solutions to enhance well-being and focus on positivity through the use of interior design elements in the treatment of adequate housing for the resettlement of displaced persons and the impact of these treatments on psychological health.

RESETTLEMENT CHALLENGES

War broke out in Darfur in the 2003 year, when rebel groups began an attack on the Government of the Sudan, killing more than 200000 people and fleeing more than 2 million. In addition, the crisis in Darfur is also a challenge for the Sudan, most notably the repatriation and resettlement of displaced refugees. On 13 October 2020, the Government of the Sudan signed the Peace Agreement with the armed struggle movements of the Revolutionary Front. The most important provision of those agreements was the Protocol on Displaced Persons and Refugees, which included a set of general principles providing for full respect and guarantee of the human rights of internally displaced persons under international and national law, whether during or after the process of voluntary return and resettlement.

The recent war in Darfur has exacerbated the humanitarian situation as well as significantly changed the socio-economic environment in Darfur, as well as the strong psychological trauma of the displaced during the war, which has created some negative adjustment (Mohammed, 2017). The armed conflict in Darfur destroyed the economic structure of the population, as men and women were active in the traditional economy before the war, and after displacement they became dependent on organizations. Thus, wage labor became the only option to earn a living (Mohammed, 2017). These challenges (security, economic, political), challenge forced the people to adapt anew situation, so it's not possible for some displaced persons to prefer to stay in their current places, especially since the services offered to them are more limited than before they are displaced. In order for the resettlement option to be realistic, appropriate conditions must be in place, such as security and the provision of material support by the political administration, as well as the agreement of displaced persons and refugees to return or settle in places where they have been displaced.

Promotion of Welfare

Good health, well-being, decent work, economic growth and reducing inequality are three of the United Nations Sustainable Development Goals 2030 (Chono, 2021). Literature shows that the promising approach to resettlement of displaced persons focuses on positive aspects rather than on solving traditional problems. Refugees are a vulnerable group at risk of mental health problems. Many analysts suggest that positive psychology interventions can promote well-being in the general population and in vulnerable groups such as those with psychiatric disorders, improving well-being is an approach to protecting people from psychiatric disorders and increasing the likelihood of recovering from psychiatric illness, so addressing the well-being of refugees is promising. Dealing with adversity is important and the ability to recover after adversity plays an important role in personal well-being, self-esteem and positive adaption. Stress is a key factor in the development of the ellipse.

Collectively, collective resilience facilitates refugee resettlement by building communities that support refugees in recovering from trauma (Chono, 2021). There are three dimensions of well-being, the emotional dimension, and it's about experimenting with positive feelings about negative feelings and life satisfaction. After myself, it's about positive relationships with others and self-acceptance. A social dimension encompassing dimensions of social cohesion, acceptance, perception and integration for prosperity. To be effective, all dimensions must be activated to meet all psychological needs (Chono, 2021).

DECENT HOME

A dwelling is defined as the place where a person lives with his family. decent home goes beyond the concept of the four walls of the room and ceiling and goes beyond them to the fact that housing is a basic necessity of healthy living that meets deep psychological needs for privacy, a place reserved for a person alone and his material needs for security and protection from weather and disaster. International human rights law recognizes the right of everyone to an adequate standard of living. The right to adequate housing was recognized as a component of the right to an adequate standard of living in the Universal Declaration of Human Rights of 1948 and in the International Covenant on Economics) (OHCHR, Alwaqee, 2010), Social and Cultural Rights of 1966. "The parties to the present Covenant recognize the right of everyone to live in an adequate standard of living for himself and his family, which provides for their need for shelter, and to the continuous improvement of living conditions. Other provisions on the right to adequate housing are contained in the International Convention on the Elimination of All Forms of Racial Discrimination, the Convention on the Elimination of All Forms of Discrimination against Women, the Convention on the Rights of the Child, the International Convention on the Suppression and Punishment of the Crime of Apartheid and the United Nations Convention relating to the Status of Refugees (OHCHR, Alwaqee, 2010).

Interior Design

In a developing country like Sudan, interior design is considered luxury and welfare. In this paper we explain how interior design plays an important and vital role for all groups because the contemporary approach to interior design illustrates the interaction between interior design and the psychological state of people. So, there is a very broad and mutual relationship between interior design and environmental and human psychology because of the multiple interactions with social, cultural, physical and environmental factors (Santosa, 2005).

Design in a more precise sense, is the process of planning something's shape of creating it in a purposeful, satisfying way that both qualitatively and aesthetically saturates human needs.
In principle, interior design is an attempt to solve life problems related to the interior of buildings. The variables to be solved in interior design are related to physical and non-physical problems. The physical problems relate to space conditions consisting of the elements of floors, walls, ceilings, furniture and facilities, such as windows to enter natural light and ventilation to rotate natural air and doors (Santosa, 2005).

Interior design steps	Descriptions
Step One	Data collection
Step Two	Users interview to collect the need and the problem
Step Three	Determination of space area that need design
Step Four	Problem analysis
Step Five	Plan drawing
Step Six	Second interview to discuss the plan
Step Seven	Material selection
Step Eight	Implementation

Table 1: *Interior Design Steps.*

Internal Design Elements, Promoting Positive Energy

The interior design contains a large number of elements, and the balance that results from using the elements in a healthy way is what produces beautiful and fun designs (Hendy & Zahra, 2018). Emotions are divided into two kinds of positive emotions and negative emotions. Positive emotions help to produce unusual, flexible and creative intellectual patterns and direct

one's behavior to diversity, creativity and the expansion of individual intellectual activity. When an individual exceeds the maximum positive emotion in the total absence of negative emotion, he or she reaches the limit of pleasure in which he or she is bestowed with sublime emotions, cascading down to spirituality. Negative emotions are unpleasant, short-term, highly variable situations accompanied by reactions that may be calm or inflammatory (Hendy & Zahra, 2018).

Interior Design Elements and Their Role as Motivators for Emotions

- Optical stimuli (color-lighting-shape).
- Touch stimuli (ores, temperature-moisture ratio).
- Audio stimuli (acoustic - noise rate).
- Olfactory stimuli (aromatics - odors from ores).

Emotions	Stimuli	Space Activity
comfort, happiness, joy, excitement, attention	Warm colors, increase luminosity, curved shapes, moderate atmosphere.	Kitchen, Work, Study, Play, Living, Food
calm, relaxation, housing, comfort, happiness	Colder colors, low lights, geometric shapes, straight lines, soft texture, moderate atmosphere, green plants and purple flowers.	Sleep, Relax, Reading

Table 2: *Elements of interior design and promotion of positivity.*

To give a sense of comfort, happiness, joy, excitement, attention, these feelings are enhanced by using interior design elements in the following way: use warm colors, increase luminosity, use curved shapes and lines, and ensure that the atmosphere is moderate in these spaces. To bring the feeling of calm, relaxation, housing, comfort, happiness. It takes colder color, low lights, geometric shapes, straight lines, soft texture and temperature. It prefers the use of sound insulators and the use of green plants and purple flowers.

Interior design and identity

Interior design and promotion of well-being help create a community identity and develop a sense of belonging. Traditional interior design is linked to the concept of settlement, where individual designs are inspired by the surrounding nature, use local materials and traditional construction methods, and respect the geographical and climatic characteristics of the region. As a result, users tend to be local products to express the identity of the community and to preserve the lifestyles and well-being of the occupants (Rashdan & Mahater, 2019). The traditional design process is constantly evolving in conjunction with cultural factors and their evolution within societies.

decent home elements	interior design characteristics	folklore and culture characteristics	Proposed new design elements
Color	A color that makes the inhabitants relaxed and peaceful.	A color that reflects the cultural identity.	natural color, white
Light	give the feeling of satisfaction and privacy	Compatible with different spiritual and social activities	sun light
shape and lines	curve liner shapes and not sharp to give a positive feeling	Shapes from the surrounding environment and cultural elements.	Circle
texture and materials	Feeling the place through touch.	materials similar to the one used on the handicrafts	A smooth texture like traditional porcelain and harsh like fronds.

Table 3: *The elements of a decent home based on concepts of interior design and folklore.*

Interior Design and the Promotion of Well-being for the displaced People

The war caused psychological and mental stress on the individual and collective level. The war in Darfur also posed great pressures for emotional stability, such as the loss of parents, the death of children, separation, a life of homelessness, oppression and fear. The effects were catastrophic for women, children and the elderly. The woman lost her father, husband and child. And women in Darfur were often targets of revenge by the warriors. For many people, displacement caused by conflict and human rights violations has meant having to leave their homes. However, after settling in the camps, the feeling of not belonging remains. That home is not just a physical place, but includes an emotional attachment, which is the nostalgia for memories.

Design plays a critical role in designing refugee homes and promoting welfare by integrating the roles between interior design, environmental psychology and human psychology to provide a healthy environment using design methodology or systematic design method (Mahmoud,2016). An effort is made to solve the problem by describing the problem by taking complete data and then describing it one by one, in a coherent way, then the problem points are found. This becomes essential for determining the formulation of the problem, and then creating a design requirements program. The process of searching for design ideas that comes out in the form of schematic drawings begins (mahmoud2016). Strengthening the positive emotions of the dwelling is one of the priorities of contemporary life as a result of the psychological pressures that man is going through, which makes him strive to achieve a safe and calm environment in his dwelling, which is his only refuge. Interior design is able to meet and absorb the physical and emotional requirements of individuals and provide a unique experience for individuals through their residence within the residential space. The interior design process is based on information and data derived from its occupants and then translated into vocabulary and elements applied in the interior spaces (Hendy & Zahra, 2018).

Proposed Users	Interior Design Needs	Challenges to meet their Needs	General Challenges of Interior Design
Mother	Cooking and farming space with smart equipment	Define the suitable space	• No basic infrastructure • Design from scratch • The poverty • The health environmental problem
Child	Playing space that are wide	A design space that allows a balance	
Youth	Entertainment space that are modern	Between local games and technologically advanced games	
Grandparents	Accessible space that reflects heritage	Provide a space that enable creativity	
Disable Person	Comfortable and accessible place	And the ability to cope with new technologies	
Guest	sleeping and dining space	Updating the functions of traditional elements to perform their traditional functions in a modern way that helps to facilitate the life of users'	

Table 4: *Proposed users of the decent home.*

CONCLUSIONS

The main recommendation from this study is that mental health is one of the requirements of modern life it's the right of all individuals to enjoy a stable life. The existing challenges must be taken into consideration regarding to the resettlement of the displaced people and the establishment of adequate housing for them. The desired goal should be achieved through the cooperation of international community organizations and civil society, and through coordination between the various state agencies and organizations working among the displaced people to identify their problems.

From the foregoing, it extracts the importance of interior design, its basic elements, and the integration of its roles with other sciences, which suits the situation of the Darfur IDPs community. The interior design takes into account the needs of communities and respects their privacy. Thhis ensures effective and favorable participation of all levels of society in the process of reconstruction, stability and resettlement. Herein lies the triple relationship between comfortable and dignified housing, inspired by the environments of natural communities affected by displacement, through of the science of interior design.

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GOVERNANCE
|
POLICY, STANDARDS, AND ETHICS

PAPERS

A VISION OF LEED-LIKE ETHICAL STANDARDS FOR A GLOBAL CONSORTIUM OF ECOVILLAGES

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Abstract
This paper proposes a set of specific LEED-like ethical principles for members of a global consortium of ecovillages. LEED is the acronym for Leadership in Energy and Environmental Design. The LEED organization offers a green building rating system deployed throughout the world. The highest grade is LEED Zero or Platinum, standing for projects with net zero goals in carbon and other resources. Modeled on LEED certification, the paper proposes a foundation for a rating system for ethical ecovillages based on a survey of global ethical systems. These guiding criteria are summarized in the ethical principles of the Songhaï ecovillage model developed by Godfrey Nzamujo: autochthony (rooted in the physical and cultural soil of the ecovillage community); autonomy (relying on green energy and excluding chemical fertilizers and pesticides); and authentic (responsible for the survival and flourishing of all community members with outreach to surrounding communities where possible). Building upon these three principles, the paper offers the Songhaï ecovillage as a working model and presents potential examples of ecovillages that meet or exceed Songhaï performance (e.g., Indian ashrams). The paper also reviews parallel movements, such as work on a Sudanese Barefoot College, that help ramp up foundations for ethical ecovillages. The paper extends the discussion to include applications for urban ecocenters. The conclusion proposes that the LEED-like ethical system for ranking a global consortium of ecovillages be produced consensually by its members. While the three ethical principles proposed through the Songhaï Centers may be a springboard for reflection, changing global circumstances call for constant revaluation of ethical principles capable of confronting existential global disasters such as catastrophic climate change, the 6th mass extinction, weapons of mass destruction, global terrorism whether government or group sponsored, and global pandemics worse than Covid-19.

Keywords: LEED Certification; Ethics and Evolution; Songhaï Ecovillage Ethics; Global Consortium of Rural and Urban Ecovillages; Community-Driven International Development.

INTRODUCTION: RANKING A GLOBAL CONSORTIUM OF ECOVILLAGES

A global consortium of ecovillages has the promise to confront both catastrophic climate change and the continuing sixth mass extinction. This paper defines an *ecovillage* as a rural or urban enclave committed to sustainability through the use of appropriate technologies (Brombin, 2019; Miller, 2018; Xue, 2014). *Appropriate technologies* are defined as those relying on renewable or green energy, recycling of other resources to the degree possible, minimizing the need for human labor that does not require creative consciousness, and promoting the grounds for survival and flourishing for every community member (www.appropriatetech.net). While the literature on the evolution of ecovillages is extensive, this paper takes as its starting point the Global Ecovillage Network, a consortium of ten thousand ecovillages throughout the world (https://ecovillage.org). The paper's aim is to establish a rating system for ecovillages based on a global survey of ethics across time and culture. To the degree possible, the paper proposes a consilience of ethics and science in order to produce ratings compatible with a wide range of cultures.

The paper's inspiration is the LEED green design and building rating system deployed throughout the world (https://www.usgbc.org/leed). LEED is the acronym for *Leadership in Energy and Environmental Design*. The highest grade is LEED Zero or Platinum, standing for projects with net zero goals in carbon and other resources. Modeled on LEED certification, the paper presents a rating system for ethical ecovillages based on a survey of global ethical systems (Verharen 2021b). Portions of the paper are taken from papers previously published by the authors. Situated in different contexts, they are intended for quite different audiences.

Based on contemporary technologies measuring carbon and other resources required for environmentally friendly design, the LEED certification can claim a measure of objectivity. Controversy in ethics across both cultures and individuals poses an obstacle to certification based on ethics. To address this problem, the paper starts with the German philosopher Nietzsche's assumption that the primary role of ethics in the field of philosophy is to guarantee life's survival: philosophers "alone are the *guarantors* of the future, they alone are *responsible* for the human future" (Nietzsche, *On the Genealogy of Morality*, hereafter GM 2014/1887, III [14], p. 314; Stegmaier 2016). In the late 19th century, Nietzsche predicted that 20th century technology would create global wars of unprecedented destruction: we have "entered the classic age of war, of sophisticated yet popular war on the largest scale (in terms of weapons, talents, discipline) . . . " (Nietzsche, *Gay Science,* hereafter GS 2001/1887, V 362, p. 277). He foresaw aircraft as agents of this destruction (Nietzsche, *Human, All Too Human,* hereafter HATH 1996/1878). He also believed humanity to be so deeply irrational that our use of science and technology could lead to self-extinction: "it is basically with little confidence that one may speak of the future of humanity" (Nietzsche GS 2001/1887, II [76], 77). He goes so far as to claim: "The goal of science is the destruction of the world" ((Nietzsche, *Philosophy and Truth: Selections from Nietzsche's Notebooks of the Early 1870s,* hereafter PAT 1979/1872-1875 fn. 9, p. 156).

However, Nietzsche recommends caution with respect to science's destructive power: "It is not a question of annihilating science, but of controlling *it*." Philosophy and science are inseparable: "Science is totally dependent upon philosophical opinions for all of its goals and methods, though it easily forgets this. *But that philosophy which gains control also has to consider the problem of the level to which science should be permitted to develop: it has to determine value*" (Nietzsche's italics, PAT 1979/1872-1875 [28], p. 8). The saving grace for Nietzsche would be humanity's use of philosophy in the service of ethics to control science and technology in ways that promote life's future.

After a brief review of Nietzsche's fusion of philosophy and science, the paper will present a synopsis of seven ethical systems that African and Eurasian cultures have deployed over the past five thousand years to promote their survival and flourishing. The paper's assumption is that long-lived and powerful cultures have discovered and deployed sustainable values. This synopsis will form the basis of the ethical ecovillage rating system.

The paper's practical section will first consider the ethics of an ecovillage model developed by an African philosopher, Godfrey Nzamujo (2002), and implemented in over 50 ecovillages in 17 countries in Africa, starting in Benin. Reduced to three fundamental principles, Nzamujo's system will serve as the foundation for the global ecovillage network ethical rating system. The section will then feature an Indian ashram that deserves top ranking, the equivalent of LEED Zero or Platinum, by reason of its accommodation of Nzamujo's three ethical principles. The paper then reviews parallel movements in Sudan and Ethiopia that help ramp up foundations for ethical ecovillages. The paper extends the discussion to include applications for urban ecocenters. A mandate follows for converting top-down international development approaches to bottom-up strategies that support both rural and urban eco-communities and move the impacted communities to the center of decision-making processes. This section demonstrates the urgency for capital support of a global consortium of ethical rural and urban ecovillages to confront existential global disasters such as catastrophic climate change, the 6th mass extinction, weapons of mass destruction, global terrorism whether government or group sponsored, and global pandemics worse than Covid-19. The conclusion argues that a global ranking system for ethical ecovillages must come community members themselves. They may choose to adopt Nzamujo's three

ethical principles or devise an altogether different system. However, any truly ethical ranking system must be grounded in the conviction that a primary task of global ecovillages is to guarantee life's future.

RELATED STUDIES: A 19TH CENTURY PHILOSOPHER'S FUSION OF ETHICS AND SCIENCE AS A GUIDE TO THE EVOLUTION OF ETHICS

Steeped in what he calls the "concept-quake" of 19th century European science, Nietzsche came to believe that "the goal of science is the destruction of the world" (Nietzsche, PAT 1979/1872-1875 fn. 9, p. 156). Science and technology coupled with humanity's intractable irrationality in Nietzsche's mind could lead to humanity's self-destruction. Humanity's saving grace in his eyes is philosophy. As its etymology in *love of wisdom* suggests, philosophy is a kind of synoptic or "mountain top" vision that encompasses all possible ways of knowing including mythology, religion, and science itself. In his early definition in 1872, Nietzsche envisions philosophy as a "meditation" on possible types of futures (*On the Future of Our Educational Institutions* (2016/1872, hereafter FE, Preface, p. 94).

Nietzsche paints the philosopher as a mountain climber attempting to cross a raging mountain torrent with huge boulders tumbling in the current. With great daring, the philosopher speeds across the torrent, stepping lightly on the boulders. A scientist, the philosopher's companion on the climb, will not cross until a safe bridge is built (Nietzsche, PTAG 2014/1873, p. 40). The philosopher's drive and daring are "propelled by an alien, illogical power—the power of creative imagination" (PTAG 2014/1873, p. 28). Grounded in humanity's deepest passion for life, philosophy's task is to ensure that life continues in the face of our species inclination toward self-destruction. To execute this task, philosophy conjures up guidelines that shape the directions of our lives in virtually all of their aspects. Nietzsche calls these guidelines *values*. The task of a value is to issue commands that tell us how to live. Nietzsche imagined that new values emerge in terrible times: "Philosophers appear during those times of great danger, when the wheel of time is turning faster and faster. Together with art, they step into the place vacated by myth." When a culture becomes "conscious of its dangers," it generates philosophers whose thinking far outstrips their contemporaries (Nietzsche, PAT 1979/1872-1875 [24], p. 6). Nietzsche's sense that values must change over time to accommodate changing circumstances accords with the major changes in ethics across cultures over the past five thousand years. The oldest recorded ethics emerging in ancient Egypt some five thousand years ago recognizes the fact that values enter into competition with one another. A community's task is to harmonize that conflict in order to guarantee life's continuity. The Egyptian ethical value, called *Maat*, is translated as harmony, peace, justice, truth in different contexts in the *Book of the Dead* (Faulkner 2005/1972, Assmann 1996, Hornung 1990/1982, 1999/1995, 2001/1999), Verharen et al. 2014a, Verharen 2012).

The second oldest ethics are found in Hinduism, Buddhism and Daoism emerging some 2400 years ago. The overarching value in these three traditions is the control of attention through meditation. That value is subservient to higher values such as awakening to one's own divinity or eliminating suffering. Nevertheless, it is the only secure path to those goals. The wisdom of these traditions is that conscious direction of attention is more likely to promote survival than allowing accidental direction as a function of environmental circumstance (Koller 2016).

At roughly the same time as the emergence of Asian ethics, Greek philosophers promoted reason as the paramount value. Reason is defined as the ability to abstract patterns from the vast multitude of experience. The generality of the patterns permits the prediction and control of experience. Both Plato and Aristotle believe that the most fortunate humans would dedicate their entire lives to the pursuit of reason (Plato 1966; Aristotle1941). Around two thousand years ago, Christ in West Asia singled out love as the paramount value. His definition of love was provocative in that it commanded a universal human community bound together by universal, unconditional love. While earlier philosophers in Africa and Asia advocated a single human community, Christ was the first to make love the paramount value.

Taking a page from Christ on the virtue of a universal community and extending citizenship in that community even to animals, the utilitarian Mill envisioned pleasure as the supreme value (Mill

2014/1859). After confirming the constant extinction of species, Darwin reminds us that survival is the precondition for any concern about the best possible definitions of flourishing (Darwin 1936/1859/1871).

And finally, four 19th century German philosophers have enshrined freedom as the value that now controls the world in the form of globalization. Kant defines freedom as human activity controlled by the iron first of reason (Kant 2017/1797). Hegel provides perhaps the most insightful definition of freedom as "the infinite capacity of activity to change its form" (Hegel 1956/1837, p. 206). Marx defines political freedom as the absence of constraint by an authoritarian government (Marx & Engels 2002/1848). And Nietzsche defines freedom as creativity that promotes life's survival and flourishing (GS).

A global ethics for ranking a global consortium of ecovillages must take advantage of these five thousand years of wisdom. Survival is the precondition for choosing diverse forms of flourishing, but survival and flourishing must be the foundation for the contemporary ethics that confronts contemporary existential challenges to life's future. Ecovillages must guarantee survival for their members. Survival must meet at least seven basic components ranked in order of urgency. First and most important is a group committed to the survival of its members. Second are shelter and clothing as instruments for temperature control—depending on climate circumstances. Third through fifth are clean air, potable water and nutritious food. Sixth and seventh are basic health care and education (Verharen et al. 2014).

Flourishing is a matter for community definition, as is clear from the five thousand years of recorded ethics. Critical for an ethical ecovillages' members are their own choices about the best values to steer their lives. A ranking system for ethical ecovillages will examine the ethics of individual villages to determine whether they take full advantage of the evolution of ethics over thousands of years.
However, objectivity in ranking requires an attempt to find a scientific basis for a constellation of values. Science presents generalized descriptions of experience. These descriptions enable the prediction and control that define humanity's uniqueness. However, science's laws, formulas and hypotheses cannot yield prescriptive power as Nietzsche insists: "All laws of nature are only relations between x, y, and z. We define laws of nature as relations to an x, y, and z—each of which we are in turn acquainted with only in relation to other x, y, and z's" (PAT 1979/1872-1875 [150], p. 51). Although science "probes the processes of nature…, it can never *command* men" (PAT 1979/1872-1875 [198], p. 141). Nietzsche imagines that values are grounded in emotions. He believes that our most commanding emotion is a lust for life. That assumption is not negotiable for him. It is a scientific "fact" that we value life. However, life has value only because of a commanding emotion. Science can be combined with ethics to the degree that science in the best case is able to describe the consequences of actions that we choose by reason of our emotions. Science can answer the following kind of question: "If I wish to guarantee my life's future, what kind of actions should I take?"

Darwin has made two specific kinds of claims about the kinds of actions that have the most promise to guarantee life's future ((Darwin, *Descent of Man*, cited in Wilson 2016, p. 210). His claims parallel the discoveries of ethical systems that have evolved over recorded history. His first claim is that groups that are capable of expanding their numbers have the best chances of survival, other things being equal. The Hindu, Buddhist, Christian, utilitarian, and German idea that all humans should define themselves as members of a single all-embracing group is the apotheosis of Darwin's claim.

His second claim is that groups should bond their members so tightly together that they are willing to die for one another. Christ's example is an illustration of this claim. However, virtually all nations subscribe to the assumption that their citizens in extreme circumstances must sacrifice their lives for the sake of the nation's survival. Compulsory conscription in times of war and capital punishment attest to the force of Darwin's claim.

Two additional claims follow from Darwin's theory of natural selection. A group has the best chance of survival if all its members have excellent lives. *Excellence* is here defined as having the greatest

chance of promoting a group's survival. Constraints on resources or mere perceptions of resource scarcity have led humans to define group membership in many cases through sexism, racism and classism. A key feature of ethical ecovillages would be the abolition of these *isms.*

The final claim also follows from the theory of natural selection. Groups that maximize their genetic, linguistic and other cultural variation have the greatest chance of survival. We have no way of knowing what roadblocks nature will throw our way if our species is to survive beyond its 300,000-year span to date. Perhaps Nietzsche's criterion for freedom as creativity is a reason for globalization grounded in the power of freedom.

METHODOLOGY: AN AFRICAN ECOVILLAGE'S PRACTICAL DEMONSTRATION OF THREE ETHICAL PRINCIPLES FOR RANKING A GLOBAL NETWORK OF ECOVILLAGES

Professor Godfrey Nzamujo, a Nigerian Dominican priest with an educational background in philosophy, theology, microbiology, computer systems and international development, started a system of rural African ecovillages in Porto Novo, Benin, that can serve as a model for ranking a global network of ecovillages (Nzamujo 2002). The villages feature appropriate technologies that enable green energy production, "cradle to cradle" recycling of other resources, agroecological food production, primary health care, and education from pre-school through post-secondary levels. Nzamujo named the villages Songhaï Centers in honor of a fifteenth century West African empire.

Nzamujo grounds his Centers in three ethical principles: autochthony, autonomy and authenticity. He defines *autochthony* as a principle of rooting a village in the physical and cultural "soil" of the over fifty centers in seventeen African countries. This principle promotes the Darwinian command to maximize diversity in order to confront any possible threats that natural selection might place as obstacles to the villages' survival and flourishing. The villages swerve sharply away from the monocropping that enslavement and colonialism brought to many communities in Africa. The villages enrich their soil through organic fertilizer produced in the villages and forbid the use of chemical pesticides. Technologies for drip irrigation conserve scarce water resources and cross-planting controls for pests (Nzamujo, Personal Communication, 15/05/2020).

Nzamujo's second ethical principle of autonomy permits the villages to be self-sustaining, once the extensive capital costs for land, structures, Information Communication Technologies (ICT), biological labs, and other start-up costs are covered. Revolutions in the ethics of ICT distribution in the form of Massive Open Online Courses (MOOCs), open access publishing, and decreasing costs of international broadband access permit the extensive educational system that is key to ecovillage autonomy. Nzamujo is careful to distinguish among autonomy, independence and inter-dependence. The ecovillages are autonomous only because of mutual support or inter-dependence throughout the Songhaï Center network. To the degree possible, the villages include neighboring communities within that support system. A number of the villages are able to produce organic food for distribution at local markets in their neighborhoods as well as manufactured agricultural tools (Nzamujo, Personal Communication, 15/05/2020).

Nzamujo's third ethical principle is authenticity. He defines this term as Songhaï community responsibility for the survival and flourishing not only of every community member, but of community neighbors to the degree possible. Nzamujo has created the Songhaï Leadership Academy to make it possible for interested parties from neighboring communities, other African or global nations, to stay at the Songhaï Center in Porto Novo, Benin, to learn how to set up ecovillages on the Songhaï model in their own areas (Nzamujo, Personal Communication, 15/05/2020).

AN INDIAN ECOVILLAGE AS CANDIDATE FOR TOP RANKING IN THE GLOBAL ETHICAL ECOVILLAGE SYSTEM

Gandhi's call for India's escape from British enslavement and colonization presages Nzamjo's three ethical principles of autochthony, autonomy and authenticity. The Indian independence movement featured local resources and indigenous technologies such as the spinning wheel that became emblematic of the cause (Singh *et al.* 2019). Of particular importance to the movement were the Indian ashrams with a history of food and other goods production, services to wider communities, and increasing dedication to renewable energy and infinite recycling of other resources.

A dramatic example is the Muni Seva ashram in Vadodaral Gujerat (www.greenashram.org) that dedicates itself to health care. Schooling includes pre-kindergarten through college levels as well as vocational education with an emphasis on nursing. The ashram includes education for girls and women regardless of caste or economic class. Like the Songhaï Center in Porto Novo, the Ashram offers residences for students. Because of the Ashram's focus on health care, the Ashram has a guest house for patients' families and well as other visitors. Costs for patients and students are kept to a minimum.

Because of its dedication to sustainability, the ashram produces its own energy through plasma arc recycling, biogas and biomass gasifiers. The ashram features what is perhaps the world's first solar-powered crematorium. All air conditioning is solar powered. The ashram at this point still relies in part on electrical power from the Vadodaral Gujerat grid which is fossil fuel powered. This problem will be critical for ranking all global ecovillages on energy independence. The ashram hopes to dissolve its dependence on the local grid by installing a 1.2-megawatt biogas plant. The products of organic farming and animal waste will fuel the biogas plant.

RESULTS AND DISCUSSION: OUTREACH AS A CHECKPOINT FOR GLOBAL ETHICAL ECOVILLAGES

The proposed ethics model enjoins research and development of appropriate technologies that allow communities to develop the principles of autochthony, autonomy and authenticity to the fullest extent. In addition to ethical ecovillages, the model promotes the development of technologies that help remote villages move toward an ecovillage model through solar installation and repair, water reservoirs, education in basic computer skills, bookkeeping and the like. Bunker Roy developed the Barefoot College in India to train grandmothers from remote villages around the world in these "ramp up" techniques. After working with Roy to develop solar villages in the Nuba mountains in Sudan, Gada Kadoda is now developing a Sudanese Barefoot College (Kadoda 2009). The model's gender-based approach helps change perceptions about women's empowerment through appropriate technology (Eltayeb 2022).

An example of a community that could benefit from "ramp up" techniques is the Awra Amba Community, established in the early 1970s in the Amhara region in northern Ethiopia by the founder Zumra Nuru. The village is known as the "Ethiopian Utopia." The community focuses on the equality of its members both male and female. With a kindergarten, schools, a library, a clinic and similar institutions, the community of 500 is a model village, combining gender equality, respect and care for children, solidarity, absence of religious rites, honesty, work and democracy. However, the village does not have access to the agroecological, energy and communication technologies of the Songhaï model. The INAT ethical model would encourage the development of an appropriate technology pilot program to serve as a model for Ethiopian rural development (Eskinder 2013, Joumard 2021).

ECOVILLAGE VERSUS URBAN APPROPRIATE TECHNOLOGY

While it's tempting, as we have done here, to focus on and work toward the possibility of green, sustainable, ecosocialist, eco-sensitive groups at the village level, such solutions are unfortunately

insufficient to address, let alone solve, the world's problems. Amalgamated over many groups, spanning large areas and numerous locations, they will aid in addressing planetary issues. But there are simply too many groups, too many other humans who do not live and will not be living in ecovillages.

In 2020, about 56 percent of the world's population was concentrated in the world's major cities (World Bank 2020) and by 2050, the number is expected to approach 70 percent (United Nations 2018a). In 2000, there were 371 cities with populations exceeding 1M. In 2018, the number increased to 548 and by 2030, 706 are expected to fit that criterion (United Nations 2018b). Similar to the variation among ecovillages, enormous variation in both city size, population density local environment, and ecological footprint exists (Wackernagel *et al*. 2006; NASA Earth Observatory 2013). Information elucidated from the study of ecovillages will provide keys to understanding the differences among these cities.

The ethics model demands the development of appropriate technology to foster sustainability in these dense, highly populated urban areas. The ethical ecovillages hold great promise as testing sites for the recognition of best practices, for developing innovative practices, and as sites for examining scalability. Results obtained at local levels can be successfully expanded and scaled beyond the village level. Before that can be done, preliminary efforts are critical, particularly with attention to both results and design. The highly concentrated density of big cities does generally result in lower energy use and CO_2 emissions than lower population density settlements. However, the majority of their resources now come from outside the urban areas (Day and Hall, 2016).

Paradoxically, increasing urban density can diminish the threat of catastrophic climate change through appropriate technology used to develop “green” cities with reduced carbon footprint. The appropriate technologies include public mass transportation to reduce driving and increase walking (Cusick 2020; Biello 2011). Critical agricultural technologies deploy urban vertical farms in unused skyscrapers (Despommier 2010) and “green belt” farms ringing cities (Maathai 2003). Shanghai, for example, is one the world’s most populated cities with 27 million in 2021 (World Atlas 2021). Shanghai’s green ring produces nearly half of its food. Compost from the city produces fertilizer and generates electricity through a landfill biogas generating plant, the largest in China (Jacobson 2012; Decker 2010).

To reduce dependency on chemical fertilizers, Commoner has proposed a sewage pipeline system closing the cycle of food consumption in the city by returning nutrients back to the soil for agricultural production (Commoner 1971, p.186-187). This recycling of nutrients must confront the current challenge of contamination of sewage by a multitude of chemicals including antibiotics, hormonal disrupters, etc. (Kumar et al. 2020).

The ethical model envisions using appropriate technologies to promote radical changes in global physical and political economies at all spatial scales consistent with the recognition that radical changes in society are imperative to confront catastrophic climate change. Overcoming global energy poverty is critical to that challenge through rapid transition to 100% renewable energy through wind turbines, photovoltaics and Concentrated Solar Power in deserts (Schwartzman and Schwartzman,2019). This renewable infrastructure must be created on all spatial scales from large, concentrated sites, globally managed, to small decentralized production managed by rural ecovillages.

The ethics driving appropriate technologies must be team-inspired, created and driven. The teams must include all stakeholders with an emphasis on community members whose lives will be most changed by evolving values that dictate behavior change. Where possible, planning should be bottom-up rather than top-down. Historical international development often followed a top-down model. On the global ecovillage ethics model, the interests of local community members in their own survival and flourishing must take precedence. Other stakeholders consist of 1) educational institutions; 2) government structures; 3) international agencies; 4) NGOs and non-profit organizations; 5) private sector and 6) engaged citizens outside of the local community members (Tharakan 2020).

The primary step on this ethical path is the development of new appropriate technologies through research in educational institutions. The private sector is also responsible for this effort. Local, state and

national governments must provide legal and economic pathways for the generalized implementation of appropriate technologies. International agencies like the World Bank, the International Monetary Fund, the United Nations Development Program must ensure the implementation of appropriate technologies especially in the Global South and areas of extreme poverty in the Global North.

All these agencies must work together to make sure that local communities have sufficient education to make judgments about the technologies that will direct their futures. At the same time these agencies must guarantee the continuing research, development, deployment, operation and maintenance of the technologies that global collective wisdom has declared to be *appropriate*.

CONCLUSION: A COMMUNITY-DRIVEN GLOBAL RANKING SYSTEM FOR ETHICAL ECOVILLAGES

The conclusion proposes that the LEED-like ethical system for ranking a global consortium of ecovillages be produced consensually by its members. While the three ethical principles proposed through the Songhaï Centers may be a springboard for reflection, changing global circumstances call for constant revaluation of ethical principles capable of confronting existential global disasters such as catastrophic climate change, the 6th mass extinction, weapons of mass destruction, global terrorism whether government or group sponsored, and global pandemics worse than Covid-19. If global ecovillage reflection on ethical ranking systems were to follow Nzamujo's principle of autochthony, that would satisfy Darwin's criterion of diversification for survival and flourishing. Ecovillages dedicating themselves to the degree possible to their agricultural and cultural traditions could countermand the contemporary movement toward a single globalized culture grounded in just a few majority languages such as Mandarin, Hindi, Spanish and English.

Perhaps the greatest challenge to ecovillage autonomy is contemporary ecovillage reliance on local fossil fuel grids. The Global Ecovillage Network must exercise every possible effort to generate sufficient capital to fund green energy. However, capital for agricultural and information communication technologies is also urgent. Given impending water scarcity due to global climate change, capital for constructing massive reservoirs to compensate for diminishing water tables is important as well.

The potential for development in the areas of authenticity is extraordinary. The Muni Sevra ashram sets an example by providing education for nurses that prepares them for national board certification. Additional resources for the ashram could begin to permit the ashram to adopt the Cuban community health center model as a substitute for traditional medical school. ICT together with MOOCs and Open Access research philosophy will permit ecovillages to introduce education for virtually all the professions required by the principles of autonomy and authenticity. The maximum application of authenticity would eliminate the present divide between the ecovillage and the wider world by re-conceiving the world as a single global urban and rural ecovillage. Urban ecocenters would pose difficulties for this proposal as ecological replacement of current water, sewage and waste, and urban agricultural technologies would be costly.

The ethical ranking system should not serve as a ground for judgment of accomplishment, but as pointing to the most urgent need for capital input and personnel training to move ecovillages to full autochthony, autonomy and authenticity based on the most promising developments in appropriate technology with special concentration on information communication for a global population.

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SUDAN ICT POLICY PLANNING: CITIZENS CENTRED, MULTI-STAKEHOLDER, AND MCDA FORMULATION FOR ICT POLICY

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Abstract
Building effective national ICT policies can be instrumental to enable a socio-economic "leapfrog" effect in developing countries. This paper suggests that the effective socio-development process should be achieved by deploying an inclusive (and informed) bottom-up approach that engages all the ICT ecosystem stakeholders in developing an effective ICT policy that paves the way to a knowledge-based economy. We propose a citizen-centric bottom-up approach to Sudan's ICT policy development through wide participation and consultation of multiple stakeholders that enables a sustainable ICT ecosystem. The exercise will be done in two steps: Firstly; benchmark studies to determine the gap in the current ICT ecosystem and devise key areas for intervention according to the outcome of these studies. These studies are informed by using various Machine Learning (ML) algorithms, namely, K-Means clustering and Decision Trees. The second step is to further democratise the process by large citizen participation through surveys and focus groups to consider the true "voice of citizens" considering the thematic areas that will be identified based on the first step (and possibly add or modify thematic areas based on the "wisdom of the crowd"). It is worth noting that these steps will be mapped into the public policy development known phases (agenda setting, policy formulation, decision making, implementation, and evaluation) while ensuring the needed engagement level of various stakeholders in each phase and in such a way that ensures citizen centricity. We propose using Multi-Criteria Decision Analysis (MCDA) framework, to cater to the voice of stakeholders, experts, and policymakers and include their stakes as policy preferences constructively. We use Analytic Hierarchy Process (AHP) as an inclusive policy formulation tool, while the Technique for Ordered Preference by Similarity to Ideal Situation (TOPSIS) will be used for policy evaluation to maximize desired outcomes based on entropy and coefficient of variation. The proposed MDCA framework leads to more informed and better decisions.*

Keywords: ICT policies; Multi-Criteria Decision Analysis (MCDA); Analytic Hierarchy Process (AHP), Decision Tree, K-Means, Regression Tree, Technique for Ordered Preference by Similarity to Ideal Situation (TOPSIS).

INTRODUCTION

Developing countries face a challenge of globalization and a transformed world economy with the advancement of ICT in a knowledge economy era. These challenges exist in a status that is characterized by a low level of socio-economic development, weak industrialization structure, high level of corruption, a burden of heavy debts, low infrastructure development, weak governance, and dominance of autocracy regimes. Effective national ICT policy carries a promise to enable sustainable human development on an accelerated path. ICT has been linked to Sustainable Human Development since it enables four qualities enlarging human capability: inclusion, efficiency, innovation, and transparency. In this paper, we argue that effective ICT policy must be anchored on those qualities, that pro capability theory of human development and its formulation must follow a citizen-centred approach through wide participation of different stakeholders rather than a top-down technocracy one. This approach was primarily motivated by Sudan's December Revolution and its core principles of (Freedom, Peace, and Justice). The trajectory of the Sudanese revolution is a contemporary proof of the need for such an approach to ICT policy development; we can't ignore the core human rights dimension of ICT, its power in the inspiration of good governance, and the potential to dismantle and humble revolution power through spreading misinformation, blocking internet access, and citizen tracking and censorships. We

aim to build a policy planning process that stems from the large participation of citizens to put their rights and priorities first, blending with good expert decision-making that enables this aspiration.

ICT can facilitate access to information in different forms, such as the large geographical coverage of internet service, this helps in reducing information asymmetry, transaction cost, and maximizing inclusion. There are notable usage gaps based on deficiency and barriers in human capability to use ICT technologies, mainly in education, digital skills, gender gap, and local content, in addition to economic barriers such as affordability. ICT promotes the efficiency of the enterprise, hence the productivity through its capability to build up an efficient logistic platform that optimizes the flow of information coupled with the flow of material, but in general, the link of ICT with information and knowledge has a direct impact on knowledge-based economy activities provide a general-purpose platform for innovation and insights.

ICT has positive externalities in other development sectors, which by no doubt accelerate the sustainable development goals. ICT has been showing externalities in Education, Health, Agriculture, Energy, and Banking systems.

ICT is quite broad by nature; the ecosystem is diverse in terms of institutions, stakeholders, and potential services. This is one of the motivations for using the different techniques that this paper proposes at different stages of public policy development (e.g., ML, MCDA...etc...); to ensure the relevance of the policies to be produced to the local and socio-economic context of the country in question (Sudan is the current target of this process). This paper is an attempt to produce a high-level plan for ICT policy development, and it is worth noting that the work done thus far is mostly the desk research/benchmark used to assist in the agenda-setting for the policy formulation

PARTICIPATORY ICT POLICYMAKING

Public policy is instrumental in guiding government interventions to achieve its stated goals of efficacy and efficiency. Public Policy is defined in many ways, such as “Anything a government chooses to do or not to do”, Anderson gave a more detailed definition, (Young, Quinn, & Local Government and Public Service Reform Initiative., 2002) defined public policy as “a purposive course of action followed by an actor or set of actors in dealing with a problem or matter of concern”, which highlights intentions, actors, and the problem identification aspects of policy. Historically public policies were developed by a designated government authority, in collaboration with think tanks affiliated with a research institute or a political school (that is; in most developed countries, where democratic institutions are well established), while this quality is almost absent in most developing countries. The policy lifecycle goes through many review checks and public information/media dissemination during which the researchers and experts articulate the policy agenda, options, and recommendations. Government agencies take their decisions according to government priorities and budget limitations, while the parliament checks the legislative framework and monitors the accountability and adherence to the law. Contemporary public policy, especially ICT is formulated in a multi-agent, and highly intense political and power landscape, where powerful actors can influence policy toward the maximization of their interests. There are two main paradigms in the ICT policy arena: ICT for socio-economic development based on the market forces, and market liberation, this is an exogenous discourse where the developed countries can have a market for their high-tech ICT products, the second paradigm is ICT for Development and Information Society, where the focus is on endogenous social forces, that enlarge society capability to utilize the ICT infrastructure. It revolves around human rights to communicate, access to information, freedom of expression, active citizen participation, and building digital skilled human capital. We tap on the right of access to information to seek active participation and an informed policy lifecycle; we look to revolutionize the process itself, to rely more on statistical evidence with informed citizens in each step, searching for the wisdom of the crowds.

RELEVANT WORK

The Philippines' Department of Information and Communications Technology (DICT), with support from the Internet Society, developed the National ICT Ecosystem Framework (NICTEF) – a successor to the Philippine Digital. The government agency is mandated by law, to hold open consultations as means to improve transparency and promote public participation. The process elicits inputs from different stakeholders including government sectors, private sectors, academia, civil society, technical community, and across age groups from executives and senior-level to the youth and young people. DICT organized a series of thematic focus group discussions and regional consultations in each of the country's major island groups to bring their needs (Department of Information and Communications Technology, 2019). DICT opened the door for further consultation inputs from those who did not attend the workshop and organized small sandbox workshops to further disseminate and articulate the policy framework.

In Africa, I4Policy devised an innovative approach to scale up a participatory approach to policy, the process was implemented in many African countries to develop entrepreneurship and SME policy. Their policy-making process focuses on participation and design thinking qualities to build a policy process with three stages (Agenda setting, Drafting, and Implementation) and 9 steps depicted in Figure (2).

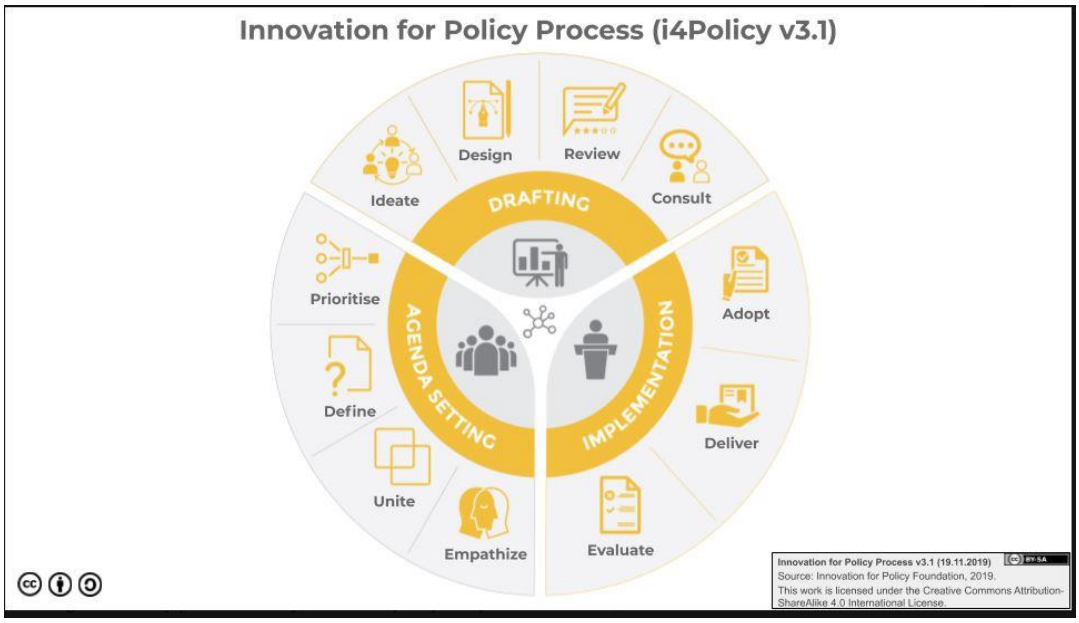

Figure 1: *i4Policy process.*

Another local example of such efforts is the Sudanese ICT Advisory Group (SICTA) work. In January 2020, SICTA conducted an ICT multi-stakeholder workshop which was the start of a serious dialogue among the wide spectrum of ICT ecosystem stakeholders. Methods to have a structured way to curate ideas included *"Design Thinking"* and *"Ignite Talks"*, mainly to enable an inclusive co-creation exercise for a citizen-centric national ICT roadmap for Sudan. Recommendations of this workshop emerged from very informed discussions and are representative of the crowd's wisdom. These recommendations directly addressed current and common challenges across pain points in the transitional government's priorities. Organizers made every possible effort to bring-in experiences from academia, citizens, and the private sector including startups, government employees, regulatory bodies, telecom operators, IT companies, and civil society. The representation of different stakeholders was shown in the following Figure 2.

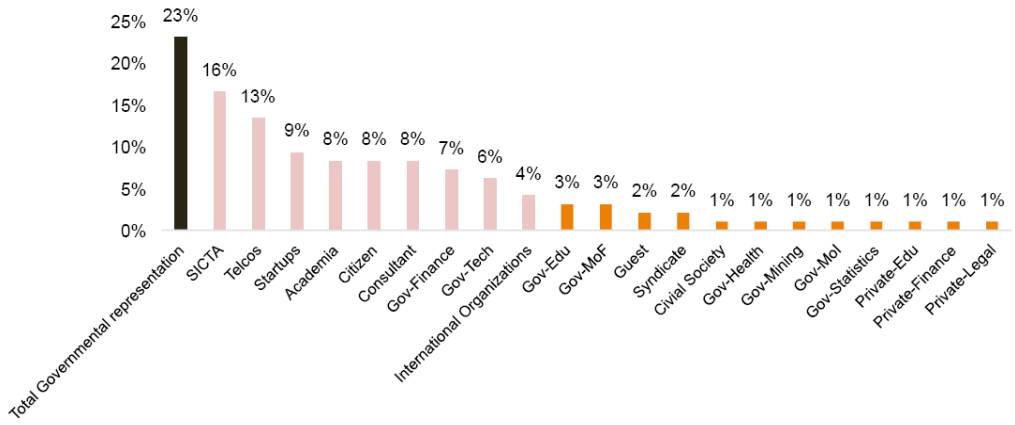

Figure 4 - Participants' breakdown by target segment

Figure 2: *SICTA ICT for Sudan workshop by participant category.*

The workshop's high-level recommendations had consensus on strengthening the Government Digital Transformation, starting from digital readiness assessment of government agencies, building digital government projects, and focusing on Public Procurement, National Data Architecture, and some ICT4D initiatives for the long term in education and health sectors. The recommendations highlight Financial Inclusion issues as well as the need for a plan for the National Broadband Network and the localization of the IT industry, which will have a significant contribution to Sudan's GDP. Figure. 3. below illustrates part of SICTA's citizen-centric vision regarding Public Policy and its linkage of the main areas of public policy and the Sudanese revolution's key principles.

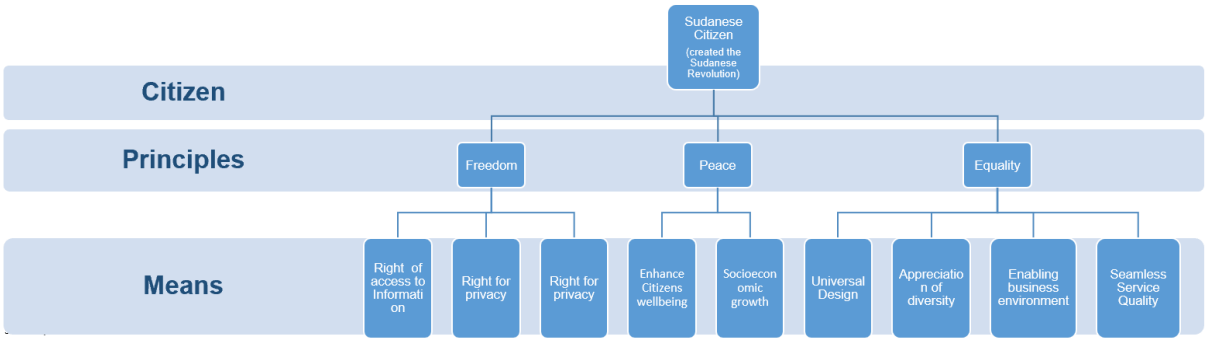

Figure 3: *Linking ICT rights to the principles of the Sudanese Revolution as per SICTA.*

In the next section, we illustrate general policy stages and show the role of evidence-based (statistical analysis) and participatory approaches in each stage. The policy lifecycle includes agenda setting, policy formulation, policy design, policy implementation, and policy evaluation. Table (1) below attempts to map the different stages of policy development to the relevant tools proposed by this paper to assist with having a structured, fact-based, and inclusive approach to policy development.

	Tools	Used Information & Data sets	Deliverables	Participants
Agenda Setting & Problem	1. Exploratory analysis 2. K-means clustering 3. Regression tree 4. Public awareness sessions Focus groups	1. Human Development Index (HDI) 2. Networked Readiness Index (NRI) 3. Global Competitive Index (GCI) 4. Mobile Connectivity Index (MCI) 5. Citizen's surveys (for curation of needs and opinions)	1. Identifying key problems related to ICT in Sudan. 2. Informing the participants(public) about these problems and how they relate to their rights, and how they relate to the developmental agenda of Sudan 3. Curating the "informed" opinion of the involved citizens	1. Policy analysts 2. Subject matter experts 3. Facilitators (with domain knowledge) 4. Citizens
Policy formulation & policy	1. Regression tree 2. Design thinking 3. Analytic Heirarchy Process (AHP) 4. Multi Cirteria Decision Making	1. Human Development Index (HDI) 2. Networked Readiness Index (NRI) 3. Global Competitive Index (GCI) 4. Mobile Connectivity Index (MCI) 5. Citizen's surveys (for curation of needs and opinions). Note that the citizen survey and brainstorming is the most critical information used in this step (AHP and MCDM)	1. Ranking of problems based on priority as seen by the public 2. Policy alternatives 3. Policy alternative prioritization	1. Policy analysts 2. Subject matter experts 3. Facilitators (with domain knowledge) 4. Citizens
Policy decision making and	1. Technique for Order Preference by Similarity to Ideal Solution (TOPSIS)	The initial outcomes from the Policy formulation & Policy alternatives step (using AHP and MCDA)	Refining the outcomes from the policy formulation& policy alternatives step. Basically finalizing the policy alternatives and their priorities	Polic analsyt
Policy implementation and	1. Implementation by the government 2. Monitoring using the initial data sets used for agenda setting	1. Human Development Index (HDI) 2. Networked Readiness Index (NRI) 3. Global Competitive Index (GCI) 4. Mobile Connectivity Index (MCI) 5. Citizen's surveys (for curation of needs and opinions)	Progress reports	1. Designated government agencies 2. Policy analysts
Policy evaluation	Use of the initial data sets as key performance indicators to assess the impact of the implementation of the proposed policy alternatives	1. Human Development Index (HDI) 2. Networked Readiness Index (NRI) 3. Global Competitive Index (GCI) 4. Mobile Connectivity Index (MCI) 5. Citizen's surveys (for curation of needs and opinions)	Assesment reports and suggestions for improving the process	Policy analsyt

Table 1: *Mapping of tools to the public policy development stages.*

I. Agenda setting and problem definition

Policy agenda setting is the first step of the process, it seeks to highlight the critical issues that public policy will solve. The clarification of problem definitions and their root causes either as potential enablers or inhibitors are the best qualities of this step. The policy must be based on addressing real problems, but again problem definition in a multi-stakeholder landscape needs careful scanning of who determines the problem and its priority, here qualitative and quantitative analysis of the problem will inform which problem lands on the priority agenda of the government. Descriptive statistical and exploratory analysis will reveal the status quo insightfully using visualization, clustering, and classification supported by diagnostic analysis (regressions) to know the factors behind the problem. Awareness sessions, discussion groups, focus groups, and surveys are different formats for active citizen engagement.

II. Policy formulation and policy alternatives

When the problems are well defined and pushed to be on high government priorities, then the search for the means that differ from current practice and business as usual is a critical step. This step requires innovation capability, system thinking, and evidence-based predictive analysis, to find policy alternatives that are orthogonal enough (reduce collinear between variables) and has a high contribution to the problem solution. It is allowed to list many options that are generated from brainstorming and analyses. In policy formulation, the role of a policy analyst, system thinking, and domain experts is crucial to come up with sound policy alternatives. For policy formulation policymakers, experts and stakeholders are engaged systematically in the process of policy formulation. the Analytic Hierarchical Process (AHP) will help to capture the voice of the citizens, stakeholders' views, and expert opinions in a

constructive way. Expert focus groups, citizen and stakeholder surveys, and design thinking workshops will build this model which ensures informed preference selection. This approach will be further cross-checked with the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) approach which tries to maximize the policy gain through predictive instruments and prioritise the policy options accordingly.

III. Policy decision-making and policy design

When the different options are formulated and their weighted preferences are captured, the preferred policy option to address the problem is then selected based on outcomes and some constraint criteria. The evaluation follows the MCDM using AHP and TOPSIS blending subjective consideration and entropy-based preference evaluation. This Multi-Criteria based decision-making forms the basis on which you can authoritatively argue for the legitimacy of your policy option [6]. After policy options are selected government authority's agency forms its strategy based on that option in form of a legislative decision project, regularity project, or implementation project, and determines its delivery organization mix (e.g., governmental or non-governmental, public or private) to provide the services or products outlined in the policy (Gasiea, Emsley, & Mikhailov, 2010). i.e., it turns the policy option into policy design.

IV. Policy implementation and Monitoring

After the policy was designed, it was implemented as guided by the design stage. A good outcome is a balance between good policy design and effective implementation. A monitoring framework devised by outcomes and constraints is the best way for efficient project management. The transparency of the progress of government projects with the regular dissemination of its monitored status will enhance government trust and hold it accountable to its citizens. An Infographic of descriptive statistics is preferred simple way.

V. Policy Evaluation.

An evaluation framework of policy design and implementation must be developed at the time of starting policy implementation, a good evaluation framework will consider how effectively measure the outcome of the policy, and how efficient policy implementation is. Critical evaluation of policy implementation must measure how close the policy is to its stated objectives and how far the adherence to regularity and legislative frameworks is. Here the evaluation and monitoring are concerns of many stakeholders such as parliament members, bureaucrats, politicians, NGOs, and citizens to shed the light using evidence-based statistics

BENCHMARK STUDY

We conducted benchmarking analysis on the ICT services performance in Sudan using qualitative and quantitative analysis, to measure the status quo, effectiveness, and efficiency of ICT services in the underlying ecosystem. This will help to set the policy agenda, develop policy options and then evaluate the policy preferences following the policy lifecycle. We used different machine learning algorithms over different data sets to inform the discussion in the "agenda-setting" and the "policy formulation" phases. This narrowing of the problem statement makes the approach more objective and informed. In this study, we will use the following dataset which already exists on its corresponding organization websites as well as the surveyed data set**.**

1. UNDP HDI dataset (UNDP, 2020)
2. Networked Readiness Index (NRI) (World Economic Forum & STL, 2020)
3. Global Competitiveness Index (GCI) (World Economic Forum, 2019)
4. Mobile Connectivity Index (MCI), GSMA Intelligence (Kenechi Okeleke & James Robinson, 2021)
5. Citizens' Science Surveys for citizens and other stakeholders

Benchmark Sudan ICT performance

We conducted a clustering algorithm for the world countries using the Human Development Index HDI as a socio-economic measure of development to find the set of countries with similar uncovered characteristics and environments to Sudan to screen the most affected socioeconomic features. We try to identify which development characteristics have the highest correlation with the ICT performance. In the first place, we determine the optimum number of clusters (K=14) using the within-cluster measure. We deployed a K-means clustering machine learning algorithm for this purpose (using more than 58 socioeconomic metrics as features for the algorithm to use in segmenting the data). Sudan was classified in cluster 2 with countries with very similar HDI performance of around (0.5), now we validate if the cluster performance in Mobile Connectivity Index coincides with this group, or are there differences? What are the major MCI features that fundamentally affect ICT performance? And which features had high splitting power to the development cluster.

No	Country	Human_Development_Index_.HDI._	Life_expectancy_at_birth	Expected_years_of_schooling
154	Pakistan	0.557	67.27	8.27594
155	Papua_New_Guinea	0.555	64.5	10.199261
156	Comoros	0.554	64.32	11.2447
157	Mauritania	0.546	64.93	8.58834
166	Djibouti	0.524	67.11	6.791215
168	Senegal	0.512	67.94	8.58486
169	Afghanistan	0.511	64.83	10.17643
170	Haiti	0.51	64	9.7
171	Sudan	0.51	65.31	7.884416
172	Gambia	0.496	62.05	9.911519
179	Yemen	0.47	66.13	8.76899

Table 2: *Sudan HDI Cluster 2.*

The Mobile Connectivity Index (MCI) is a tool that measures the performance of countries against the key enablers of mobile internet adoption, enables comparison with regional and global peers, and highlights areas where engagement is required to support efforts to accelerate digital inclusion [7]. GSMA suggests a process for policymakers utilize this comprehensive dataset. Their process includes the following steps (Kenechi Okeleke & James Robinson, 2021):

- **Investigate**: through a systematic review of the performance on MCI.
- **Benchmark**: your country's performance with its peers.
- **Priorities**: your focus area.
- **Research**: to find the reason behind the issue.
- **Resolve**: adopt policy and monitor performance.

Their suggested policy planning approach is the same as the generic policy steps that we illustrated at the beginning. We conduct the clustering of the MCI dataset using the K-Means algorithm with K=13 as guided by visualization of total square error within the cluster (WSS).

Sudan was allocated in Cluster 4, just before the last cluster, with 32.8 as the cluster's mean value, and "Discoverer" as the dominating class label, there were 5 countries on the top of the cluster classified as Emerging countries, including Sudan with MCI Index =35.13 a near 3 point above cluster means. A quick comparison between table 2 (HDI clusters) and table 3 (MCI & HDI clusters) shows that the countries that appeared in both tables were Comoros, Mauritania, and Sudan. Both Comoros and Mauritania were classified as "Discoverer" as per MCI, while Sudan was classified as "Emerging", this indicates that Sudan's utilization of its mobile connectivity is suboptimal in terms of developmental impact, this statement and its implications are further validated through further analysis in the data and by triangulating using the Network Readiness Index (NRI) as a third source.

No	Country	Index	Network.coverage	HDI_Cluster	Cluster
157	Uganda	40.9	69.19	Cluster_1	Emerging
156	Tanzania	40.11	47.22	Cluster_1	Emerging
170	Zimbabwe	36.57	58.9	Cluster_1	Emerging
169	Zambia	35.34	56.4	Cluster_1	Emerging
134	Sudan	35.13	40.18	Cluster_2	Emerging
88	Liberia	34.43	51.34	Cluster_1	Discoverer
67	Haiti	32.81	46.5	Cluster_3	Discoverer
108	Mauritania	32.09	26.43	Cluster_2	Discoverer
98	Madagascar	31.33	58.76	Cluster_1	Discoverer
110	Malawi	26.94	76.22	Cluster_1	Discoverer
60	Guinea-Bissau	24.42	70.68	Cluster_1	Discoverer
37	Comoros	23.98	76.29	Cluster_2	Discoverer

Table 3: *Sudan Cluster based on HDI and MCI.*

To shed the light on the clustering structure, we investigated which MCI features are more influential to the cluster segmentation, we used a regression tree to visualize this feature selection process. The tree can use one of many criteria to perform classification such as regression, logistic regression, and information gain; here we use regression as splitting criteria. We depict the recursive regression tree (implemented by ***rpart*** a recursive partitioning function in R), using the previous MCI clusters as tree labelling classes, while the rest 56 features are used as regression data. The described methodology helps in two directions: visualize interpretability of statistical learning methods, and feature engineering. The listed features are the most influential ones from the predictor set that classify the clustering effectively, which mean that it's the determinant of performance against the other features. The result shows different areas in each dimension of the four pillars which have a significant prediction power. We look from other angles at MCI predictors using the same methodology to select which features are most influential in interpreting the segmentation of the Human Development Index HDI.

No	***MCI Feature***	***MCI Sub_Pillar***	***Pillar***
1	Mobile apps developed per person	Local Relevance	Content & Services
2	Basic Skills	Basic Skills	Consumer Readiness
3	School Life Expectancy	Basic Skills	Consumer Readiness
4	Other enabling infrastructure	Other enabling infrastructure	Infrastructure
5	Gender parity in income	Gender Equality	Consumer Readiness
6	Taxation	Taxation	Affordability

Table 4: *Dominant features in MCI.*

The ranking of the features is dominated by soft socioeconomic features that raise the importance of human capability and skills regarding the creation and usage of digital content, which needs a better education system and quality of education. Using the same methodology above we examine the performance of world countries against the Global Economic Forum GE Forum, the Networked Readiness Index NRI. NRI looks at ICT from a different perspective. The index measures how countries could utilize their network infrastructure in their socio-economic development capability. The NRI's new version focused on the harmonious collaboration and interaction between people and technology with a governance framework that promotes trust, and inclusion and ensures security. Such socio-technical capabilities and governed environment are aimed to ensure a positive impact on our economy and quality of life, helping us to achieve SDGs (World Economic Forum & STL, 2020). The NRI and its Pillars are depicted below.

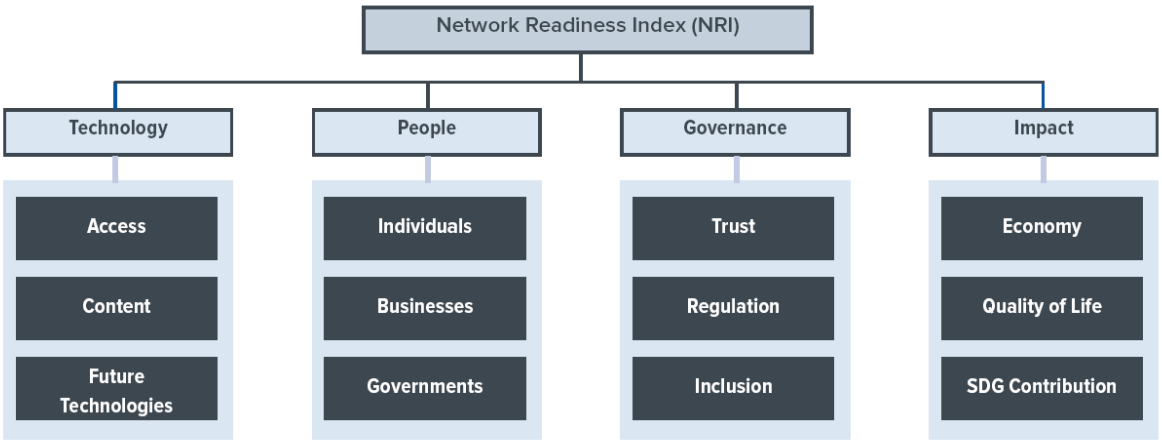

Figure 4: *NRI pillars.*

When we cluster the NRI data using (K=14), the most important NRI features to interpret the NRI classification are visualized using the Decision tree. Again, this will help us to refocus our discussions on the problem that we need to address by ICT policy. The rank of each NRI's features is summarised in Table 5. The NRI's influential features are geared more around innovation, education, quality of life, and inequality as a measure of economy and impact. The Technology pillar showed that investment in emerging technology with the innovation capabilities to develop applications and digital content is a crucial feature while server security and local content are trust and inclusion enablers of the NRI's governance.

No	NRI's Feature	NRI Sub Pillar	NRI Pillar
1	PCT patent applications	Economy	Impact
2	SDG 4: Quality Education	Individuals	People
3	Investment in emerging technologies	Future Technologies	Technology
4	Mobile apps development	Content	Technology
5	Happiness	Quality of Life	Impact
6	Government promotion of investment in emerging technologies	Governments	People
7	Secure Internet servers	Trust	Governance
8	Income inequality	Quality of Life	Impact
9	Availability of local online content	Inclusion	Governance

Table 5: *Features ranking for the NRI.*

When NRI features are used as predictors to HDI clusters, the dominant features are the innovation capabilities to develop new technology, software app, and creation of digital content, these capabilities are supported by education capabilities such as adult literacy and tertiary enrollment, while the government's role to expose its service online and shrink the gender gap are central mission as depicted in features ranking table.

No	NRI's Feature	NRI Sub Pillar	NRI Pillar
1	PCT patent applications	Economy	Impact
2	Wikipedia edits	Content	Technology
3	Tertiary enrollment	Individuals	People
4	SDG 5: Gender Equality	SDG Contribution	Impact
5	Adult literacy rate	Individuals	People
6	Government online services	Governments	People
7	GitHub commits	Content	Technology

Table 6: *Dominant features in NRI.*

Now, the analysis of both MCI and NRI showed consistently that a considerable gap comes from the usage gap in comparison with the coverage. That is, coverage is less an issue than usability! It can be seen in Figure 8 how Sudan is pulled back in MCI mostly by consumer readiness and affordability (when compared to its cluster). This example was meant to show the impact of studying the problem from different aspects to help in formulating a more relevant problem statement that helps focus the efforts to resolve the true issues (mostly in the "agenda-setting" and "policy formulation" phases of policy development)

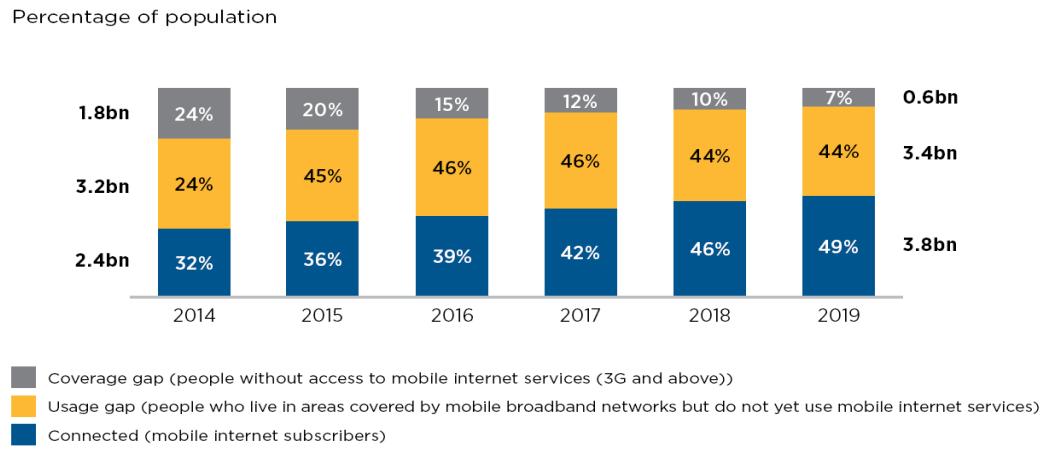

Figure 5: *Usage gap vs Coverage gap.*

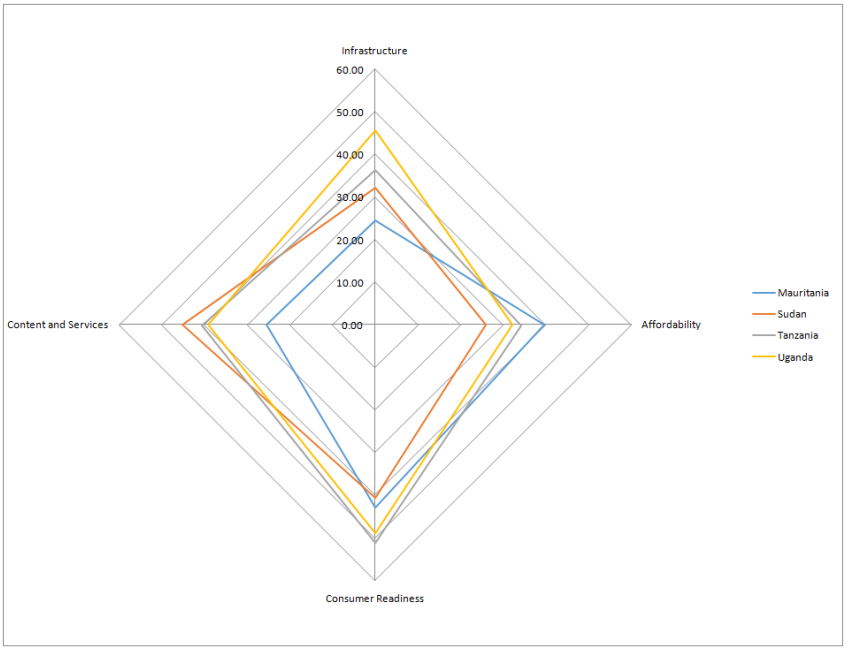

Figure 6: *Sudan's strengths and weaknesses compared to cluster.*

Policy formulation and Policy Decision Making

Here our role is to aid through MCDA/MCDM the policymakers to make informed decisions. Table 7. below illustrates the main idea of using TOPSIS and MCDA (Gasiea, Emsley, & Mikhailov). The quantification of the weights "w" values and the "X" values should be done jointly by the policy researchers and experts along with the key stakeholders in specified workshops after the thematic areas are defined using the Machine Learning techniques described in this paper, and after the awareness sessions are carried out across the different key stakeholders (especially the citizen workshops). It is

worth noting that AHP and TOPSIS are both subsets of the MCDA approach that complement each other (hence they are deployed in different stages of the policy development process).

	Thematic Area1	***Thematic Area2***	***Thematic Area3***	***Thematic Area4***
Relative Weights	*w1*	*w2*	*w3*	*w4*
Policy alternative 1	X_{11}	X_{12}	X_{13}	X_{14}
Policy alternative 2	X_{21}	X_{22}	X_{23}	X_{24}
Policy alternative 3	X_{31}	X_{32}	X_{33}	X_{34}
Policy alternative 4	X_{41}	X_{42}	X_{43}	X_{44}

Table 7: *Sample for deploying TOPSIS method to aid in MCDM.*

We first calculate the normalized matrix from Table 7. using the formula below

$$\overline{X}_{ij} = \frac{X_{ij}}{\sqrt{\sum_{i=1}^{n} X_{ij}^2}}$$

Then we calculate the weighted normalized value using the formula below

$$V_{ij} = \bar{X}_{ij} \times W_j$$

We calculate the ideal best and ideal worst using the formula above then we calculate the Euclidian distance from the ideal best and ideal worst using the formulae below.

$$S_i^+ = \left[\sum_{j=1}^{m} \left(V_{ij} - V_j^+ \right)^2 \right]^{0.5}$$

$$S_i^- = \left[\sum_{j=1}^{m} \left(V_{ij} - V_j^- \right)^2 \right]^{0.5}$$

Both policy formulation and result dissemination will include many awareness campaigns to emphasise our Citizen Centricity approach and facilitate advocacy toward adopting this agenda.

Policy Evaluation

The use of the MCDA/MCDM framework will also cover the formulation of an evaluation matrix based on TOPSIS methods and desired outcomes, the evaluation metrics will be disseminated with accompanying policy option preferences (João Clímaco and José Craveirinha, 2019).

FUTURE WORK

Some artefacts related to the use of MCDA and TOPSIS methods will be prepared for actual use within the different groups that will be engaged in the different steps of the policy formulation. Furthermore, stratified sampling of the Sudanese demographics depending on regions, age groups, gender, and income levels (as main features) will be needed to ensure that the engaged groups represent the opinions of all of the population. Different awareness campaigns and workshop sessions will be needed to prioritize the areas that the anticipated policies need to address (based on the thematic areas that come from the "agenda-setting" phase that will be performed using the analytics tools illustrated in this paper. Finding

other relevant efforts that were done by Sudanese NGOs (such as SICTA) and similar organizations can be of great value-added to ensuring the integration of efforts towards an informed development of Sudan's ICT policies.

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PEOPLE-CENTERED EVALUATION OF INDUSTRIAL POLICIES IN POST REVOLUTION SUDAN 2019-2021

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Abstract
This paper explores the industrial policies and trajectories that the transitional government of Sudan (TGS) adopted in the years 2019 – 2021 to evaluate their impact on prospects of people-centered development, addressing industrial policy as a fundamental infrastructure to accommodate people-centered development and appropriate technology implementation. The paper reviews the industrial reality in pre-revolution Sudan and its impacts on development from a people-centered approach, then evaluates industrial policies adopted by the TGS whether explicitly or implicitly, on their ability to achieve people-centered development and promote appropriate technology implantation. The evaluation examines the strategy documents issued by the TGS, and the legislations enacted over the same period with direct impact on industrial policy.

Keywords: Industrial Policy, People-Centered Development, Appropriate Technology, Policy Evaluation.

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SUSTAINABILITY, SOCIAL INEQUALITY, AND HUMAN WELLBEING

|

GREEN ECONOMY AND INNOVATION

PAPERS

INTEGRATED DEPRIVATION AREA MAPPING SYSTEM FOR DISPLACEMENT DURABLE SOLUTIONS AND SOCIO-ECONOMIC RECONSTRUCTION, SUDAN

Nuha Eltinay [1], *Monika Kuffer* [2], *Caroline Margaux Gevaert* [2], *Inas M.M. Ali* [3], *Charlotte Flasse* [4], *Cheruiyot Onyambu* [5], *Maysoon Badi* [1], *Asgad Gummah* [6], *Kumi Julia* [6], *Ibrahim Kushieb* [6], *Wafa Sakhi* [1], *Taha Elzaki* [7], *Mosub Abdallah* [8], *Marwa Ali* [8], *Mustafa Hamza* [8], **and** *Fatima Ahmed* [7]
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Abstract
African great metropolises are rapidly growing due to rural-urban migration. In Khartoum, Sudan, the urban population increased from around 245,000 in 1956, to over 8 million, due to wider changes in urbanization patterns driven by climate change, civil-unrest and protracted forced displacement. With the lack of sustainable planning strategies to secure land tenure and access to services, the level of deprivation in Khartoum informal settings witnessed a swift increase in urban poverty, that requires mapping the vulnerabilities of the urban poor and providing evidence-based data to support displacement 'durable solutions'. In response, IDeaMapSudan was launched in 2020, as a joint collaboration between Sudan Urban Development Think-Tank, Ministries of Social Development, Physical Planning, Infrastructure and Transport, and the Faculty Geo-Information and Earth Observation Science (ITC) at Twente University, to achieve three key objectives: 1) Provide capacity-building on using Earth Observation (EO) and spatial data innovation to fill the gaps in existing administrative GIS maps, 2) Develop a community-led geo-spatial database for mapping deprived areas (e.g. informal settlements) using socio-economic indicators for deprived areas in Khartoum, 3) Establish an 'Integrated Deprivation Area Mapping System' for data sharing and communication, that can guide the city planning decision -making process. Using Expert discussions and local field data collection, IDeaMapSudan revealed that local data on deprivation do not exist or are scattered within different local authorities, and the need to overcome the challenges of urban governance and technical congruence between EO data and community-driven vulnerability assessments is essential, by having a spatial distinction between slums, informal settlements, precarious areas, and other deprived areas, beyond the limited understanding of physical deprivation and humanitarian led vulnerability assessments.

Keywords: Deprivation, Earth Observation, Geospatial Information, Informal Settlements, Urban Poverty.

INTRODUCTION

Urban poverty in Sudan
According to the African Development Bank, 25% of Sudan's population falls below the extreme poverty line (ADB, 2018). The definition of poverty is the "lack" or "deficiency" of the necessities required for human survival and welfare (Wratten, 1995). Urban poverty is associated with urbanization drivers that shape economic and social exclusion patterns, access to public services, income and employment opportunities. Witnessing decades of conflict, instability, climate change vulnerabilities, weak urban governance, rural urban migration and internal displacement, the situation of urban poverty is exacerbating in Sudan. There have been

several attempts by government agencies, NGOs, donors and international organizations to measure urban poverty with the aim to tackle its key drivers. Nevertheless, with the lack of evidence-based data on vulnerability levels, the challenges towards the implementation of effective pro-poor policies will continue to hamper actions towards inclusive urban development in Sudan. Poverty, and in particular urban poverty, is a complex concept and should not be reduced to only income poverty (e.g., as expressed by the poverty line). Threshold values such as $1.9 per day provide a general impression about income poverty, but are limited due to difficulties in setting suitable thresholds and in particular access to reliable income data (Kakwani & Son, 2016). Furthermore, deprivation experienced by individuals, households and communities is more complex than such a simple income measure.

The concept of deprivation understands poverty as a multi-dimensional phenomenon (Abascal Rothwell, Shonowo, Thomson, Elias, Elsey, Yeboah & Kuffer, 2021). For example, households might be deprived in terms of durable housing material or access to basic services (e.g., water). Communities might be deprived in terms of infrastructure or availability of open spaces. Deprivation-related data are routinely collected in some High-Income Countries (HICs). For example, the UK has a long-standing tradition of producing deprivation indices (McLennan et al., 2019) such as the index of multiple deprivation (Figure 1). However, Lower Middle-Income Countries (LMICs) do not have easy access to data nor do they have the capacity to collect and process data that would reveal the complex geographic patterns of multiple deprivation. Existing data on LMICs that relate to aspects of deprivation often have consistency and accessibility issues. For example, data are collected for some areas but are not available at city scale and/or data are stored in a way that they cannot be accessed. Furthermore, local stakeholders often do not have the capacity to work efficiently with the rapidly growing amount of open data and innovations in Free and Open-Source Software (FOSS). Open data combined with FOSS could be a solution to overcome the bottleneck for LMICs, but capacity development is required to utilize such new and constantly evolving sources.

Overview of IDeAMapSudan

The IDeAMapSudan Project stands for (Integrated Deprivation Area Mapping System for Displacement Durable Solutions and Socio-Economic Reconstruction, Sudan). It was launched in Sept 2020 through a consortium led by the Faculty of Geo-Information Science and Earth Observation of the University of Twente (UT)-Netherland in partnership with Sudan Urban Development (Think-Tank) Organization (SUDTT)-Sudan, African Population & Health Research Centre (APHRC)-Kenya, and Université Libre de Bruxelles (ULB)-Belgium. Launched mid-2017, it aims to build the capacity of local entities, especially government bodies, to create and use an integrated system for mapping deprived areas. As such, a collaboration was established with the ministries of: Social Development, Urban Development & Roads and Bridges, Transport, and Physical Planning (Khartoum State) to implement the project.

Measuring Urban Poverty

There are different indicators established to measure poverty, locally and internationally, however the integration of data and its representation in geographical form to reflect poverty and the levels of deprivation in Khartoum is lacking (Eltayeb, 2003). The lack of spatial data creation and collection, data management & analysis, and the ability to translate spatial data into relevant policy is the major drive for the IDeAMapSudan Project. Therefore, the aim of IDeAMapSudan is to develop a community-led geo-spatial database for mapping deprived areas (e.g. informal settlements) by linking the geospatial data with community-based data, in collaboration with local governments and civil society organizations. That will help in

understanding the displacement and urban poverty challenges and opportunities and support decision making for sustainable socio-economic reconstruction in Sudan. The project consists of four main phases as follow:

1) *Gap analysis and basic spatial analysis:* Mapping local key stakeholders including government and non-government entities, and working in collaboration to identify data gaps and potentials of EO for urban development in Sudan.
2) *Technical training of trainers (ToT):* a team of young professionals was selected from two Ministries in Sudan to gain advanced technical knowledge on GIS and EO including community-based data collection. The ToT team is trained to lead the creation of IDeAMapSudan System and building the deprivation model. Through working with communities and local NGOs the system is tested in two pilot areas in Khartoum state.
3) *Working with IDeAMapSudan:* the team will work on transferring the knowledge through conducting training workshops for local communities, government and NGOs.
4) *City-to-City (C2C) political knowledge exchange:* to discuss and stimulate the regional scaling of IDeAMap in the region.

RELATED STUDIES

Data to map the Geography of Poverty

Data is key for development; yet up-to-date, actionable data is often missing (The World Bank, 2021). For example, official population counts in informal areas differ greatly in distinct sources of official estimates (Thomson et al., 2021). Crowd-sourced information, such as Open Street Map (OSM), can supplement that, but they do not have a homogeneous quality (Herfort et al, 2021). Earth Observation (EO) can help fill this knowledge gap. There has been a significant increase in the amount of satellite imagery available to the public over the past decades (Kavvada Metternicht, G., Kerblat, F., Mudau, N., Haldorson, M., Laldaparsad, S., . . . Chuvieco et al., 2020). Such imagery enables comparing urban areas over time, by comparing current imagery with historical satellite imagery, and also space as the urban form in one city or neighborhood can be compared with another (Taubenböck, Esch, Felbier, Wiesner, Roth & Dech, 2012). Indeed, EO has shown much potential for mapping urbanization patterns and deprived areas (Kuffer, Pfeffer, and Sliuzas, 2016). Very-high-resolution, commercial imagery enables the identification of buildings and building typologies (Kuffer *et al*, 2016) and drones can help develop detailed plans for urban upgrading projects (Gevaert, Sliuzas, Persello, & Vosselman, 2018). Other types of satellite sensors can collect supplementary information. For example, radar satellites can pass through the clouds and capture the extent of flood events (e.g., UNOSAT, 2020) and night-light imagery can give a hint to the economic productivity of certain neighbourhoods (Bennett & Smith, 2017). Perhaps the greatest limitation of EO data is that it can only directly capture physical information – about the structure of buildings – and can model socio-economic conditions but it does not directly measure the latter. This is why it is extremely important to match the observations from space with community-based socio-economic information and an understanding of the local context.

Overview of IDeAMap: A conceptual modelling framework

To support routine and accurate mapping and characterising of deprived urban areas, the IDeAMap network developed the Domain of Deprivation Framework to identify relevant geospatial and EO data (Abascal *et al*., 2021). This framework builds on existing deprivation frameworks (e.g., the IMP 2019). Such frameworks avoid modelling deprivation as a binary phenomenon, but as a continuous layer. Existing deprivation mapping frameworks typically

use census data. However, in many LMICs such data do not exist or are dated (e.g., the last census in Sudan took place in 2008). Such dated data do not reflect the present physical and socio-economic conditions. In particular in fast-growing and transforming LMIC cities such data are rapidly outdated also with regular censuses (i.e., commonly every 10 years). The Domains of Deprivation Framework (Figure 1) groups locally meaningful indicators into 9 domains at 3 scales. Two domains reflect deprivation measured within households. Four domains reflect area-level deprivations (social hazards & assets, physical hazards & assets, unplanned urbanisation, and contamination). Three domains reflect aspects of deprivation that relate to the connectivity to the city (i.e., infrastructure, facilities & services, and governance). A guide for authorities (Thomson *et al.*, 2021) provides guidance for the operationalisation of all domains with openly available geospatial data (e.g., night-time lights, air pollution) and contextual image features (e.g., Sentinel-2 satellite imagery).

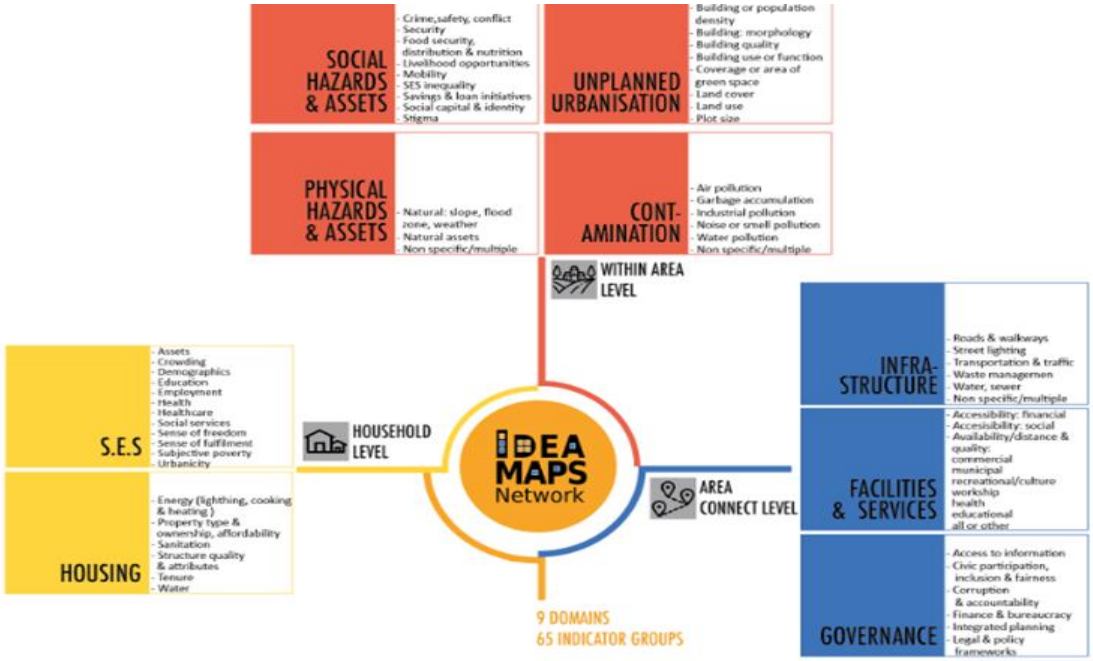

Figure 1: *IDeAMap Domains of Deprivation Framework (Abascal et al., 2021).*

METHODOLOGY

The methodology provides an overview of the efforts to co-design a deprived area mapping system for Khartoum that leverages the strengths of EO data, open data and FOSS combined with training the capacity of local key actors to develop and use such a system. IDeAMapSudan aims to overcome data availability gaps on deprived areas and focuses on low-cost and sustainable solutions. Parallelly, the capacity of local stakeholders (technical and non-technical) will be built by using EO and spatial data innovations.

Introduction to Study Area

The total population of Khartoum State according to the last census in 2008 is 5.274 million people, who is almost 14% of the total population of Sudan. This makes Khartoum the largest state in terms of its number of populations compared to the other states of the country (Central Bureau of Statistics, 2009). Based on the 2.4% annual growth rate, its population projection is estimated at 6.793 million in 2020. The proportion of the urban population of Sudan has been continuously increasing since the first census in 1956 when it was recorded as 8.8% compared

to 29.8% in the 2008 census where 80% of Khartoum's population were classified as urban (National Council for Physical Development/UN-HABITAT, 2014).

Greater Khartoum, within Khartoum State, comprises three cities: Khartoum, Omdurman, and Khartoum North (Bahri), separated by the Blue and White Nile rivers. Several development plans were developed for Greater Khartoum responding to the rapid growth of the city, however most of the plans failed to be fully implemented and its capacity to address the needs of vulnerable groups and urban poverty issues is questioned. Not only the lack of financial resources hindered the implementation of those plans, but also due to land issues and the lack of coordination and conflict between the different governmental institutions (Pantuliano, Assal, Elnaiem, McElhinney, Schwab, Elzein, & Ali, 2011). Demolition of illegal settlements (squatters), relocation to new sites, re-planning of informal settlements to be incorporated within the urban context, and up-grading of some areas were major policies undertaken by the Government to address the informal expansion of Khartoum (Three City Land Nexus Research Team, 2020). As mentioned before, IDPs and poor migrants have settled in different areas around the city. Ahmed & EL-Battani (1995) identified three categories of the poor in Khartoum; 1) Urban poor, people with low levels of education and semi-skilled workers, 2) IDPs, who were forced to leave their places seeking better living conditions in Khartoum, 3) the so called "New Poor" who became poor as a result of liberalization policies to lower wages and remove subsidies. A more recent study in 2009 led by UN-HABITAT considered 60% of Khartoum's population as urban poor and were classified based on their locations (Table 1) (Murillo, et al., 2009).

	IDP camps	Squatter areas	Villages	Low-income neighborhoods	
				High middle density (including renting)	Low density (sites and services)
Estimated area	18 km² 1,800 hectares	15 km² 1,500 hectares	38 km² 3,800 hectares	12 km² 1,200 hectares	94.5 km² 9,450 hectares
Estimated population	400,000	400,000	700,000	700,000	2,100,000
Density inhabitant-hectare	222	266	184	583	100
Percent of total population	5	5	10	10	30
Percent of urban population	10	10	15	15	50

Table 1: *Categories of Urban Poor by location (Murillo, et al., 2009).*

The continuous growth of Khartoum's population and its expansion versus the absence of adequate development plans has put more burden on its residents, especially the poor urban communities. In addition to their low level of income (monetary poverty), they are also suffering from non-monetary poverty by lacking adequate access to services, basic infrastructure, and income generation opportunities. This multi-level deprivation also leads to high levels of crime and other illegal activities.

Delineation of the extent of the study area

Greater Khartoum is a large city. Studying urban deprivation at such a large scale is complex, as such two different scales of study area were defined. On one hand, a larger study area of the

urban areas of Greater Khartoum was manually delineated, with the aim of creating generalized maps using freely available satellite imagery, for example land cover maps to help gain a wider understanding of the landscape of Khartoum. A broad area was delineated in order to include deprived areas on the outskirts of Khartoum that may become included as part of the city with future urban expansion. For guidance, this delineation used recent satellite imagery (Sentinel-2 imagery for 09/09/2020), and a number of existing datasets with differing definitions defining urban areas, or human settlements: WorldPop gridded maps of building patterns (Dooley Boo, Leasure and Tatem, 2020), GRID3 settlement extents (CIESIN & Novel-T, 2020) and Africapolis (OECD/SWAC, 2020). More information on these datasets can be found in Table 2.

On the other hand, for a more detailed analysis of deprived areas within Khartoum, two small scale pilot study areas were identified in order to develop and test IDeAMapSudan, with the participation of local communities in data collection, and production of detailed maps. The pilot study areas of Dar Alsalam (Omdurman), and Jebel Aulia were selected for their contrasting characteristics. Dar Alsalam concerns IDPs that used to be displaced elsewhere, but were then given ownership of planned houses in Alsalam, whereas Jebel Aulia is very old and inhabited by IDPs from South and West Sudan, or the Pantio neighborhood which is unplanned. Jebel Aulia has a large population with a significant proportion of refugees and immigrants from conflict areas, often settling in a spontaneous way. For the first phase of the project, the area around Jebel Aulia was selected as it suffers from socio-economic deprivation, but the western part of Jebel Aulia also has issues as it lies on the regularly flooded eastern bank of the White Nile. This frequent flooding also contributes to the vulnerability of the area. The delineation of the larger study area, and selection of the pilot study areas were presented to local experts within a workshop, to analyse their suitability.

Workshops for data needs assessment, stakeholder mapping and different EO approaches

In 2021, two expert workshops were held in Khartoum. The first workshop allowed for an information needs assessment, definition of the study area and understanding of deprivation domains. The second workshop deepened the understanding of what defines deprivation in Khartoum, gaps in locally available data and inputs for the selection of suitable EO methods for base maps. Workshops were attended by experts from ministries, NGOs and academia and held in hybrid format with a local and online attendance (due to COVID-19 restrictions). The second workshop focused on answering three main questions: 1) What is the definition of deprivation in Khartoum? 2) What are current and/or previous relevant projects/studies? 3) What are the major data gaps and information needs?

Local data collection in the case study area of Jebel Aulia

Jebal Aulia is one of the seven localities of Khartoum State located in the southern part of Khartoum city and bounded by the White Nile from the western side. The official census in 2008 reported its population as 942,429 which is about 18% of Khartoum's total population in the same year (Central Bureau of Statistics, 2009). As mentioned previously, Jebal Aulia is one of the key areas that received IDPs and it also suffers from recurrent floods causing major damages in infrastructure and households. In August 2021, three days were dedicated to collect local data in the field using a random sample of the study area (total sampled points 166 - accessible points 139). For the 139, a detailed observational survey was conducted that covered various aspects of physical and socio-economic deprivation. For each surveyed point, the location is described using a standard form and a photo is taken. For the data collection QField was used as an open-source app for collecting data that allows to load offline maps before going into the field.

Different EO approaches for the production of a base map of Jebel Aulia

EO imagery can be essential for understanding urban dynamics. However, it is necessary to extract meaningful information from an image in order to analyse it. The most common (geo) information extracted from EO imagery is that of land cover, i.e., the observed (bio) physical cover on the Earth's surface (Di Gregorio, A., 2005) based on their differing spectral characteristics. Maps of land cover (at different points in time) are essential for understanding the landscape (e.g., where are the built-up areas) and how and where this evolves over time (e.g., urban expansion). Besides basic physical information, also complex information (e.g., socio-economic conditions) can be extracted from EO imagery such as the location and characterization of deprived areas. There are many different methods for extracting such information. Many different aspects must be taken into account such as:

- the imagery available (spatial resolution, extent)
- the spatial unit to classify (pixel vs. object)
- the classification method (rule-based, machine learning, deep learning, etc.)

An analysis was carried out by the ToT team in Jebel Aulia, to test and compare different methods for the classification of land cover (including areas that might be slums or deprived). Three different methods were tested and validated by using data collected in the field:

- Method 1 → Object-based classification using very high resolution PlanetScope imagery and rule-based method of classification.
- Method 2 → Pixel-based classification, using Sentinel-2 imagery and the Random Forest algorithm for classification
- Method 3 → Pixel-based classification, Sentinel-2 imagery and the k-nearest neighbours method of classification.

Overview of the data ecosystem to city level modelling of deprivation

The Domains of Deprivation Framework guides the integration of different data that relate to multiple aspects of urban deprivation. The outputs are twofold: 1) a city-wide gridded map of deprivation on a continuous scale from most-to-least deprived (at a 100x100 m grid) and 2) a local detailed map that reflects neighbourhood level deprivation for the case study area.

The city-scale deprivation map allows to depict the spatial patterns of urban deprivation but also highlights specific domains (e.g., access to infrastructure). The input for selecting relevant domains and indicators are the results of the expert workshops that provided guidance on relevant deprivation indicators for Khartoum. For each selected indicator, available open and local datasets are selected and compiled into a data ecosystem for deprivation modelling. For the experiential phase, the data ecosystem is compiled at the Center of Expertise in Big Geodata Science (CRIB) at ITC. CRIB is a horizontal facility for big Geodata technology in education, research, and institutional strengthening activities. CRIB allows cloud computation of big data, which avoids computational constraints that have been limiting city scale analysis (in particular in resource constrained environments). The final data ecosystem will be locally available in Khartoum at a server that allows stakeholders to access, update and further develop the system. The neighborhood scale map of deprivation is informed by local data sets of the study area (Jebel Aulia), the EO base map produced for the study area and local field survey of the area. The local map provides a detailed localized characterization of a deprived community for developing localized policies. Furthermore, the local map allows for a comparison of the city scale map and an assessment of limitations of its output.

RESULTS & DISCUSSION

As the project is still ongoing, this section provides an overview of the preliminary results and discusses future work plans.

Delineation of the study area

The delineation of the general urban area of Greater Khartoum can be seen in Figure 2. Unlike the urban extent defined by the WorldPop (Dooley *et al*. 2020), a continuous area has been delineated in order to better understand the context and dynamics of the built-up areas with their surroundings. As for the suggested pilot study areas, the vast majority of the workshop participants agreed that Alsalam and Jebel Aulia were good choices as they provide different dynamics of deprivation. Their location of the suggested study areas within Khartoum can be seen below, as well as the final delimitation of the Jebel Aulia pilot study area used for the preliminary investigative analysis.

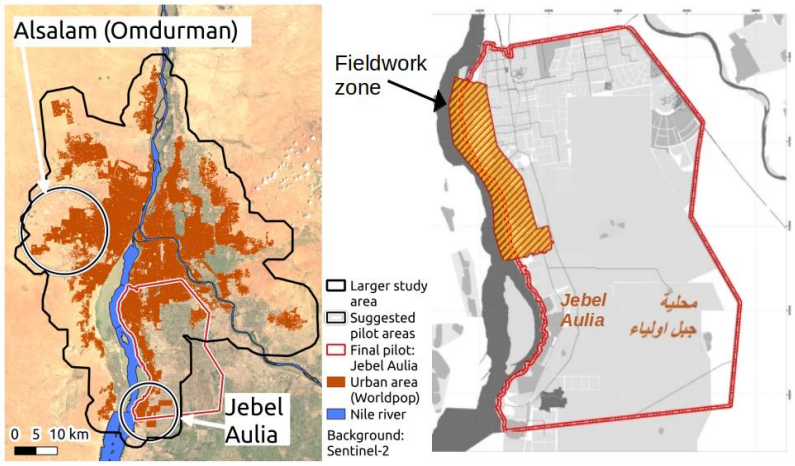

Figure 2: *Manual delineation of the larger study area, locations of the two suggested pilot study areas, final delineation of the Jebel Aulia pilot study area for fieldwork (by the authors).*

Selection of Deprivation Domains and Indicators

The IDeAMaps framework was used for the workshop held with local experts to identify domains and indicators that are locally relevant for the three scales, i.e., household, within area, area connect level. The workshop and expert discussion also provided an overview of ongoing local projects, which allowed us to identify four related projects (i.e., Land nexus 2018 -2020, Abo Adam Project to convert agricultural land into residential land, Urban poverty alleviation UNDP/Habitat – 1999-2000 and Mayo the path to resilience (GIS & EO)- June 2021). Four major data gaps and information needs have been concluded during the workshop:

- Social data (e.g., population, household characteristics and socioeconomic data)
- Flooding data
- Integrated and updated maps (most of the time maps does not reflect the actual status)
- Vulnerability map – fragile area map (with multiple deprivation domains).

Local Mapping of Deprivation using selected EO approaches

The analysis carried out by the ToT team in the pilot study area of Jebel Aulia produced three land cover maps, which can be seen in Figure 3. While the three methods provided land cover maps with high levels of accuracy, the analysis inferred that the Random Forest algorithm

provided the best results for differentiating built-up areas from other classes, with an overall accuracy of 94%, but without any differentiation between formal or informal buildings. To discriminate deprived from other built-up areas high level image features like texture can support and be employed with deep learning.

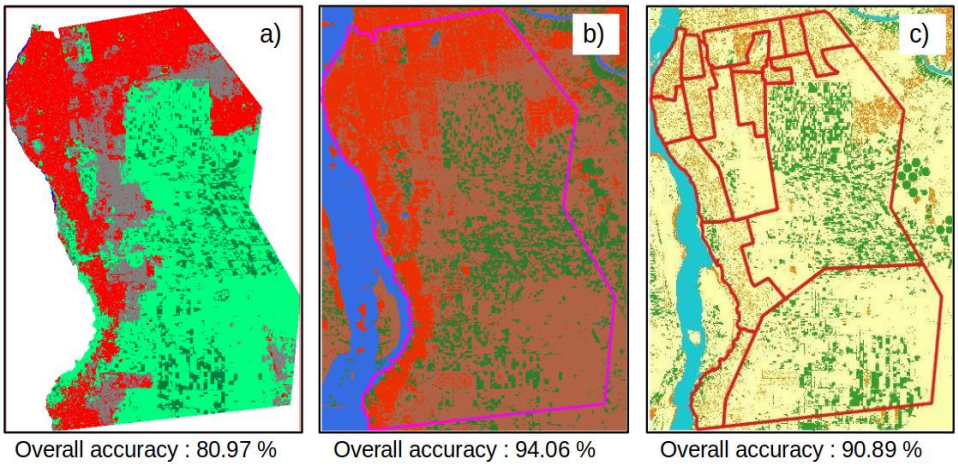

Figure 3: *Base maps of the study area. a) Method 1, b) Method 2, c) Method 3 (by the authors).*

Besides land cover maps, local data related to aspects of deprivation have been collected. This included local services, infrastructure and flood zones (Figure 4-right), results providing distance to services, infrastructure and had hazard susceptibility.

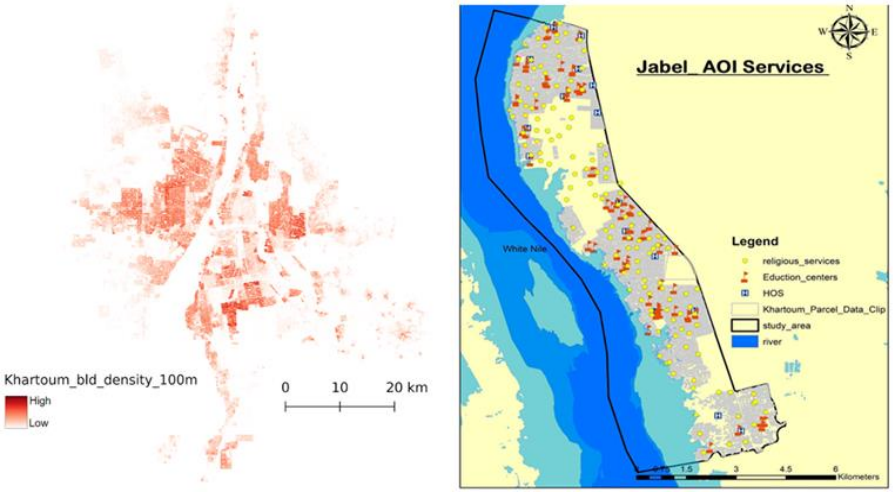

Figure 4: *Deprivation indicators at two scales, left: built-up density of Khartoum (unplanned urbanization domain); right: local survey results (by the authors).*

First data build in the data ecosystem and draft design of the data ecosystem

Based on the components of deprivation identified earlier, an inventory was compiled of open data which can be used to support deprivation mapping at a city scale (Table 2). These datasets have been compiled within CRIB. For example, built-up density (Figure 4-left) can be related to unplanned urbanization and is often a simple but useful proxy of deprivation. The next steps for the project will combine indicators to arrive at an overall deprivation index for the city of Khartoum.

Theme	Type	Description	Spatial resolution	Date	Source
Satellite imagery	Sentinel 2	High resolution imagery of the earth's surface as of 2015. Mosaic images can also be produced.	10-20m	from 2015	ESA (nodate)
	Sentinel 1	Radar imagery		from 2014	ESA (nodate)
	Elevation	Digital Elevation Model (DEM) of the Shuttle Radar Topography Mission (SRTM)	~30m	2000	NASA (2015)
	Nightlight	Images taken at night, at low resolution	500m	2016	NASA (2016)
Population	Worldpop	Grid cells of population count. Various different methods of calculation are available.	~100m	Annually from 2000	Worldpop & CIESIN (2018)
	Global human settlement population	Grid cells of population count	(~250m)	2015	Florczyk et al. (2019)
Urban / settlement areas	Worldpop	Gridded maps of building patterns (urban and rural). Thresholds defined if a group of contiguous cells have a minimum number of buildings (5000) or if there is a minimum number of contiguous built-up cells (1500)	~100m	2020	(Dooley et al. 2020)
	World settlement footprint	Global human settlement mask, WSF201**T**5	10m	2015	Marconcini et al, (2020)
	Global human settlement layers	Various datasets of the spatial distribution of (multi-temporal) presence of built-up areas, and different settlement typologies, and identification of urban centers, based on various sources (Sentinel-1, Sentinel-2, GHS population layer…)	Multiple (10m - 1km)	Multiple (from 2015)	Florczyk et al. (2019)
	Africapolis	Data on urban agglomerations in Africa. Based on a large inventory of housing and population censuses, electoral registers and other official population sources. Satellite and aerial images are used to inform on the physical evidence on the ground, that is the built-up area and the precise location of settlements.	N/A	1950 - 2015	OECD/SWAC, (2020)
	GRID3	Boundary extents of settlements (built-up areas, small settlements and hamlets). Thresholds defined based on building footprint density (>=13) and minimum built up area size (400,000m^2.	N/A	2020	(CIESIN & Novel-T, 2020)
	Google Open Buildings	Map of all building footprints in Africa (extracted from EO data and AI methods)	N/A	2021	Google
Land cover	CCI	Prototype high resolution land cover map over Africa based on 1 year of Sentinel-2A observations, from the Climate Change Initiative (CCI)	20m	2015-16	ESA (2017)
	Copernicus	Land cover maps and land cover fractions.	100m	2015 - 19	Buchhorn et al (2020)
	ESRI	Land cover map	10m	2020	Karra et al (2021)
Amenities / infrastructure	OSM	OpenStreetMap (OSM), multiple layers of buildings, roads, waterways, points of interest etc. Dataset is constantly being updated	N/A	2021	OpenStreetMap (2020)
	Health facilities	Locations of sub-Saharan health facilities	N/A	2020	WHO (2020)
Other	Administrative boundaries	Administrative boundaries levels 0-3 for Sudan	N/A	2018	GADM (2018)
	Flooding	Water observed by satellites for flood events (UNITAR). Provides PDF maps and vector data of surface water detected by VIIRS-NOAA around known flood events.	N/A	Multiple	UNITAR (2021)

***Table 2**: Overview of some of the main spatial datasets available freely online.*

Discussion - Towards building a spatial understanding of urban deprivation in Khartoum

Expert discussions and local field data collection revealed that local data on deprivation do not exist or are scattered within different local authorities and are inaccessible to inform planning and decision making. There is a continuously growing amount of datasets available, often EO data products or crowd sourced data (e.g., OSM). However, local authorities require skills, knowledge and the capacity to work with such data, understanding their scope and limitations. For example, how to optimally process and combine open datasets with local (often patchy and dated datasets). IDeAMapSudan aims to fill local data gaps and support urban policy towards addressing several of the SDGs (e.g., SDG 1 and 11).

Before entering the modelling phase of building deprivation models several pre-steps are required, this includes the definition of the urban extent and the local conceptualization of deprivation and the understanding of local information needs. To support the sustainability of the data ecosystem (presently under development), capacity development is required. At present, we have been training the capacity of technical and contextual experts (poverty and planning) to co-design and co-develop the data ecosystem. To further promote the sustainability of the data ecosystem, capacity development is focusing on FOSS that can be used by local organizations also after the completion of the project. After the first prototype of the deprivation ecosystem, a number of deprivation maps were produced by the team (Figure 5), showcasing the distribution of public services, environmental contamination and social hazards. Further training will focus on a larger group of staff of different ministries, NGOs and local academics to use the model outputs. In the future, we envisage the data ecosystem as a platform to exchange data and to communicate on urban deprivation related topics between government actors, NGOs and local academia. This will require a system design that deals with data ownership and privacy issues. For example, the rationale for using a 100x100 m gridded mapping system is to reduce privacy issues by not revealing household or personal data. Other questions, related to maintaining the system updated and ensuring FAIR data principles (Wilkinson et al., 2016), will be part of the next design stages.

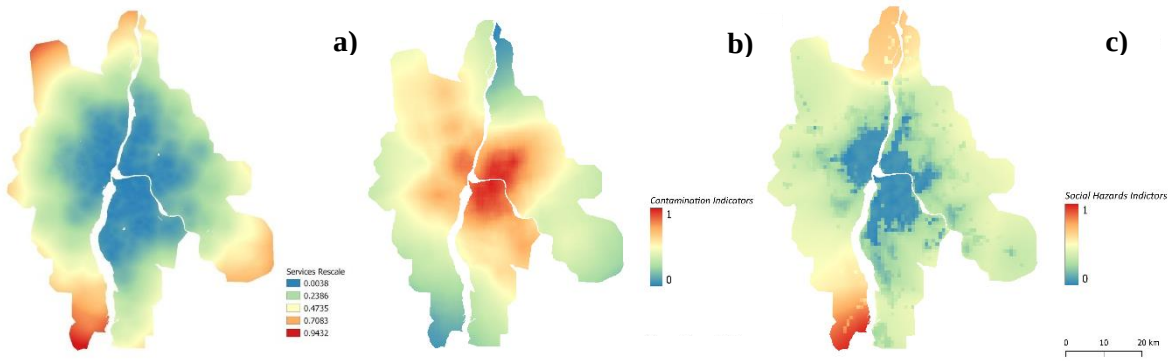

Figure 5: *Khartoum State Deprivation Maps a) public services, b) environmental contamination and c) social hazards (by the authors).*

CONCLUSION

The aim of this paper is to localize global knowledge on deprived area mapping with EO for Khartoum and presents the workflow to set-up the IDeAMapSudan network and data ecosystem. It considers the local needs, actors and data ecosystem to establish IDeAMapSudan as well as the capacity-building component to hone the technical skills required to set-up, maintain, and update the system. IDeAMapSudan addresses two major gaps in relation to urban deprivation data. First, we use available data (global and local) to provide data which are locally

of high demand but do not exist to support planning and policy making to address SDG 1 ("No Poverty") and SDG 11 ("Sustainable Cities"). Second, we build the capacity of local stakeholders (from ministries and NGOs) to work with the data ecosystem depicted to support these policies. The combination of building required data, making them accessible to a wide group of local stakeholders and training their capacity will be the first step towards evidence-based policy making to addressing local SDG monitoring in a resource constrained environment.

ACKNOWLEDGEMENTS

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APPROPRIATE METHODS TO ENSURE HOUSING PROVISION FOR THE LOW-INCOME GROUPS IN KHARTOUM, SUDAN

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Abstract
One of the main challenges for the urban poor to obtain adequate housing is finance. Accessing housing loans from the formal and informal sectors requires an economic pledge out of the reach of the poor. One of the basic ideas to address this is to replace facial/physical collateral with social one; and design credit programs appropriate to the conditions of the poor. Numerous successful rural credit experiences for the poor exist in Asia and Africa. One of the most popular approaches is Grameen's *approach to social entrepreneurship programs in rural Bangladesh. In this program, the bank provides small loans for income-generating projects. Housing loans are endorsed after the poor increase their incomes. Mobile banks, Solidarity group, progressive lending, saving and insurance programs, and intensive supervision are the main features of the designed credit program. The study addresses the following question: How can we design similar accessible credit programs which are adequate to solve housing provisions for the urban poor in Khartoum State? Grameen's approach conceptualizes the design of the proposed funding program. The incomes of the poor were estimated based on the employee salary structure and statistics from secondary sources. We calculated the values of the loans required to implement incremental housing programs for the poor. The study conducted a feasibility study to assess the financial system sustainability. The preliminary results indicate the possibility of implementing the proposed financing system. The estimated value of the periodic installments of the loan is within reach of the poor. Also, we found that the proposed financial system can achieve sustainability and self-sufficiency, which reveals a possible direction to solve housing financing problems for the urban poor in Khartoum State.*

Keywords: Peer Pressure, Housing Loans, Social Entrepreneurship, Mobile Banks, Solidarity Group.

INTRODUCTION

An estimated 75% to 90% of all new housing exists outside the formal housing development process in developing countries (Ferguson, 2000:3). Investment occurs progressively over five to 15 years (Ferguson, 2003:185). At most, the top 20 percent of the income spectrum can access institution finance (Okpala, 1994:1573). Low/middle-income groups have limited access to resources for settlement and construction and thus cannot afford to purchase the least expensive commercially built units. Also, without financial support, the supplementary construction process often proves to be very inefficient and lengthy and results in poor-quality homes and neighborhoods (Ferguson, 2000:3). Providing credit seems to be a way to provide financial support to the poor. But because the poor lack physical collateral and the size of loans do not match their ability to repay, they have no access to institutional credit. Informal periodic savings and credit associations (RSACA), relatives and friends, and co-operatives can be a source of finance or credit (Khandker, 1998:11), yet, the savings of the poor and their relatives are limited, so it's unlikely to be adequate. Since housing loans are medium to long-term credit and inflation rates in developing countries are usually higher than interest rates, they are not desirable by credit institutions (Ferguson, 2003: 188).

The development sector has become enthusiastic about microcredit recently; through well-designed micro-credit programs, financial services can reach a large scale to the poor to initiate small entrepreneurship, generate income, and thus work their way out of poverty. The advantage of microcredit over subsidy programs is their financial sustainability (Fisher and Sriram, 2002:19); recycling credits can sustain the finance, in contrast to grants (Yunus, 2007:10). Many governments and donors support micro-credit for small entrepreneurship and direct a small package of these funds to house; an estimated proportion of Grameen and Banksol's micro-credits go to housing (Ferguson, 1999:191). Micro-housing loans are relatively small and thus are suitable for progressively construction processes; designing an integrated package of micro-entrepreneurship & micro-housing credits can help the poor.

To enhance the delivery mechanism and overcome the problem of the economic pledge, several scholars identified the group-based micro-credit programs (Stiglitz, 1990:351; Varian, 1990:1; Hulme & Moseley, 2006:8). In addition to screening bad borrowers, group-based credit enhances monitoring and enforcement among its members (Varian, 1990:2; Hulme & Moseley, 2006:8; Khandker, Khan & Khalily, 1995:3). Numerous innovative group lending models have emerged, yet the Grameen approach developed by Muhammed Yunus stands as the most famous one, spread widely in Bangladesh and replicated in many other countries (Khandker *et al.* 1995:87; Seibel & Torres 1999:118,119). The World Bank has adopted it in numerous projects (Khandker *et al.* 1995; vi). The pilot project of Muhammad Yunus replaces physical collateral with social one, uses mobile banks, and designs loans with terms suitable for the poor. The Grameen bank achieves high repayment rates and high outreach in rural Bangladesh covering almost 93% of the villages in 2021. The bank won the Nobel Peace Prize in 2006 and won wide fame and praise in the literature.

This study investigates a possible direction to solve housing financing problems for the urban poor in Khartoum State. The Microfinance of the Central Bank of Sudan is one of the official micro-credit programs supported by the government since 2006. Unfortunately, these programs are devoted to agricultural and commercial sectors, and housing loans are scarce. Like all traditional microcredit programs, the micro-finance institutions require economic pledges, and loans are made at central offices in urban areas, reducing their outreach to the poor. The financial sustainability in most microfinance institutions is far from being achieved, as they have little capital and do not accept deposits and savings or adopt insurance systems as in the Grameen approach. To understand outreach and financial sustainability problems in the microfinance programs of the Central Bank of Sudan, we compared them with the Grameen Bank, then we developed a quantitative model to test the potentiality of both approaches to financing housing programs for the urban poor in Khartoum. In the end, we made some suggestions that can be useful for policymakers, researchers, and those interested in development issues in addressing poverty, housing provision, and microfinance programs.

The study organization was as follows: Section 2 reviews the current literature on micro-finance and the Grameen approach; section 3-overview the Khartoum context, housing affordability, and access to finance; Section 4- illustrates the methodology; 5-demonstrate the results; 6-The final section concludes the paper with a discussion and conclusion based on the research findings. For this study, micro-housing finance means; Microloans usually range from 250 to 5000 US $ and are repaid over 2 to 10 years at amortized market interest rates in the short term. Small housing loans allow home improvement and expansion or the construction of new units (Ferguson, 2000:3).

SUSTAINABILITY AND OUTREACH IN MICRO-CREDIT PROGRAMS

A large body of the literature on microcredit evolution addresses sustainability and outreach (Sontag-Padilla, Staplefoote, and Morganti, 2012; Khandker *et al.* 1995; Khandker, 1998; Seibel & Torres, 1999). Micro-credit evolution usually gauges against these benchmarks (Khandker, 1998;14). In general, financial sustainability refers to the ability of the institution to sustain an enterprise over the long term. Profit organization aims to achieve profitability, while non-profit organizations aim to maintain or expand services and develop resilience in the face of accidental economic shocks in the short term (Sontag-Padilla, Staplefoote, and Morganti, 2012:2). Outreach measures the extent of coverage and the quantity of the service for the target groups (Khandker, 1998:13). The microcredit industry seeks to resolve the differences between outreach to the poor and financial sustainability. The formal financial sector is concerned with sustainability, while the traditional non-governmental organizations (NGOs) are anxious about the outreach. Since the latter relies primarily on subsidies, they are rarely replicable or self-sufficient (Fisher and Sriram, 2002:20). The good micro-finance practice combines both outreach and sustainability. Achieving self-sufficiency is a prerequisite for the sustainability of credit institutions and increasing their outreach.

THE GRAMEEN JOINT LIABILITY GROUP MODEL

In many developing countries, Cooperative societies and rural banks extend credit to the poor, most of which transfers to the rich, and recovery rates remain low (Khandker, Khalily & Khan, 1995:1; Hulme & Moseley, 2006: xiii). Muhammad Yunus took up an initiative in his pioneering work in Grameen Bank in 1976 to address recovery and outreach in credit programs for the poor, providing loans to those who own less than half an acre of land in Bangladesh (Yunus, 2007). He developed a group-lending approach consisting of five members who are jointly responsible for loans and meet weekly in a center close to their residential area to collect deductions (Yunus, 2003:95). The members of each center range between (30 and 40) consisting of (6 to 8 groups) (Said, 2007:119,124), and each borrower gets up to 5,000 taka/160US$ (Hossain, 1988:118) to repay in 50 weekly installments. Weekly meetings, transparency in transactions, publication of payment statements, credit discipline, and absolute insistence on timely repayment and graduation in the loan contributed to the credit discipline of customers. The bank soon became a project of the Central Bank and supported the project by facilitating financing from the International Fund for Agricultural Development (IFAD) (Hossain, 1988:115).

Over forty countries replicated the Grameen approach, and the World Bank has taken the initiative to sponsor GB-type schemes (Khandker, Khalily, and Khan, 1995). One study observed some of GB's replicators institutions suggest that when GBs are low in operation viability, they are correspondingly low in outreach (Seibel and Torres, 1999:124). In the Philippines, when the Grameen experience was replicated by many NGOs, despite its success in achieving high repayment rates, it was far from achieving financial sustainability (Seibel and Torres, 1999:119). Their reliance on external funds from donors reduces the incentive to mobilize savings and regularize expenditures. CARDO is an example of GB (NGO) in the Philippines; it is self-sufficient and has high outreach. It adheres to the central bank standard of financial sustainability. The Bank's experience provides evidence that credit institutions must reduce administrative expenses and increase savings to achieve sustainability, thus expanding their reach to the poor (Seibel and Torres, 1999:125).

KHARTOUM CONTEXT

Sudan has a long history of armed conflict, civil war, and natural disasters (such as drought and floods), which led to high rates and migration from the countryside to cities, especially to the national capital, Khartoum. The estimated population of Sudan is 41.1 million, 7 million of whom live in the national capital, Khartoum (The Sudan RPDNRA Team, 202:1). The population growth rate and the urbanization rate are 2.39, 3.24 respectively (Donaldson, 2020:243), as Khartoum receiving about 49% of immigrants and IDPs (Atti and Alhassan, 2016:495). The inflation rate has started to rise from 57% in 2019 to 269.3% in 2020 (CBOS, 2020:4). The population below the national poverty line in Sudan (2017) is 50.6% of the population (Donaldson, 2020:243). Spending on housing decreased to less than 2% Since the mid-eighties matching with the programs for structuring the economy (Osman, 2008:2). These had consequences on the poor's access to finance.

Overview of Housing Provision in Khartoum

Recent estimations indicate a deficit of two million housing units in 2016 (Ahmad and Abdullah, 2020:117). The population of slums in Sudanese cities was about 50,000 people in 1960 and leaped to 600,000 in 1985 (Gamie, 2015:17). There was about 83 squatter housing in Khartoum in 1990, accommodating about 60% of the total housing (Gamie, 2015:18). To fill the gaps in housing provision and address slums and illegal housing, the government implemented several schemes and strategies; these include:

1. Site and service projects from the early sixties until the early twentieth century (at a rate of 6113 units annually) (Osman, 2008:4).
2. Scheme to address slums and IDP camps of approximately 273,711 units (Osman, 2008:4) (at a rate of 5,336 units annually).
3. And almost the same as the previous figure in urban re-planning and upgrading projects (Osman, 2008:4) (at a rate of 5,336 units annually).
4. Public housing schemes since 2001 by The Housing and Development Fund (at a rate of 4,600 annually), almost half of these units are provided as "economic housing" to the non-eligible (Data of the Housing and Reconstruction Fund, Khartoum State).

Estimates of the annual demand for housing refer to 60 thousand units (Hafazalla, 2006:376), which means that the site plan and services, the development and resettlement of project plans provide less than 20% of the annual need, and the public housing schemes provide less than 8% annually.

Osman (2008:4) indicates that less than two-thirds of the units in the site & services schemes remain vacant due to a lack of financing or speculation (Murillo, Osman, Mustaf, Kafeel, Elghazali, Osman & Eltahir, et al., 2009:72). The Khartoum state began gradually withdrawing from site plans and services until they stopped in 2007. The Khartoum State Housing and Reconstruction Fund was established in 2001 to construct annually 4,500 popular housing consisting of a room, a kitchen, a bathroom, and a fence built with cement or clay blocks, thus supplying about 7.7% of the annual demand. Recently, the Housing and Development Fund shifted toward economic and investment housing and reduced the number of popular housing.

Housing Affordability in Khartoum

Low-cost housing is out of reach for most Sudanese due to the high construction cost compared to the income. One previous study estimated Low-cost housing Price (in 2019) in an urban area is 3 600 000 SDG (Donaldson, 2020:243). The estimated cost of building materials and the cost of labor for the construction of a core house provided by Housing and Reconstruction Fund Khartoum State consisting of (room + kitchen + toilet + fence) (in December 2021) is equal to

(6358 USD), (Table 2). Though the salaries increased six-fold in 2020, the inflation rate increased, and the local currency depreciated, this makes the employees in the lower and middle grades live on less than two dollars a day. The highest salary since 2020 is (50,795 Sudanese pounds=116 US dollars), with an income of less than 4 US dollars per day (Table 1).

Income groups	Daily income (USD)	Housing Deduction (USD)	Salary USD)	Salary SDP)	* No. of years
D (18-13degree)	0.3	7	19	8196	76
C (12-5 degree)	1.4	14	42	17676	38
B (4-1 degree)	2.4	25	71	31227	21
A (3rd-1rst class)	3.5	37	105	46208	14

Table 1*: The salary of the employees according to the career ladder in 2020, the daily income of the individual, the housing deduction and the number of years to save the cost of a simple housing unit (Source: Ministry of Finance and National Economy, prepared by the authors).*
Note: Housing deduction equal to 35% of the salary, (1 USD=438 SDP),
**Number of years required to save the cost of a simple housing unit (equal to* 6358 USD) of the employee's salary in exchange for a 35% deduction.

According to the new salary structure, employees in the lowest rungs (17 to 13) of the career ladder live on less than $1 a day, up to the fifth have less than $2 a day, the first levels have less than $3 a day, and employees in leadership positions have less than $4 a day. The cost of the core house is out of the reach of all employees (Table 1). Employees in lower grades (D) who save 35% of their salary will take an average of 76 years to quote the construction price of a small core house.

Access to Finance

Despite the 374 branches in Khartoum in 2020 Central Bank of Sudan Report (CBOS, 2020:53), obtaining housing loans is challenging for low-income groups. The Central Bank of Sudan (CBOS) is the official body responsible for setting basic policies and legislation regulating the work of the banks. It banned real estate financing for two periods (1983-2001) (Ahmad and Abdullah, 2020:138) and (2014-2019) (CBOS). Banks set conditions that make housing loans out of reach of the low-income group, including land tenure, mortgage, approximately 18% interest on loans annually, and the mortgage value should not exceed 50% of the net income. In 2006 the Central Bank of Sudan recommended allocating 12% of the banks' portfolio to microfinance, The Central Bank of Sudan report in 2020 indicate the use of 5% of their portfolio to support microfinance programs 2020 (COSD Report, 2020:32). The legislation sets some restrictions on the microfinance institutions to accept deposits, so only four federal institutions are authorized to accept deposits (Babiker-b, 2019:11). By the end of 2019, the number of banks was 37 (Babiker-b, 2019: 14), non-bank microfinance institutions 46 institutions, and the clients reached 2.4 million (CBOS report; 2019: 34).

THE METHODOLOGY

This study investigates the applicability of the Grameen approach to micro-housing loan programs in Khartoum. The study compares the design of microfinance programs in Sudan with the Grameen model. The study developed a quantitative model to test the economic feasibility of Grameen's approach to financing housing programs for the urban poor in Khartoum based on information on Khartoum state residents in terms of income rates, basic

housing unit costs for a low-cost home (Table 2), and the volume of microfinance loans in Khartoum.

Due to the lack of recent data on the informal sector, the study relied on income data for the new salary structure of the formal sector (approved by the Ministry of Finance and National Economy in 2020), which represents only 40% of the working force. Also, the housing unit costs used the estimates of the Housing and Development Fund in Khartoum State for a basic house consisting of a kitchen, a room, and a bathroom. It also approved the size of the microfinance loans offered by Faisal Islamic Bank and the interest rates it charges (for the first scenario). The model was designed based on Grameen Bank data collected from previous studies: (Hossain,1988: Said, 2007: Khandker, Khalily & Khan, 1995: Hulme, & Mosley, 2006: Hulme, & Mosley,1996), as well as reports published on Grameen Bank's official website (Grameen website: www.grameenbank.org).

The three scenarios represented three different systems:

1. The first scenario represents a traditional microcredit model in Khartoum that does not accept deposits or savings. It provides only microcredit for micro-entrepreneurship with a loan size (200,000 Sudanese pounds = 457 dollars) repaid in two years, with annual interest rates of 21.5%.
2. The second scenario represents a model applying the Grameen approach that provides aggregate micro-credit to micro-entrepreneurship loans (120-240) USD for one year, then housing loans of (1800 USD) for five years. This value is sufficient to construct a room, a fence, or (a kitchen and a bathroom).
3. The third scenario represents a model that works according to the Grameen approach, which provides aggregate micro-credit to micro-entrepreneurship loans (120-240) dollars, and housing loans with a value of (6600 dollars) for 15 years. This value is equivalent to the cost of building a basic low-cost house consisting of a room, a kitchen, a bathroom, and a fence.
4. Based on the indicative average USD price set by the Central Bank of Sudan on 12/12/2020 (1USD=438 pounds). The study calculates for the quantitative model a hypothetical loan of one million dollars to establish a bank branch to distribute loans for small projects and housing loans. The suggested sources for this loan will be: From the Central Bank of Sudan, commercial banks, or donors, to be repaid in installments for ten years at an annual interest rate of 3%. By applying the quantitative model, we will test whether one or all of the three scenarios will allow success in paying the annual installments of the lender and achieving self-sufficiency for the credit institution and profits in the long run.

The savings and deposits are of three types:

1. Mandatory savings equal to 2.5% of the loan plus 0.5 US & repaid with the weekly installment Table 3).
2. Insurance equal to 2.5% of the loan.
3. Voluntary customers and non-customers estimated at 1% annually distributed loans.

Members can only withdraw mandatory deposits after paying all installments and after the customer decides to withdraw from the bank, unlike voluntary ones. For the first scenario, the study used the value of microfinance loans in one of the banks (Tadamon Islamic Bank) and the interest rate. Operating costs (including administrative fees) are 18% of the value of the distributed loans. The USD values were used instead of the SDP to facilitate a comparison between the three models. The savings and deposits are of three types:

Definition item	Cost in SDP	Cost in USD
The cost of building materials for one room	691781	1579
The cost of building materials per kitchen	460858	1052
The cost of the fence	752157	1717
Total cost per toilet	116885	267
The total cost of the house building materials	2021682	4616
The total cost of the house building materials and labor cost	2380141	5434
The total cost of the building materials and labor (plus profits of 17%).	2784765	6358

Table 2: *The cost of building materials and the cost of labor for the construction of popular housing, an area of 300 meters, components (room + kitchen + toilet + fence). Source: Housing and Reconstruction Fund Khartoum State - Department of Estimates (Popular housing house cost estimates December 2021. Note: 1USD=438 SDP.*

		S1		S2	S3	
	Micro-credit	**Housing loans**	**Micro-credit**	**Housing loans**	**Micro-credit**	**Housing loans**
Loans size in US$	457	non	120/240	1800	120/240	6600
loan repayment period (years)	2	-	1	5	1	15
Annual interest on loans (%)	21.5	-	5	3	5	3
weekly voluntary deposits in USD	0	0	0.5	0.5	0.5	0.5
Compulsory savings as a percentage of the loan (%)	0	0	2.5	2.5	2.5	2.5
Insurance as a percentage of the loan (%)	0	0	2.5	2.5	2.5	2.5
Ratio of Voluntary Deposits to Annual Loans (%)	0	1	1	1	1	1
Annual interest rate on deposits (%)	8.6	-	3	5	5	3

Table 3: *Showing the general features of the credit program in the three proposed scenarios. Notes: The operating cost represented 18% of the loans distributed annually, and the repayment rate was 95% of the total loans distributed annually. An interest rate of 5% on micro-enterprise loans and 3% on housing loans, weekly deductions of US$0.5 from each client, mandatory savings equal to 2.5% of the loan amount, insurance equal to 2.5%, voluntary savings from clients and non-clients equal to 1% of the distributed loans. Total expenses include the distributed loans and the operating costs plus the monthly installments to repay the loan from the central bank, commercial banks, or international organizations.*

	S1		S2		S3	
	Micro-credit	**Housing loans**	**Micro-credit**	**Housing loans**	**Micro-credit**	**Housing loans**
Number of annually borrowers in the first two years	1000	0	2000	0	2000	0
Number of annually borrowers since the third year	1000	0	1500	300	1500	100
Total in 10 years	10000	0	16000	2400	16000	800

Table 4: *Number of loans distributed in the three proposed scenarios over ten years.*

RESULTS

The microfinance programs in Khartoum differ significantly from Grameen Bank in terms of outreach to the poor due to the program's design. The Grameen Bank has increased its outreach

through center networks spread in poor rural areas, compared to the limited number of microfinance institutions in the center far from the poor. Key design features in the Grameen approach missing the microfinance programs in Khartoum include; Solitary group, progressive lending, saving and insurance programs, and intensive supervision. Microfinance institutions in Khartoum adopt traditional economic guarantees such as; guarantee checks and a guarantor.

The system of deposits, savings, and insurance in the Grameen approach can achieve financial sustainability, while only four federal institutions are authorized to accept deposits (Babiker-B, 2019:11). The following paragraphs compare outreach, program design, and financial sustainability in the Grameen approach and microfinance institutions in Sudan.

Outreach

The two tables (5 & 6) compare the design of the microfinance programs in Khartoum and the Grameen Bank. Table (5) compares the size and outreach of the microfinance programs in Khartoum and Grameen Bank. Grameen Bank, October 2021, has branches 2568 and provides services in 81,678 villages, covering more than 93 percent of the total villages in Bangladesh *(*www.grameenbank.org). The number of banking and non-banking microfinance institutions is limited in Khartoum (37 banks, 46 non-banking institutions), which are often located in central areas far from the resident of the poor. The Grameen Banks' members are five times those of Khartoum's microfinance banks.

	Khartoum*		**GB*****
	non-banking institutions	**Banks**	
Date of Establishment	2007	2007	1983
basic organizational units	45	37 **	Branches 2568 covering 81,678 villages
Number of members (millions)	0.262	NA	9.4
Percentage of women in the total members	29%	29%	97%
Total funding (millions) in local currency	5,591.98	20,178.31	NA
Payment rates	95%	NA	97%

Table 5: *The size and outreach of the microfinance programs in Khartoum in 2020 compared to Grameen Bank in October 2021. Source: *(Microfinance Unit. 2020:*8,11,15,16); ** (Babiker -b, 2019:14), ***Grameen Bank website, retrieved in 3 October 2022 (*www.grameenbank.org).

Design Features

The GB uses solidarity groups, savings, and insurance in contrast to the microfinance programs in Khartoum that apply the physical pledge (Table 6). *The progressive lending, saving and insurance programs, intensive supervision, and peer pressure are the main design features in The Grameen Bank which are missed in* micro-finance programs in Khartoum.

	*MFP in Khartoum	GB*
housing Loans	no	yes
loan repayment period (years)	2	1, (3-5 house loans)
place of payment	central offices	village centers
repayment frequency	Monthly	weekly installments
Voluntary deposit	no	yes
Compulsory saving	no	yes
insurance	no	yes
Group shared responsibility	no	yes
Physical collateral	yes	no
progressive lending	no	yes
Intensive supervision	no	yes

Table 6: *A comparison between the design features of microfinance programs in Khartoum compared to credit programs in GB.*

Financial Sustainability

The modeling results in Table 7 demonstrate that the first traditional system achieved its financial sustainability after the eleventh year, while the second and third scenarios in the fifth and seventh years, respectively. The accumulated savings, deposits, and insurance funds contributed to achieving faster self-sufficiency. Modeling results also show that the accumulated savings in insurance and deposit funds (not including interest-paying loans) can create enough capital to cover expenses after ten years. Contrary to the first scenario, that represents the system of a microfinance institution that does not accept deposits and savings.

Years	revenue/expense			Deposits and savings/expenses		
	S1	*S2*	*S3*	*S1*	*S2*	*S3*
1st	0.5	0.8	0.8	0	0.2	0.2
2nd	0.9	0.7	0.9	0	0.3	0.3
3rd	0.9	0.6	0.5	0	0.2	0.2
4th	0.9	0.8	0.6	0	0.3	0.3
5th	0.9	1.1	0.8	0	0.4	0.4
6th	0.9	1.3	0.9	0	0.6	0.5
7th	0.9	1.6	1.1	0	0.7	0.6
8th	0.9	1.7	1.3	0	0.8	0.7
9th	0.9	1.8	1.4	0	0.9	0.8
10th	0.9	2.0	1.6	0	1.1	1.0
11th	1.2	2.4	2.0	0	1.4	1.2

Table 7*: Comparing the returns/expenses ratio and between deposits and savings/expenses in the three proposed scenarios.*

In the second scenario, it is possible to provide 16,000 micro-credits and 2,400 micro-housing loans when applying system two or to provide 16000 micro-credit and 800 housing loans, in ten years, for the third option (Table 4). The size of the monthly installments is not out of reach for low- and middle-income groups, and micro-housing loans can be reasonable if provided progressively. The monthly installments will be (12, 23,34 USD) respectively in, and (12,23, 55 USD) in scenario three, assuming that micro-entrepreneurship will enable borrowers to double their incomes, thus raising the borrower gradually through grades until they become eligible for housing loans, for example, borrowers in level C require two loans to be qualified for the housing loans, and those in level D require three or four loans. Housing loans are more

reasonable in the second scenario (34 USD Monthly for five years) than in the third scenario with monthly installments (53 USD Monthly for 15 years).

DISCUSSION AND CONCLUSION

Recognition of microcredit and micro-housing loans' significance in the development and housing provision is increasing. The financial policies of the Central Bank of Sudan are hesitant toward housing loans. Banks are reluctant to invest in micro-credit programs. Designing integrated programs can combine the benefits of improving income and housing conditions for the poor. The study examines a successful model to lend to the poor, which combined micro-entrepreneurship loans and housing loans, which achieved high connectivity and financial sustainability (the Grameen Approach). A comparative analysis of the design features of microfinance programs in Sudan and the Grameen Bank helps identify failures and successes and draws lessons. The traditional microfinance programs reveal failures in outreach.

The mobile bank approach of GB increases its outreach, Grameen centers, branches, and offices spread in the countryside and suburbs where the poor reside. The microfinance institutions in Sudan are confined to central areas far from the homes of the poor. Peer pressure of the solidarity group and intensive supervision is used instead of the physical collateral in GB. Saving and insurance programs enhance the financial sustainability of GB. All these features are missing in microfinance institutions in Sudan.

Progressive lending is another feature in GB that increases incentives to repay and enhance the condition of the poor. This approach seems suitable for housing loans to the poor. In Sudan, the salary structure places several households below the poverty line or close to it, and construction costs are high. Micro-credit housing loans will be out of reach for these groups. There are two solutions to this dilemma: either providing subsidies to these segments or helping them to improve their income through microcredit first.

Savings, deposits, and insurance schemes increase the financial sustainability of microcredit institutions, so providing various packages of deposit and insurance services and encouraging clients and non-clients to deposit in credit institutions will enhance its sustainability and subsequently increase its outreach.

Housing loans and their long repayment period can impede adherence to Grameen's strict rules without modification. Weekly meetings can be monthly or bi-monthly, depending on the circumstances of the groups. The high inflation rates in Sudan can undermine long- or medium-term housing loans. Most financial institutions put high-interest rates to tackle the inflation problem. One possible solution to balance inflation with the high-interest rate is to estimate loans in USD value but pay it in local currency. This type of financial transaction is not contrary to the Islamic Principles in the prohibition of riba**.**

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TECHNOLOGY R&D | SERVICES INDUSTRY

PAPERS

THE DEVELOPMENT OF AN APPROPRIATE ASSISTIVE DEVICE FOR WATER SAFETY TRAINING IN SOUTH AFRICAN SCHOOLS

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Abstract
Drowning is a prevalent problem in South Africa, particularly among young children and in poor communities. International studies indicate water safety training and awareness contribute significantly to reducing drowning incidents. Drowning prevention modules, forming part of school-based swimming training, support preventative measures. However, there is no prescribed or recommended equipment for this essential training. Currently, local swimming instructors have two options for assistive devices: expensive commercially available equipment used by swimmers (i.e., pool noodles and kickboards) or recycled products. This paper reports on an Industrial Design Master's study which established that swimming instructors and teachers are implementing an 'unorthodox' approach by using empty plastic bottles as assistive devices during water safety training sessions. As a result, the training takes longer and is less effective within the curriculum. This allowed for the identification of an opportunity to develop an appropriate assistive device for water safety training by following a human-centred design approach. The design outcome is a low-cost and scalable solution that suits implementation on a small and large scale and relies on recycled and easily available materials. The researcher interpreted the user comments from a design, materiality, and manufacturing perspective during the discovery phase, and this informed the development of a final solution. The final design solution was tested by a teacher for final evaluation of appropriateness for implementation. Failures and successes were documented as part of the prototyping leading to the final design solution and will be unpacked in the final paper. The final user input evaluated the success of the design solution, as well as assisted in the fabrication of several units for testing. Recommendations for future study included curriculum changes in South African Government schools to include school-based swimming training as well commercial concepts to explore within the private swimming training context.

Keywords: Drowning, Assistive device, Water Safety Training, Low Cost, Human-centred Design.

INTRODUCTION

Drowning is the third leading cause of accidental, preventable deaths worldwide (du Toit-Prinsloo, Morris, & Saayman, 2016). Drowning incidents can however be prevented through appropriate educational approaches. Studies indicate that water safety training and awareness contribute significantly to the reduction of drowning incidents.

Although there is no prescribed or recommended equipment for this essential training, most instructors use swimming aids/flotation devices such as pool noodles and kickboards to help learners become familiar with new techniques. The use of safe and appropriate equipment during swimming training is one of the legal and ethical duties of a swimming instructor for safety reasons (Engelhorn, sa). However, in some contexts, due to a lack of funds/equipment

available, swimming instructors and teachers are implementing 'unorthodox' approaches such as using empty plastic bottles as assistive devices during the water safety training sessions.

This paper reports on an Industrial Design Master's study that aimed to design a contextually appropriate assistive swimming device that supports low-resourced governmental school children during water safety training.

CONTEXTUALIZATION

In South Africa, fatal drowning incidents occurred at an estimated average of 1541 drownings per year between 2011 and 2015, (Isaacs, 2018). Research shows, that accidental deaths attributed to drowning happen for the most part to children younger than five, particularly in the case of young children in middle- and low-income countries (Solomon, Giganti, Weiner, & Akpinar-Elci, 2012, p. 268; Donson & Van Niekerk, 2013; du Toit-Prinsloo, Morris, & Saayman, 2016; The Princess Charlene of Monaco Foundation, 2018). Drowning incidents can however be prevented through the strengthening of public awareness and teaching water safety skills (World Health Organization, 2014). A review completed in 2014 by the WHO (Preventing drowning: an implementation guide, 2017) on swimming training curricula suggests that swimming training contributes to a decrease in near-drowning and drowning cases (World Health Organisation, 2017).

According to Gravett, De Beer & Du Plessis (2015:215), teaching aids support learners in acquiring important concepts. The general use of assistive swim devices seems to be dependent on the personal preference of the instructor or teacher (Parker, Blanksby, & Quek, 1999). Although not specified in the current school curricula prescribed by the Department of Basic Education, research suggests the importance of the use of floatation devices to assist learners with staying afloat as they familiarize themselves with the new environment. There are two main categories of assistive swim devices: 'on-the-body' and 'off-the-body'. On-the-body assistive devices such as arm floats and flippers are secured onto the learner whereas off-the-body devices such as kickboards and pool noodles are held on to by the learner. Safety is of vital importance when designing an assistive device as it should not present an additional risk to learners. However, in many low-resource countries, schools do not have access to or cannot afford purpose-designed floatation devices. As a result, teachers/instructors use empty plastic bottles as 'floatation devices' (World Health Organisation, 2017).

Water safety programmes need to be certified by appropriate bodies and taught by accredited instructors (World Health Organisation, 2017). However, there is no swimming training in the education system of South Africa for teachers. Teachers receive a CAPS document (school curriculum) with the set instructions to instruct learners. In South Africa, caregivers and parents rely primarily on the services of swimming schools or government schools to provide the necessary facilities, staff, and equipment. In under-resourced schools, teachers rely on teaching aids supplied to them, and with limited resources, challenges are experienced (Gravett, *et al*, 2015). The ‘shoestring’ approach is then taken up by teachers which require out-of-the-box thinking or creativity to develop their own teaching aids (Gravett, *et al*, 2015:24).

METHODOLOGY

This study aimed to *design a contextually appropriate assistive swimming device that supports low-resourced governmental school children during water safety training*.

To achieve this aim, the following objectives were defined:

1. Investigate, research, and analyse existing water safety training methods and precedent products.
2. Identify what assistive devices are being used, and analyse their suitability, accessibility, function, and ergonomics.
3. Identify the needs for water safety training by investigating the needs of water safety/swimming instructors.
4. Explore the ergonomic/usability needs of the learners themselves through instructors/other experts.
5. Develop appropriate equipment designs suited to the identified requirements.
6. Obtain a final evaluation on the appropriateness of the design from the main participants of the study (swimming instructors).

This section outlines the theoretical framework and methods applied to achieve the research aim and objectives.

Theoretical Framework

Attempting to understand and practically solve a real-world problem, rooted in a particular context, this study was framed within the pragmatic paradigm, guided by the theory of research through design (RTD). As this study was situated within a particular context, specifically low-resource government schools in South Africa, this study was approached through the lens of appropriate technology to evaluate and validate the suitability of the design outcome to address the study's central aim. To meet the human and contextual needs in an appropriate and suitable product outcome, a human-centred design (HCD) approach was followed which allowed the researcher to gain valuable insight and experiences from experts through their involvement in the design process (IDEO, 2018). The HCD process in product design consists of three phases Inspiration, ideation and implementation (Keating, 2017). The three phases were used to design the overall structure of this study (further unpacked below).

Triangulation reduces the risk of systematic bias and chance associations collected from a diverse variety of participants using different methods for a broadly developed understanding of the problem (Cresswell, Ebersohn, Eloff, Ferreira, Ivankova, Jansen & Plano Clark 2017:42). Therefore, this study adopted the theory of triangulation in its selection of participants and data gathering methods.

Participant Selection

In designing an assistive product specifically for children, a designer needs to keep in mind that the product is not only going to be used by the primary child user but also by caregivers (swimming instructors/teachers) and that the design should accommodate other expectations (Cresswell, *et al*, 2017:42). Even though children are the primary users ethically they cannot be included as participants, and it is also unlikely that children of such a young age would be able to articulate the necessary information. Children's participation in the study was limited to observations by the researcher. The secondary users (teachers/instructors) were purposively selected because they use the device themselves and have 1st hand experience observing children using existing devices and sharing their professional insight and experience within

swimming training (Cresswell, *et al*, 2017:198). This study aimed to design a solution for swimming training in low recourse government schools not having the funding to buy assistive devices. However, due to the Covid-19 pandemic, access to government schools was limited therefore, the participants included 3 swimming instructors, from private swim schools, and a school teacher.

Methods

Multiple methods were used throughout the study. These methods are unpacked below, according to the three HCD phases of *Inspiration*, *Ideation*, and *Implementation.*

Inspiration

To enhance the rigour and validity of this research and to ensure a well-rounded data set, this study adopted the strategy of triangulation of data, whereby data was gathered using multiple methods and sources (Munro, 2015:55). The inspiration phase included desktop research (literature review and precedent study), participant interviews, and personal experience/observations. The Inspiration phase concluded with a thorough data analysis and synthesis of the data gathered to define a detailed list of design requirements, considerations, and constraints.

Firstly, an in-depth literature review explored various aspects of the research topic providing an overview of the necessary insights and information. Secondly, the researcher conducted a precedent study to identify existing/available assistive swimming devices and to analyse their suitability, accessibility, function, and ergonomic aspects.

Thirdly, field research consisted of personal experience and observations, and semi-structured interviews with purposively selected participants. The researcher first participated in an instructor training course, via MS teams, for Learn to Swim level 1 to observe the instructors obtain a deeper understanding of the training methods used and the use of assistive devices during training (Cresswell, *et al*, 2017:90). Upon completing the theoretical training, the researcher participated in practical training sessions to better understand what was dealt with during the theoretical sessions. During the supervised practical sessions, the researcher had to execute the training methods taught during the theoretical training sessions. Further observations were conducted at 2 private swim schools, whereby the researcher observed the training session from the side of the pool. After observations, the researcher conducted one-on-one semi-structured interviews with three swim instructors from the above-mentioned schools. These interviews provided deeper insight into the needs and requirements of swim instructors and learners while providing information on the types of equipment used, and the pros and cons thereof.

The final step in the Inspiration phase involved inductive data analysis to allow findings to emerge from the raw data (Khandkar, 2009). The process began by re-reading the notes and transcripts from the data-gathering phase and highlighting keywords (Braun & Clarke, 2012). These words were then written on green, pink, light pink and yellow sticky notes for participants one to three and desktop research, respectively. Once all the data had been externalized, the researcher began the process of classification, whereby words/concepts were grouped into themes according to similarity and relevance (Braun & Clarke, 2012). The mind map was used to create a visual representation of the relationship in collected data to identify gaps for follow-up questions (Allen & Smith, 2010). Findings from follow-up questions were added to the relevant themes on the thematic map (whiteboard). Within the synthesis process,

the themes were further categorised into three groups namely, ‘needs and requirements in training’, ‘design constraints’, and ‘design considerations.

To ensure the credibility of this research, the requirements, considerations, and constraints were reviewed by a participant to verify the accuracy and relevance thereof. These design requirements assisted the researcher with the basis to start the ideation phase.

Ideation
Objective 5 was achieved in the Ideation phase. The Ideation phase explored various possible design solutions to meet the defined design requirements. Within this phase, the researcher followed a design cycle (Design, Make, Test, and Refine) adapted from the action research model paradigm of praxis (O'Brien, 1998; Zuber-Skerritt, 2005). During these cycles, the researcher engaged with Participants through interviews and prototype testing, continually garnering further insights and feedback on the three design directions, ultimately informing and guiding the final design solution.

Implementation
Finally, objective 6 was achieved during the Implementation phase. The Implementation phase of this study involved the refinement and final evaluation of the design outcome. The outcome was evaluated by participant 4. Acquiring the final input from the participant ensured the successful completion of the design to suit their needs. This final evaluation of the appropriateness of the design solution assisted in refining the design and confirming the accomplishment of the main aim of the study. Finally, all aspects were consolidated to prepare the design for final implementation.

RESULTS

Inspiration
The overarching themes identified during data analysis were:

- 'Dependence': The device should not result in over-dependence
- 'Age and Ability: The device should accommodate a range of ages and/or abilities
- 'Safety': The device should be safe to use
- 'Improvise and Adapt': be multipurpose/adaptable for the needs of the instructor/lesson
- 'Context and Cost': The device must be low-cost and suited to the context of low-resource schools.
- 'Devices and Uses': allow for a variety of uses/techniques for integration into the curriculum

These 6 themes were further synthesised and *prioritised* according to the three lenses of ‘needs and requirements in training’, ‘design constraints’ and ‘design considerations’, to formulate the design brief. During the synthesis process, the researcher identified overlaps between the 'needs and requirements in training', 'design constraints', and 'design considerations' categories. For example, catering for a range of ages/abilities is both a requirement and a constraint. IDEOs model of innovation describes how for a product to be innovative/successful, it needs to balance desirability, feasibility, and viability concerns (Brown, sa). Similarly, the design of an assistive swimming device needed to accommodate the identified 'needs and requirements in training', 'design considerations’ and ‘design constraints'. As the model of innovation indicates, the "sweet spot" in the centre represents the design(s) that meet the needs of all three of these categories. When viewing the synthesised data model, it was identified that the core theme,

overlapping all three of these lenses was the 'context and cost' theme. This suggested that designing the solution around the context and cost considerations would be essential to meet the main aim of the study. With this in mind, the design brief was therefore to *design a low-cost, multipurpose and adaptable assistive device that would be suitable for various ages and swimming abilities.*

Ideation (Design process)

The researcher chose to explore variations of the current approach of using empty plastic water bottles to keep the cost low while improving the safety and usability of the learners and instructors. Three initial design directions were identified and explored within the ideation phase:

- Concept 1: Using available components (bottles) and exploring the solution, mainly to keep the cost as low as possible.
- Concept 2: Using available components (bottles) and exploring the solution with some designed parts to be manufactured and keeping the cost as low as possible.
- Concept 3: Designing the solution with only the means of manufactured parts and exploring low production costs.

Concept one (Fig 1) consisted of two empty two-litre soda bottles and a standard low-density polyethene (LDPE) irrigation pipe connecting the two bottles. The irrigation pipe is heated to stretch and fit over the sealed bottle cap. As it cools, the pipe crimps tightly around the cap and bottleneck. The pipe allows for flexibility and a more comfortable handgrip on the bottles. The length of the pipe can be made longer and shorter depending on the age group for which the device is intended, allowing more adjustability for the instructor. This concept uses low-cost standard components and requires minimal skill to make, and crucially would minimize human error when used.

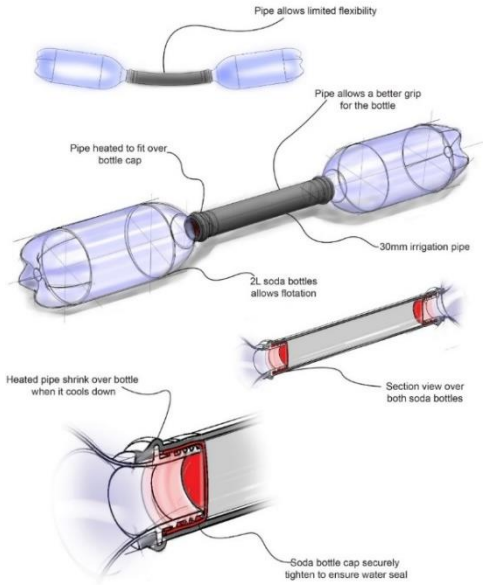

Figure 1: *Concept one (Image by author)*

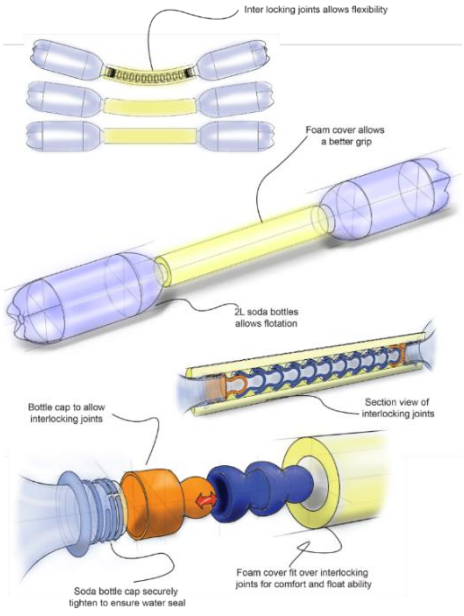

Figure 2: *Concept two (Image by author)*

Concept two (Fig 2) consisted of standard components and two types of injection moulded parts. The concept consisted of two empty two-litre soda bottles, injection moulded interlocking joints and a foam tube cover. The interlocking joints consist of identical parts clipping into each other and creating a bendable joining system for connecting the two bottles. The intention of using the interlocking joints is to add flexibility to the device and increase comfort when used. The interlocking joints create a bend and stay option when used as the resistance of the joints allows the device to stay bent as needed for example bending the device around the learner's body. The standard bottle caps would be replaced with the second injection moulded component to accommodate the interlocking joints. The interlocking joints would allow for ease of use and would make it easier to replace the bottle or use a different size bottle if needed to accommodate different buoyancy for learners. The use of these interlocking joints increases the functionality of the device and allows for more adjustability and adaptability within the swimming lesson.

Concept three (Fig 3) consisted of injection moulded Interlocking joints and end caps with two different diameter foams covering the interlocking joints. The interlocking joints consist of identical parts clipping into each other and creating a bendable joining system identical to concept two. The interlocking joints within this concept three however consist of more interlocking joints extending from end to end of the device and allow the complete length of the device to be bendable and adjustable within the bend and stay concept. The interlocking joints from end to end allow for the device to be securely extended by connecting another device alongside it and allow for a longer assistive device if needed. The end cap can easily be removed for the extension of the device. the use of these standard components would compromise the durability of the assistive device as it is not purposefully made. The use of

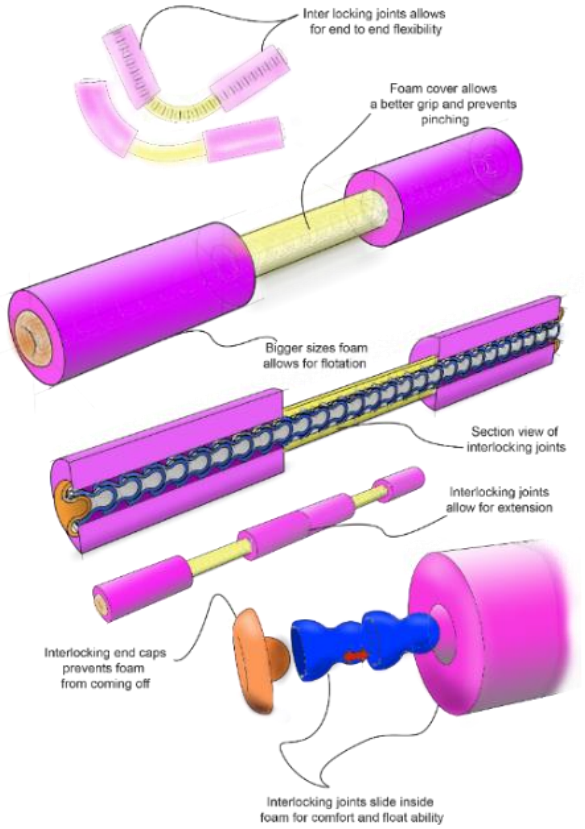

Figure 3: *Concept three (Image by author)*

more durable foams would be ideal, but unfortunately, will increase the price. This concept is the most expensive concept of the three however the end-to-end bendability increase the function of the device and can be used to improve more skills.

Following the steps detailed above, each concept was prototyped and tested. A detailed account of this design process falls outside the scope of this paper; however, this section highlights the key findings from this process. From the three concepts, it was apparent that concept one was the most viable option for low-resource government schools. From the testing phase the following aspects were suggested to include in the final design:

- Adding a handprint on the handgrip to reduce possible human error when the device is used
- Colouring the bottles to make them more attractive to users
- Possibly including more flexibility while using standard components
- possibly cover the LDPE pipe with foam for a more comfortable grip
- Handgrip length should be shoulder-width of a child, preferred length 370mm
- Visual instruction on how to make the DIY concept one (Easy to understand)
- Visual instruction on how to use the device within the government school curriculum.

Implementation

During the implementation phase, the researcher applied the feedback received in the ideation phase. Once the researcher had refined the design and developed the required instruction leaflets, the researcher obtained the final evaluation and appropriateness from participant 4, a government school teacher. The researcher provided the participant with a printout of the developed instructions and everything needed to build the design. The participant was asked to follow the instructions and assemble the assistive device, to accurately observe and evaluate the effectiveness of the instruction leaflet. Once the participant had made two devices, the instructional leaflet was used as a data-gathering tool to gather the participant's feedback and suggestions and problems encountered with the instructions from observations and the participant's experience in teaching and making the device. This allowed the researcher to enter another iterative process with the instructions to make the instructions more suitable to the end-users and more understandable. In concluding the interview with the participant, the researcher discussed the visual instruction on how to use the device within the government school curriculum and found that the school teacher was satisfied with using the device as the examples indicate. Based on the comments received, the researcher applied the feedback to the design and instructions to form the final design solution.

Design Outcome

The outcome of this study consists of multiple components working collectively to form a contextually appropriate solution. These components include:

- the design of the device itself (Fig 4),
- an instructional leaflet and video on how the device should be made (Fig 5), and
- examples of using the device within the government school curriculum (Fig 6).

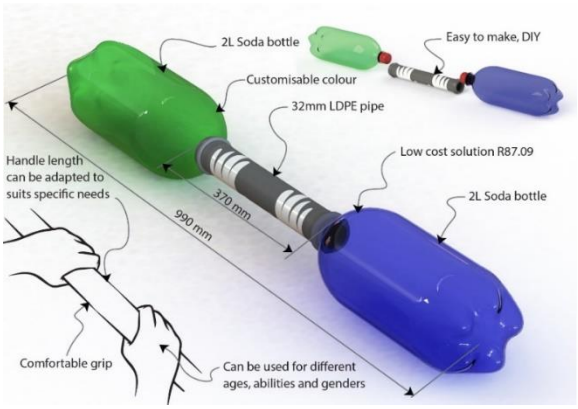

Figure 4: *Final design (Image by author)*

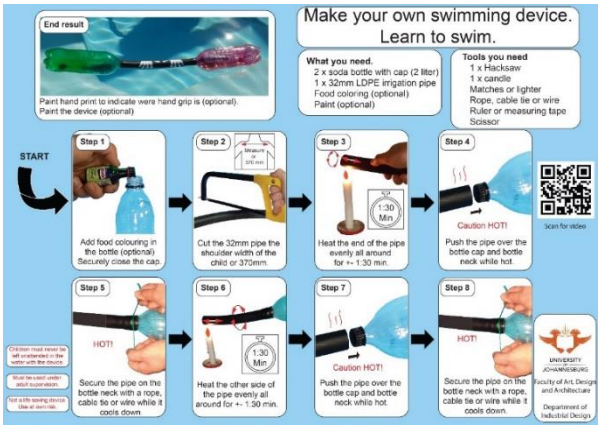

Figure 5: *Final assembly instructions (Image by author)*

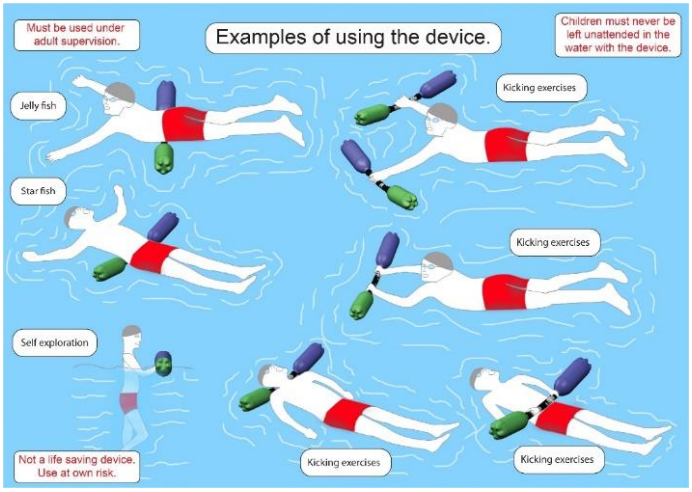

Figure 6: *Examples of using the device within the current school curriculum (Image by author).*

The final design solution makes provision for children of different ages, abilities, genders and growth patterns of children with it being able to be specifically made for a child. Cutting the pipe to the shoulder width of a child ensures that when a child holds on to the device, he/she won't experience discomfort as the shoulders would not be forced to function further than the neutral position. The final design solution allows for a child's further development; however, the device should be remade once the child's body size increases and a smaller size bottle may be used when the skill improves. The use of the two soda bottles on the sides and the handgrip in the middle assist with the balance of the body in the water and therefore assist with maintaining posture on load articulation. By having instructions on how to make the device this design solution makes provision for adaptability, customization and low cost. The video accompanying the instructions assist with any issues the instructor might have made while making the device and allows for effortless assembly. The leaflet showing the examples of using the device would encourage and support untrained instructors in using the device to achieve the intended results.

The estimated total cost of the materials to make the proposed assistive swimming device is R3,09 (the cost of the pipe). The 'optional' aspects of the design (such as the food colouring,

handprints etc.) would increase the cost of the device, however, this would still be more affordable than the cheapest devices are currently available.

FINDINGS AND DISCUSSION

At the onset of this study, the researcher's preconceived idea was that the design solution would be a manufactured outcome and that the department of education would be the target market and the design solution would be distributed to the schools. However, having followed the HCD methodology, working closely and engaging with the participants and gaining their valuable input and insights, the researcher discovered that the initial preconceived idea was ill-suited to the intended context, and if it were to be approached with a manufactured product the distribution and the replacement of those devices would not be possible, and would be no different to the cost-effective products already available on the market. The problem is not necessarily the lack of available equipment, but rather, access to such equipment in low-resource schools. Therefore, designing yet another low-cost product would not solve the identified problem. Instead, having a low-cost, open-source, DIY design solution better satisfied the immediate implementation and the low-cost factor that was within the context of government schools in South Africa. Using the DIY approach and allowing the teachers to make their own assistive devices creates an opportunity for teachers to adjust the design solution to what works better for them in their environment.

From the initial findings, context and cost are important aspects of this study. Therefore, having the design solution as instructions on how to make your own device (DIY) has the lowest cost possible and therefore the implementation of these design solutions would have a faster impact within the context of the problem. The teachers do not have to rely on supplied manufactured parts and therefore speed up the implementation process. Implementing this design solution would only entail distributing the open-source instructions as well as the examples of using the device to government schools. Although the assembly and the construction of the design solution have been tested within this study, controlled functional testing of the design solution (assistive device) should be done before use. The functional testing might lead to more design iterations. Additional assembly testing and refinement of the instructions would also be required within the context of government schools.

CONCLUSION

This study concluded with an instructional leaflet of the design solution (assistive swimming device) developed for the low resourced government school curriculum of South Africa, by including trained swimming instructors as well as a schoolteacher in the development process. The use of this developed assistive swimming device would contribute to other similar environments such as swimming foundations that do not have the necessary funds to purchase commercially manufactured products. This concluded solution could be better suited than other solutions currently used within the context of the study and probably worldwide. The final design solution can provide an improved learning experience for the learners as well as a teaching experience for the instructors or schoolteachers. This final design solution can provide instructors with much needed safer effective teaching, and possibly reduce drowning with the means of learning to swim faster and easier.

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WASTE WATER TREATMENT VIA ACTIVATED FLY ASH ADSORBENT

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Abstract
Population growth and increased water consumption have enlarged the generation of waste water, which must be processed and reused through waste management systems. With the current emphasis on the environment, researchers are becoming more aware of the need to develop new materials and technologies to achieve safe and cost-effective waste reuse. Fly ash waste from power plants is a hazardous material that should not be disposed of in landfills. The properties of ash can be altered for reuse in water waste management sector. Therefore, it is imperative to control and modify its characteristics. Fly ash mechanical modification can improve the adsorption activity for heavy metals and dyes from waste water. The research considered the chemical and mechanical modification of activated ash through the morphology transformation, glassy stability ratio adjustment, etc. For many metals and dyes, modified fly ash application in waste water treatment demonstrated maximum adsorption capacity in slightly neutral media (pH: 6.00-7.9) at low temperature (30-60 o C). According to the research findings, improving surface reactivity by removing crystalline dense layers coating the active internal surfaces of fly ash causes changes in the microstructure and reactivity of ash, which increases the reuse of this low-cost environmentally friendly resource.

Keywords: Fly Ash, Mechanical Activation, Heavy Metals, Adsorption Parameters.

INTRODUCTION

Fly ash is composed of different amounts of silica, alumina, iron oxide, lime, magnesium oxide and alkali, some unburned carbon (BG Kutchko, 2006), (O. Dogen, 2006), (M. Fan, 2001) and has a large surface area. Ash that contains more than 70% SiO_2, Al_2O_3 and Fe_2O_3 and less than 5% CaO is classified as Class F fly ash, and those which contains higher CaO and 50% of SiO_2, Al_2O_3 and Fe_2O_3 is referred to as Class C. Fly ash is a loose porous solid composite of large specific surface area, which reaches 2500- 5000cm^2/g (Zheng Bin Guo, 2007).Thus fly ash have a strong adsorption capacity with many active sites that enhance the chemical and physical adsorption process, (Tao, 2005).

Fly ash C utilized in construction fields and soil stabilization (Afaf Ghasi,2015) due to its cementitious properties, while fly ash F compositions and morphology lead to adsorbent deployments. Its particles are amorphous, porous, spongy, and 75% of its particles size lies within the range 45 -100 µm. Ash layers contain reactive amorphous glass coated by mullite, quartz crystalline phases, (Miloš Šešlija, 2016). The quartz with mullite forms thick glassy layers, chemically stable, causes low reactivity particle surface, which defends the active inner constituents, (Afaf Ghais.et.al,2020).

Reactivity of fly ash and ions exchange capacity depends on amorphous glassy content and the loss of ignition (LOI). Low reactivity fly ashes are either excessively crystalline or coarse particle. Fly ash with higher LOI contains the fraction of un burnt carbon characterized by large particles size $\leq$ to100 µm, which reduce the reactivity of ash, (Afaf Ghais.et.al,2020).

Fly ash activation methods, chemical, thermal and mechanical applied in several fields depend on the end product morphology and uses. The advantage of using mechanical activation (MA) is to improve the bulk and surface reactivity, through physicochemical changes in the bulk and surface particles, without changing the overall chemistry of the material, (P. Balaz,2008), (A.J. Juhasz,1994). Compering the mechanically activated fly ash with activated carbons which produced by chemical activation processes, the material costs and regeneration challenges is less in case of MA ash, (De Gruyter, 2021).

As waste water treatment is one of industrial application to reduce the heavy metals, dyes, etc. Mechanical activated fly ash as low temperature process can be utilized for metal removal with high efficiency. (A.J. Juhasz,1994)

WASTE WATER HEAVY METALS AN DAYES

Heavy metals (HM) are part of the unwanted matter in wastewater because of their solubility, which allows them to be ingested by living creatures; they go into the food chain and begin to accrue in the human body. Methylene blue (MB) is one of the common water-soluble dyes used for cotton, wood industry, its presence causes both toxicological and esthetical effects to the environment, even as very trace quantities. Table (1), presents the heavy metal impacts and the recommended level by World Health Organization (WHO).

Heavy Metal	Impacts	Recommended Allowed Levels by USEPA and WHO
Pb	Anaemia, brain mutilation, anorexia, malaise, lack of appetite, liver, kidney, gastrointestinal mutilation, mental retardation in infants, and nervous system disorder	15 ppb
Ni	Chronic bronchitis, reduced lung function, lung cancer, contact dermatitis, cardiovascular disease, asthma, lung fibrosis, and respiratory tract cancer	0.02 mg/L
Cr	Epigastria pain nausea, vomiting, severe diarrhoea, producing lung tumours	100 ppb
Hg	Damage to the nervous system, protoplasm poisoning, corrosive to skin, eyes, muscles, dermatitis, kidney damage, and gastrointestinal (GI)	1 mg/L
Cu	Neurotoxicity, and acute toxicity, dizziness, diarrhoea	1300 ppb
Cd	Damage to the kidneys, respiratory systems, and skeleton.	0.005 mg/L
As	Causes cancers of the urinary tract, bladder and skin, bronchitis, dermatitis, bone marrow depression, haemolysis, and hepatomegaly	10 mg/L

Heavy Metal	Impacts	Recommended Allowed Levels by USEPA and WHO
Zn	Causes short term metal-fume fever, gastrointestinal distress	3.0 mg/L
MB	Causes high blood pressure, red blood cell breakdown	200 ppm

Table 1: *Heavy Metal Impacts and Recommended Levels (Uyiosa OsagieAigbea, 2021).*

Adsorption process is promising method to reduce the HM and dyes in waste water, economically visible process, where heavy metals can be removed and minimized even at a low concentration, (Abas,2016). Moreover, adsorption process tender to produce high quality treated effluent and offers flexibility in design and operation. Adsorbents used can be regenerate by suitable desorption process because of their reversible characteristic, (F. Fu,2011).

This paper reviewed the morphology improvements of mechanical activated fly ash via surface IR, crystalline phase change and LOI. The adsorption parameters that control the removal of heavy metal and dyes in waste water through MA fly ash F were also considered.

RESEARCH METHOD

Fly ash F with low calcium content grinded mainly in high energy ball mill, as illustrated in (A. Sharma, 2015), (Gabor, 2016). Chemical structure of FA determined by Energy Dispersed X-ray analysis (EDX), (Saha, 2018), (K. T. Paul, 2007). Material structure can be known by Fourier transform infrared spectroscopy (FTIR) in transmission mode. The X-ray diffraction (XRD) method is used for mineral phase investigation. Morphology and particle shape of the material studied by optical or scanning electron microscopy (SEM) or by transmission electron microscopy (TEM), (Gabor, 2016).

Adsorbent Characteristic Modification

Mechanical Activation:

Mechanical activation (MA), includes mechanical dispersion (size reduction), surface activation and mechano-chemical activation. Fly ash reactivity improved by increasing the surface area and changes the physicochemical properties in the bulk and on the particles surface. The Mechano-chemical activation changes the internal particles into different structures.

Morphology modification enhance the chemical reactions perform on the particle surface, (Gabor, 2016). Modifications such as chemical composition, particles size and shape, with mineralogy improved were reviewed below as results of fly ash mechanical activation.

Chemical Compositions Modification:
The chemical composition modified by activated fly ash was studied through the glass stability ratio and the un- burn part of ash (LOI).

Glassy Stability Ratio:
The glassy stability ratio (GSR) characterised the crystalline tendency in glasses. It calculated from the weight percent ratio of the of glass-network-former oxides (GFO) to glass network modifier oxides (GMO) in fly ash as followed:

$$GRS = (SiO_2/\Sigma(Na_2O + K_2O + CaO + MgO + Al_2O_3)$$

The GRS of milled fly ash F in a ball mill was changed after grinding for 5.10.15 hr. Table (2) represented the change of GRS ratio, for the categorized ash FA0, FA5, FA10, FA15 respectively.

Fly Ash	FA0	FA5	FA10	FA15
GFO w%	61.9	62.2	63	66
GMO w%	30.66	30.56	30.39	29.02
GRS	2.02	2.04	2.07	2.27
LOI	2.6	2.6	2.0	1.85

Table 2: *GRS and LOI Modification of Mechanical Activated Ash.*

Loss of ignition (LOI):
LOI is used as an indicator for determining the residual carbon content in fly ash. Ash LOI and the fineness are often interdependent because the carbon particles tend to be coarser. Coarser gradation can result in a less reactive ash, (Pedersen,2008). The LOI for 5, 10,15 hr. for milled fly ash F was determined.

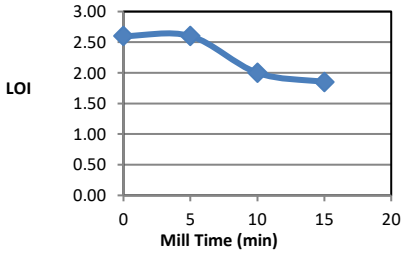

Figure 1: *GRS Changes with Milling Time Time.*

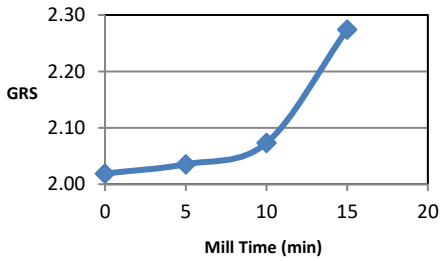

Figure 2: *LOI Changes with Milling.*

Figure 1 shows that increasing the milling time will reduce the LOI. The mechanical activation of fly ash F results in finer particles with higher reactivity. As a result, the active surfaces of adsorbent particles will be more in the adsorption process. In figure 2, the GRS, the property of glasses with a lower crystallization tendency, was increased, implying a change in the crystalline nature of the fly ash surface and evidence that the crystalline dense stable layer of ash F surface was removed.

Particles Shapes and Particles Size Modification:
Increasing the grinding time will increase the specific surface area, BET, figure (3). Also, the particle surface will be more uneven and rough, irregular in form, compared to spherical raw fly ash particles. Even shapes mean new dislocations, more disclosure of the active surface and subsequently develops of the surface reactivity (Patil, 2015)

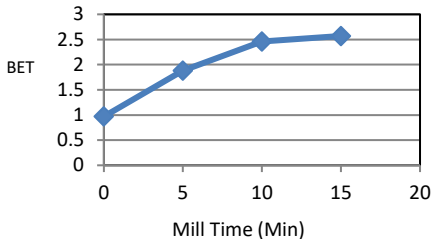

Figure 3: *BET Changes with Milling Time.*

Mineralogical Phase Modification:

Main mineralogical phases in fly ash are quartz, mullite, lime and hematite, (Mucsi, 2016). The milling energy in mechanical activation, impacts the crystal and molecular structure, and change the ash mineralogy. The peak intensity (IR) was found to be increased with increasing milling time as indication for the breaking down of the quartz structure and formation of Si–OH group. Increase in IR. Table (3) showed the IR change for MA fly ash from many previous researches.

Band	RFA (IR)	MFA	Remarks	References
OH, stretching of Si- OH	No appearance of peak	3500-3400	Formation and presence of Si–OH was evidence for the breaking down of the silica structure	(Hui Li Y. C., 2015)
OH, stretching of Si- OH	3600-3000	3600-3300	Increment in broadness after milling as evidence of the breaking down of the quartz structure and formation of Si-OH groups	(Abadi A. G., 2021)
Si–O–Si symmetric stretching	Absent peak	798 cm^{-1}	The milling showed changes in the intensity of IR peaks after 60 minutes	(Sanjay Kumar, 2011)
Si-O-Si symmetric stretching	1100	1166	Indicating structural rearrangement during 15h mechanical milling	(Abadi A. G., 2021)

Table 3: *IR Band for Milled Fly Ash.*

Modified Fly Ash in adsorption:

Studies of milled fly ash indicate that Si-OH will increase with time. Fly ash will dissolve and form the active groups of SiO^- *and* $Al_2O_3^-$ *which will react with the positive heavy metal* (HM^+)*, depending on the pH for each adsorbent metal. While for MB the adsorption occurs in an alkaline environment, (Li Z, 2018) , (Sahoo PK,* 2013)*,. The adsorbed performance of MA fly ash F was shown in the following equations:*

$SiOH + OH^-$ _____ $SiO^- + H_2O$
$AlOH + OH^-$ _____ $AlO^- + H_2O$
$SiO^- + HM+/MB^+$ _____ SiO-HM / SiO -MB
$AlO^- + HM+/MB^+$ _____ ALO-HM / AlO-MB

Adsorption Parameters:

Parameters that should considered in waste water treatment applying the milled fly ash include the physical and chemical characteristic of the adsorbent and adsorbate. Temperature, contact time, pH and the concentration of adsorbate in the water. The sorption isotherms which used

to explain to describe the mechanism on how adsorbate ions interact on the surface of the adsorbent, also differ depending on the adsorbate substance. Fly ash F, had been reported to be an effective substance for removal of heavy metals. However, it is shows lower adsorption capacity unless it is treated or activated, (V. Nikolic, 2015).

Effect of pH: Study by al-Zboon, (Kamel Al-Zboon, 2011) showed that adsorption efficiency increases from 1% to 90.66% as pH of the solution increase from 1 to 5 and slightly decrease at pH 6. Therefore, pH 5 is indicated as zero-point charge.
Effect of Adsorbent Dose: Dose of adsorbent determine the capacity uptake of heavy metals by adsorbents. Usually, increase in the dose of adsorbents will increase in the adsorbed capacity until its reach equilibrium. Wang study adsorbent loading from 0.5 g until 2.0 g, for removal of copper increase with increase of adsorbent loading.
Effect of Primary Concentration: Adsorption dosage is strongly affected by the initial concentration of heavy metals. Generally, adsorption capacity increased with the increased initial concentration of heavy metals. Initial concentration influences the overcome mass transfer resistance between solid and aqueous phases. Several studies have shown that removal efficiency of heavy metal is concentration dependent and there exist decreasing trend if further increase initial concentration.
Effect of Interaction Time: The interaction of functional group between the solution and the adsorbent surface needs contact time. Specific time needed to maintain equilibrium interaction; therefore, the adsorption process undergo completion. Cadmium removal using zeolite based geopolymer achieve equilibrium contact time at 7 hours. However, modified fly ash for lead removal gain equilibrium contact time at 120 min.
Effect of Temperature: The natures of the processes either exothermic or endothermic are depends on the adsorption equilibrium that affected by the temperature used. Adsorption capacity increases with the rises of the temperatures. This happens due to the enlargement of pores and activation of the sorbent surface. Research by Javadian shows removal of cadmium was increase with temperature range from 25ºC to 45º C, (Nurliyana Ariffin, 2017).

Milled Fly Ash Adsorbent:
Milled Fly ash has large cation exchange capacity and higher specific surface area which enhance the heavy metals removal from aqueous solutions. The maximum adsorption capacity can reach 99 % for some metals, Table (4). Also, most of adsorption investigations of MA fly ash showed that Langmuir and Freundlich isotherms were applied.

Fly Ash Modification	**Heavy Metal**	**Max. Adsorption (mg/g)**	**Operating Conditions**	**Reference**
Dried, ground and sieved	Cu(II),Pb^{+2}	22 mg/g Pb 21.5mg/g $Cu^{+}2$	pH: 6.4 CT: 20min -4 hr Temp:30-60ºC	(Allinor, 2007)
Washed, filtered, dried and ground	Cu (II)	98%	pH:4 Temperature 50^{0}C	(Nath K, 2007)
Mechanically activated	Cu(II),Mn(II), i(II),Pb(II) and Zn(II)	99% for all metals	pH: 7 Temp: 30ºC	(Haibibu Xiyili, 2017)
High energy milled fly ash	MB	95 %	CT: 50 min pH =7.9	(Hui Li M. D., 2018)

Table 4: *Operation Parameters of (HM/MB) Adsorption on Mechanical Activated Ash.*

DISCUSSION OF RESULTS

Fly ash mechanical activation; increase the active surfaces for adsorption on the amorphous particles. It enhances the reduction of unburn part of fly ash and increase the silicon/ aluminium ion exchange capacity.

Heavy metals and dyes adsorption on milled fly ash F surface undertaken at low temperatures with higher than 95 % capacity, and the pH for most metals are 4-7.9. Working at nearly neutral and low temperature enhances the application of the low cost activated fly ashes as environmental-friendly adsorption substance.

CONCULSIONS

Waste water pollution results in severe environmental problems. In this review, the modification of fly ash F by mechanical activation and the adsorption parameters of heavy metal and dyes were investigated.

Mechanical modification of fly ash F improves the ash surfaces to be set for adsorption process by increasing the silica content and surface activity. GSR reduction with milling time increase, represents amorphization form in fly ash structure and dissociation of dense crystalline phases on ash surface, lead to appearance of the active surfaces. Also, the increasing of BET, can improve the availability of un occupied adsorbent surface for better separation. Milling process will let the unburnt coarse particles crushed down and reduce the loss of ignition. Broadness of Si-O stretching band in milled ash, renovated the reactivity of silicon- aluminium negative charges to adsorb the positive heavy metals and dyes, which gave higher adsorption capacity on milled fly ash surfaces.

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WATER AND SANITATION

PAPERS

FLUORIDE REMOVAL FROM GROUNDWATER IN THE EAST NILE AREA (SUDAN) USING LOCALLY AVAILABLE CHARCOAL

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Abstract

The East Nile area is located in Khartoum state. The main source for drinking water in the area is groundwater. However, fluoride concentration in the water is more than the maximum allowable dose which is 1.5 mg/l. This study aims to demonstrate and innovative, affordable and efficient filter to remove fluoride from drinking water. Many researchers have found that aluminum oxide coated adsorbent is the most affordable technology for fluoride removal. However, adsorption is pH dependent and the water pH in the East Nile area is relatively high (around 8) which is hindering the adsorption process. Locally available charcoal was crushed, sieved, and coated with aluminum oxide. Then, different coating configurations were tested in order to produce an adsorbent with a high pH point of zero charge pH_{PZC} in order to overcome the effect of high pH of water. Moreover, Different methods were used to characterize the adsorbent including: Scanning Electron Microscope (SEM), Energy Dispersive X-Ray Spectroscopy (EDX), and pH point of zero charge pH_{PZC}. The produced adsorbent has pH_{PZC} of 8.5 which is very essential in enhancing the fluoride adsorption process. A pilot household fluoride filter was also designed and installed in a house that has water with 4.34 mg/l F^- and pH of 8.4. The filter was operated at a flow rate 250 cm^3/min. The total cost of treating one cubic meter was about 0.63$, while the cost for the same water before adsorbent coating modification was 2.33$/$cm^3$.

Keywords: Fluoride, Adsorption, Charcoal, Sudan.

ONLY THE ABSTRACT IS PUBLISHED IN 10TH ICAT PROCEEDINGS FOR THIS PAPER BECAUSE IT HAS BEEN SELECTED FOR PUBLICATION IN A SPECIAL ISSUE OF THE AFRICAN JOURNAL ON SCIENCE, TECHNOLOGY, INNOVATION AND DEVELOPMENT (AJSTID).

WATER QUALITY MODEL FOR BLUE NILE KHARTOUM STATE- SUDAN USING HEC-RAS APPLICATION

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Abstract
The quality of the Blue Nile River has deteriorated during the past decades due to inappropriate sewage systems, so the aim of this research was to make a one-dimensional model to model the river water quality in terms of CBOD and DO concentrations. The river was divided into three measuring stations for river water quality (manshiya, kobar and mk nimir) the results of the model were compared to those calculated in kobar bridge, as it is the only available data. The results showed the poor quality of the waters of the Blue Nile River in terms of high CBOD concentrations (19.89633 mg/l), according to the international water quality guidelines for ecosystems (IWQGES) estimates, especially in the days following the rainy season. These results were consistent with the previous studies, and thus Hec-ras can be considered as a tool Effective for modeling river water quality.

Keywords: Hec-ras, CBOD, DO, IWQGES, Water Quality.

INTRODUCTION

Background

Water is necessary for all living things and to meet human needs for drinking, food, agriculture and bathing, so the quality of this water must be suitable for human use and not harmful to health. However, during the past decades, the water quality in all water bodies around the world has deteriorated due to increasing population growth, industrial development and many other reasons (Gupt *et al.*, 2009). Surprisingly, although rivers are a major source of water supply, they are commonly used as the main way to dispose of sewage (Bartram and Ballance, 1996). Therefore, appropriate strategies for water quality management must be developed and evaluated, especially in developing countries that lack adequate funds for management costs and adequate monitoring to assess water quality.

Water quality modeling contributes to simulating the transport of pollutants in surface waters and creating different scenarios that create solutions to reduce the concentration of these pollutants and thus reduce the cost of labor and materials needed in the laboratory for water quality analysis (Wang *et al.*, 2013). During the past decades, many water quality models such as SIMCAT, Qual series, HEC -RAS, MIKE-11 and WASP have been developed (Wool, Ambrose and Martin, 2013)(Kannel *et al.*, 2011). Although river systems are very complex and require extensive and accurate data to complete the simulation, the development of computers has contributed to the development of many models related to river water quality (Ismail and Robescu, 2017)(Velísková *et al.*, 2014).

Problem Statement

In Sudan, the water quality of the Blue Nile has deteriorated due to old and inadequate sewage systems in the residential areas adjacent to the river, and this is not consistent with the use of this water for drinking (Magdi et al., 2016). A study was conducted in this regard aimed at evaluating the impact of some concentrations of pollutants in the Nile River and its tributaries,

the White and Blue Nile, and their impact on the use of this water for drinking, according to (IWQGES) (Magdi et al., 2016). The study concluded that the levels of biological oxygen demand were higher than the acceptable limit in the Blue Nile River in all sampling stations (Al-Manshiya, Kobar, and Al-Muk Nimr) located in the same area of the current study. This conflicts with the use of this water for drinking and its withdrawal for treatment at the Bahri drinking water plant.

Objectives

The current study in this paper aims to make a one-dimensional hydrodynamic model to assess the water quality in the Blue Nile River in the area between the Mansheya and Mak Nimr bridges with respect to CBOD and DO levels and to know the effect of the point source located in the Kafori area in Bahri city on the quality of the water withdrawn from the Bahri drinking water plant.

MATERIALS AND METHODS

***Study* area**

The Blue Nile flows from Lake Tana in Ethiopia, where the Nile supplies about 80% of the water during the high flow season, and the rest is supplied by the White Nile and its other tributaries. The Blue Nile provides a major source of fresh water for its downstream users, Sudan and Egypt. In Ethiopia, there is not much measuring data for rain for the Blue Nile. Therefore, in the absence of sufficient hydrological and meteorological data from the upper stream, the hydrological assessment of the Blue Nile becomes more dependent on downstream measurements. Therefore, most studies of the Blue Nile usually start near the Sudanese-Ethiopian border and progress towards Khartoum (Mishra *et al.*, 2003). In this study, there are two stations to measure the heights of water inside the Blue Nile in the state of Khartoum, starting from Al-Manshiya Bridge (upstream) and ending at Al-Mak Nimr Bridge (downstream).

Figure 1: *Blue Nile River from Manshiya Bridge to Mk Nimr Bridge.*

Model* implementation *and input

The river scheme chosen for this study extends for a distance of 7.4 km from Al-Manshiya Bridge (upstream) to Al-Mak Nimr Bridge (downstream), and the total number of cross-

sections is 49 distributed along the Blue Nile River in the study area with a distance ranging from 100 to 300 meters (Figure. 2).

The model requires hydraulic data, information about the geometry of the rivers, and water quality data to develop a water quality model. The water quality file consists of three components: temperature, Nutrient parameters (algae, DO, CBOD, dissolved PO42-, dissolved organic phosphorus, dissolved NH4-NO3, dissolved NO2, dissolved NO3, and dissolved organic nitrogen), and meteorological dataset (air temperature, atmospheric pressure, humidity, wind speed, solar radiation, and cloudiness). In this paper, DO and CBOD were included in the model, and other parameters were assumed to be negligible. This is because the discharges of domestic wastewater have been identified as the major source of pollution in the river. Moreover, DO is very essential for all higher aquatic life, and low values of DO in rivers can unbalanced ecosystems with fish mortality, odors, and other aesthetic problems (Cox, 2003).

The water quality data used in this study was provided from a previous study due to the lack of water quality data for the river by the state and the competent authorities (Magdy *et al.*, 2016). Geometric and hydrological data were obtained, such as the natural elevations of the land in the river, which is a contour map, which represents the coordinates of the land elevation of the river. The water level in the river was obtained during the past years from the Ministry of Irrigation and Resources in Sudan, the model was run by considering the water heights as the boundary conditions for upstream and downstream, and after operation it was found that the Manning modulus is equal to 0.026 in the main channel and 0.027 on both sides of the main channel.

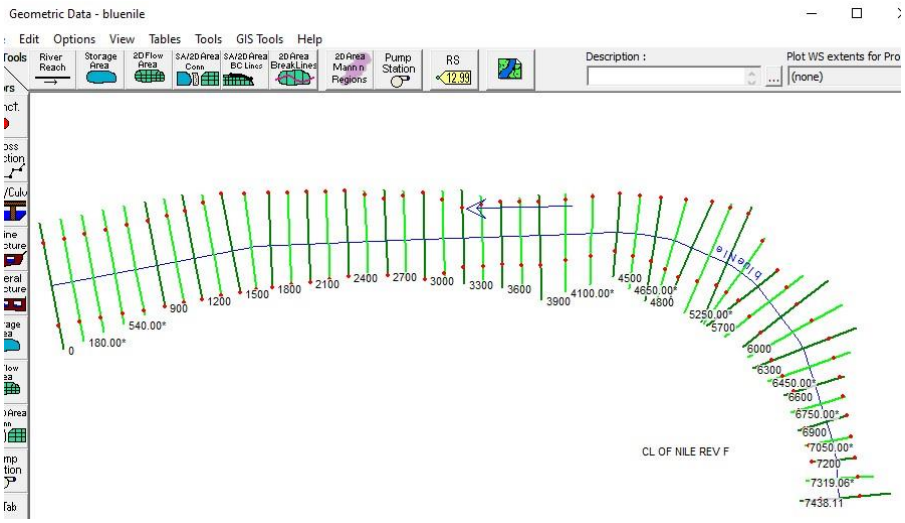

Figure 2: *The cross-sections into hec-ras app.*

Assumptions

The model project was chosen as one-dimensional due to the fact that the width of the Nile is very small in concerning the length of the river in the study area, and also because the two- and three-dimensional models require more complex data, which increases the uncertainty and reliability of the model's results. Bridges data was not entered as it did not effect.

It was assumed that the discharge in the point pollution source is equal to 0.13 cubic meters per second in the river station No.3000 to operate the model. The value of the dispersion coefficient in the water quality model was assumed to be equal to the value of the dispersion

coefficient of the Mississippi River (237.2 square meters per second), due to the similarity of the two rivers in the properties.

Model* calibration *for water quality

The one-dimensional model was calibrated using data collected from previous studies at Terminal 2400 located in kobar Bridge. Different data sets were tested during the period from August 29, 2015 to December 26, 2015 and the R^2 value was 0.88 for CBOD and 0.92 for DO. Unfortunately, we could not verify the values over another period due to a lack of data on water quality in the country.

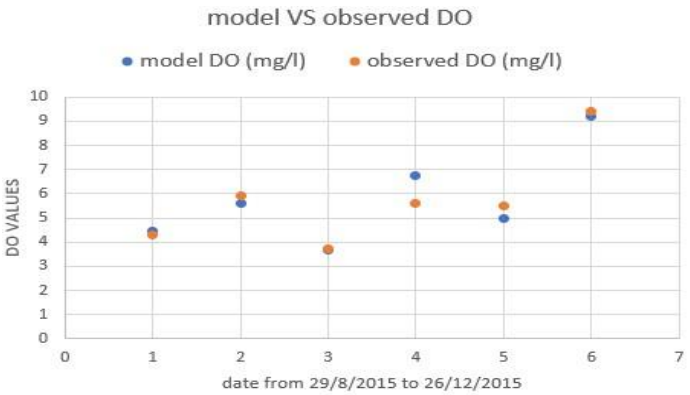

Figure 3: *The calibration process for DO at kobar bridge (R.S NO.2400).*

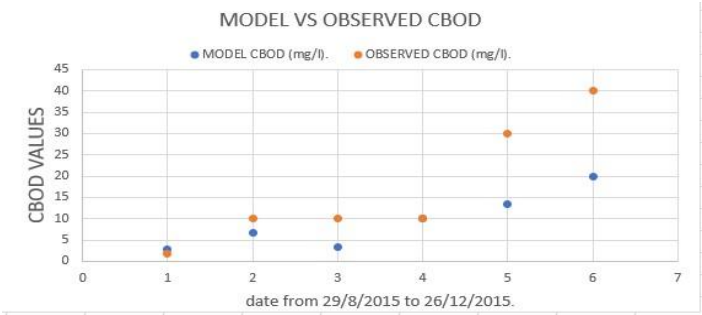

Figure 4: *The calibration process for CBOD at kobar bridge (R.S NO.2400).*

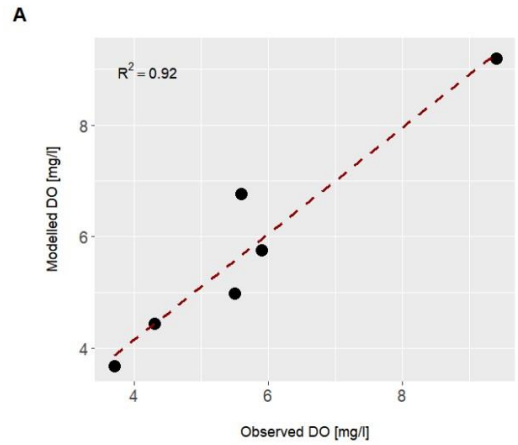

Figure 5: *Root square value for DO.*

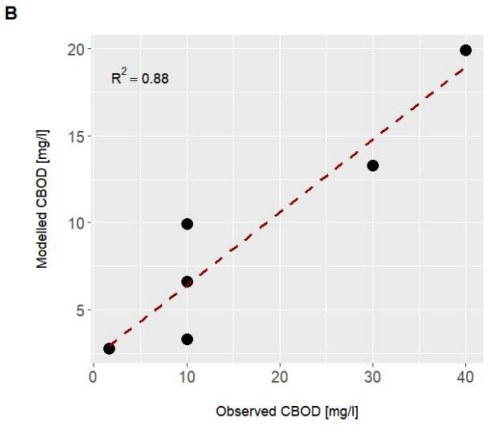

Figure 6: *Root square value for CBOD.*

RESULTS AND DISCUSSIONS

The results were very similar to those in previous studies of DO as shown in **Table 1**, and although they were not largely identical for CBOD, they confirm the same finding in previous studies, that CBOD values were greater than 10 mg/l on some days as they reached the highest value on 26/12/2015 (19.89633 mg/l), indicating that they Not acceptable according to (IWQGES), this is an indication that improper sewage systems of residential areas adjacent to the river, such as the Kafori area in Bahri, are leading to increased levels of CBOD in the Blue Nile especially in the dry season, which is detrimental to the quality of the river's water. The color change from yellow to dark red in Figure 7 shows an increase in CBOD values at the end of the rainy season and the beginning of the dry season.

Date (Day)	Observed DO (mg/l)	Modelled DO (mg/l)
29/8/15	4.3	4.433
12/9/15	5.9	5.75
26/9/15	3.7	3.67
31/10/15	5.6	6.759
28/11/15	5.5	4.97
26/12/15	9.4	9.18

***Table 1**: Calibration for DO Data.*

***Figure 7:** Hec-ras schematic plot for CBOD values between the cross-sections in 31/10/2015.*

Figure 8 shows the calculated values of CBOD levels under the Hec-ras program in the area where the water is withdrawn by the bahri drinking water plant, and we find that these values were above the acceptable limit in the last three days of the available water quality data.

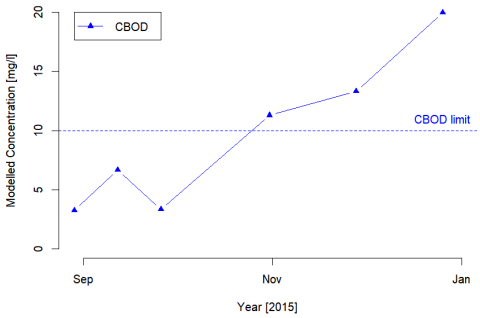

***Figure 8**:CBOD levels in (mg/l).*

CONCLUSIONS

The levels of CBOD concentration increased at the end of the rainy season and continued to rise to higher than 10 mg/l until day 26/12/2015 the last day in the available data for water quality, which makes us curious to know how far these values, which indicate the poor quality of the river water in the dry season, making it undrinkable and thus Hec-ras can be considered as an effective tool for modeling the water quality of rivers.

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MODIFIED CERAMIC POT FOR WATER PURIFICATION METHODS IN RURAL AREAS IN SUDAN

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Abstract

*Access to safe, clean, and sustainable resources for drinking water plays a vital role in public health in margina*lized *environments. There are numerous conventional water-treatments available in rural areas in developing countries. In this paper, we report of the critical and mechanistic evaluation of the performance of ceramic pottery filters (Zeer), which has been used as traditional water purification, cooling and storage technology for a long time. The filter is prepared according to the design guidelines specified by Potters for Peace design. Three disks of ceramic pot filter were prepared, characterized and applied to reduce copper, zinc, nitrite, and nitrate ions from aqueous solution. Moreover, silver nanoparticles manufactured by green methods were impregnated into the ceramic pot filter and tested for their ability to remove bacteria and fungi. Results obtained showed that the ions removal efficiency increased with higher concentration and reached equilibrium after fifteen minutes. Copper ions recorded a high removal rate of 42%, while nitrate ions' removal rate reached 21%. Using X-ray diffraction analysis of the ceramic pot, samples were shown to contain two main crystal systems: 70 % orthorhombic or Holtite and 30% monoclinic belong to kaolin. Other minor components were also detected such as quartz, iron oxide, and some impurities. Studies also demonstrated that the silver nanoparticle highest peak was positioned between 430nm and 440nm, showing that the formation of silver nanoparticles could be confirmed by UV spectrophotometry. The present study provides a comprehensive evaluation of the ability of modified ceramic pots to be employed as an appropriate technology for water treatment systems.*

Keywords Ceramic Pot, Water Treatment, Silver Nanoparticle.

INTRODUCTION

The majority of rural water sources (surface water) are polluted with dissolved minerals and pathogenic organisms that are extremely infectious and disease-causing. Microorganism particles or the presence of heavy metals in water due to leaching or other processes are always the most fatal diseases touched through water (Ajayi and Lamidi, 2015). Relatively small-scale water treatment techniques, boiling, chlorination, solar water disinfection, natural coagulation and bio-sand filtration are being used to remove water-related disease-causing microorganisms. Protozoa can be completely removed using a bio-sand filter. Some of these techniques degrade water quality, and the by-products harm consumer health (Reddy et al, 2022). Even though municipal water in developed nations meets World Health Organization (WHO) safe drinking water standards, water filters are nevertheless widely used to improve taste or remove any unwanted contaminants. Numerous types of filters have been developed to be more suitable for third-world countries, but the cost remains unacceptably high, and many goods are imported, adding to the cost (Hasballah, 2018).

In underdeveloped nations, studies have demonstrated that household water treatment and safe storage interventions enhance water quality and lower the incidence of diarrheal illness. Chlorination, sun disinfection, ceramic filtration, slow sand filtration, and flocculation/disinfection are five of these proven alternatives that are commonly used in developing nations (Sobsey et al., 2008; Tiwari et al., 2009). The decision of which solutions are best for a community is frequently complex, as it is influenced by existing water and sanitation conditions, cultural acceptance, implementation feasibility, technology availability, and other local factors. This series of technical bulletins are intended to assist companies in evaluating and choosing the best solutions (Cornelius, 2010). Ceramic water filters (CWFs) are a point-of-use water treatment option that may be found in over 20 countries (Schweitzer et al, 2013; Abebe et al., 2015). Locally obtained materials such as clay (kaolin, Holtite, Nile silt) and sawdust are used to make 3, 7–10 CWFs. CWFs have been shown to remove over 99% of particles with an average diameter greater than 1 mm, and consequently diseases that are larger than that. Antimicrobial compounds such as silver nanoparticles (nAg) were injected into CWFs, which resulted in a 5-log reduction in bacteria (99.999%) (Sullivan, 2017). Although CWFs have been thoroughly investigated for pathogen removal in older research, little is known regarding their capacity to remove organic and inorganic contaminants. Furthermore, there is a dearth of systematic evaluation of the utilization of silver nanoparticles with various surface functionalization's in the context of CWF.

The surface of nanoparticles can be functionalized with various agents, allowing the size and surface charge of the nanoparticles to be determined. The surface functionalization agent's chemical characteristics can have an impact on the CWFs' contaminant removal ability, along with the sorption of organic and inorganic pollutants, as well as the filter's bacterial removal effectiveness. Surface functionalization has an impact on the interaction of nanoparticles with other molecules and media, as well as their surface charge and particle size. The amount of silver released from nanoparticles, contaminant sorption, and nanoparticle stability has all been demonstrated to be affected by these factors. Surface modification of nanoparticles has the potential to alter their antibacterial capabilities. Due to characteristics such as surface charge, silver ion release, agglomeration, and particle size, previous investigations have demonstrated that nAgs surface functionalization agents can improve the microbiological removal performance of the CWFs. However, the elimination of organic and inorganic contaminants from CWFs treated with various nAgs is not included in these investigations (Sullivan et al., 2017). Ceramic filters loaded with silver nanoparticles and manufactured in a developing-world community utilizing local materials and labour are socially acceptable and can dramatically enhance home water quality. The present combustible materials and the use of silver nanoparticles, affect the transport and elimination of *E. coli*, a key indicator pathogen; the use of silver nanoparticles improves the effectiveness of ceramic water filters and backs up previous findings for ceramic filters built from various source materials (Craver et al, 2008). Increasing the amount of combustible materials enhances performance, if the filter's structural integrity is maintained. All of these findings speak to the fact that this point-of-use technology is effective and can effectively improve water quality in the developing world (Kallman et al, 2011).

To fill in these gaps, researchers created disks out of Red Art clay and soaked them with silver nanoparticles with various surface functionalizations. Because Red Art is widely available and used by potters all over the world, it can be used as a control material to compare the effects of clays sourced from various geographical locations. Finally, because Red Art is a commercial product, its properties are more consistent than clays sourced locally. Using synthetic water,

the disks with and without nAg additions was tested for their ability to remove heavy metals and organic contaminants (Sullivan et al, 2017).
Herein, we provide the critical and mechanistic evaluation of the performance of ceramic pot filters prepared according to the design guidelines specified by Potters for Peace design as described by (Lantagne, 2001). Three disks of ceramic pot filter were prepared, characterized and applied to reduce copper, zinc, nitrite, and nitrate ions from aqueous solution, In addition, silver nanoparticles manufactured by green methods were impregnated into the ceramic pot filter and tested for their ability to remove microorganisms.

MATERIALS AND METHODS

Materials

For ceramic pottery, kaolin is the main components and it was obtained from north Khartoum. It was sieved to 200-mesh. Sawdust obtained from the local market was sieved to 20 to 40 mesh. Nile silt clay, obtained from Nile bank, was added to enhance ceramic pot strength. Particle size distribution (PSD) is as follows:

Disk **S1**: 70% kaolin, 20% Nile silt clay and 10% sawdust; Disk **S2**: 80% kaolin, 10% Nile silt clay and 10% sawdust; Disk **S3** was 90% kaolin 5% Nile silt clay and 5% sawdust**. Figure 1** shows PSD of ceramic pot slits. The samples loaded on Ceramic potter's samples were characterized via X-ray diffraction (XRD), which is used to indicate crystallinity of the material, crystal system, purity, and empirical formula, as well as the mineralogical compositions of the samples. All samples were ground into fine homogenous powder and exposed to XRD instruments generated by (D8 advanced powder diffractometer) with Cu Kα radiation. The diffraction was collected at 0-90° with a step size of 0.028°, while CaF_2 was used as internal standard, the technique done by using a Panan Analytical X'Pert³ MRD (Netherlands) as outlined by Shen et al (2011).

Figure 1: *ceramic pottery disk used for lab test,* ***S1****,* ***S2*** *and* ***S3.***

A green method was used to prepare silver nanoparticle as Haider(yr?), and his co-works prepared as follow; A *Mentha Piperita* leaf extract was used to prepare silver nanoparticles. Fresh leaves were collected from the local market. First washed with tap water to remove contaminated and other obstacles, followed by distilled water washes several times, and then dried at room temperature for five days. Leaves were ground to a fine powder; about 20g of powder were added to 200ml distilled water and boiled for 30 min. The extract is filtered and washed by ethanol, and stored at 4°C. The extract of the leaf (5ml) was mixed with 45ml of 5mM silver nitrate ($AgNO_3$). The mixture was stirred until the color changed and nanoparticles had been formed. The filtrate is washed by distilled water followed by centrifugation. (Haider, et al, 2015). The synthesized nanoparticles were characterized by ultraviolet-visible (UV-vis) spectroscopy. The formation and growth of AgNP's were monitored as a function of time on a Shimadzu spectrophotometer (Model UV-1800, Kyoto, Japan) operating at a resolution of 1 nm from 200 to 800 nm.

Representative Gram-positive and negative microorganisms (*Bacillus subtilis* NCTC 8236 (Gram +ve bacteria), *Staphylococcus aureus* ATCC 25923(Gram +ve Bacteria), *Escherichia coli* ATCC 25922(Gram -ve bacteria), *Pseudomonas aeruginosa* ATCC 27853 (Gram -ve bacteria), and *Candida albicans* ATCC7596. Under National Collection of Type Culture (NCTC), Colindale, England and American Type Culture Collection (ATCC) Rockville, Maryland, USA were used to evaluate the antibacterial and antifungal activity of silver nanoparticles.

Ceramic pot disks S1, S2, and S3, have tested their ability to reduce the following ions; Zinc, copper, Nitrite, Nitrate. Those ions had been prepared by $ZiCl_2$, $CuCl_2$, $NaNO_2$, and $NaNO_3$ respectively under room temperature, constant pH and five hours the filtrate was analyzed by spectrometer Photometer 7100 UK.

Reducing ions concentration experiment

Adsorption experiments were conducted to evaluate the efficiency of the ceramic pottery to reduce copper, zinc, nitrate, and nitrite ions from an aqueous solution. Certain concentrations (100ppm) of those ions at specific contact times (5, 10. 15, 20 and 25 hours) and constant pH were subjected to different amounts of adsorbant disks, based on the design of the relevant experiment. Ions adsorption efficiency on ceramic pot disks were obtained by the following formula:

$$\text{Adsorption efficiency} = \frac{C_0 - C_e}{C_0}$$

Where C_0 is the initial ions concentration in the aqueous solution; C_e is the concentration of ions in the aqueous solution at different min 5, 10, 15, 20 and 25 hours (Hejri et al, 2019).

RESULTS AND DISCUSSIONS

Characterization of ceramic pot

X-ray diffraction results of ceramic pottery, shown in Fig 2, demonstrated that ceramic pot samples contained two main crystal systems; 70 % orthorhombic, with main components being Holtite and 30% monoclinic, mostly kaolin; other minor components detected included quartz, iron oxide, and some impurities. The sample showed a characteristic peak at 2 theta scale 21, 25, 50, and 60◦. Crystalline results were matched with the Joint Committee of Powder Diffraction Standards 2003. Calcite wasn`t detected in the sample because it decomposes at 600–850°C, while, calcium silicate appeared in the range 850–900°C.

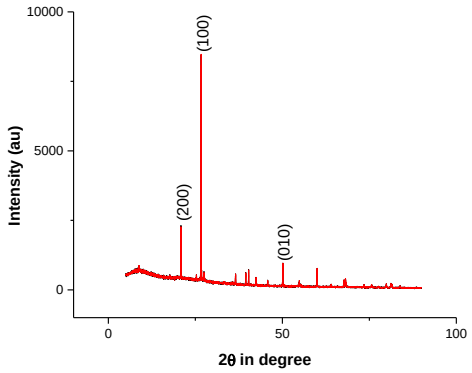

Figure 2: *XRD patterns of ceramic pottery.*

From the literature, the mineralogy of the samples have been shown to be mainly non-calcareous; this has been investigated by EDS instrumental analysis. Seetha and Velraj (2016) analysed an ancient pot in India using XRD; their results corresponded to the aforementioned ceramic pot. Black pottery in ancient Baekje Seoul, South Korea has revealed mineral composition, including a brown soil color which is in the core, and illite and kaolin (Moon et al, 2021).

Characterization of silver nanoparticles

The reduction of silver ions to silver nanoparticles by using *Mentha Piperita* leaf was analyzed using an ultraviolet (UV) Spectrophotometer. Scanning was performed from 200 to 800 nm, with wavelength speed 4200 nm/min with accuracy ±1nm. Fig. 3 shows the UV spectra of silver Nano-particle which were prepared by described green methods. The highest peak position between 430 and 440 nm indicated the formation of silver nanoparticles. The early formation of nanoparticles started at 410 nm with a broad peak which indicates that the particles are poly-dispersed (Bhagat et al., 2015).

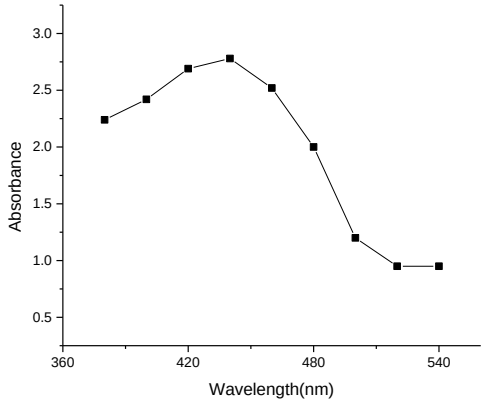

Figure 3: *UV–vis absorbance spectra of the Ag NPs.*

Microbiological Analysis

Bactericidal effects of synthesized AgNPs against aforementioned tested microorganisms, which determined employing the surface viable counting technique. The zone of inhibition interpretation ZOI around each disc was measured and is listed in Table 1 below. The antibacterial results indicate that each sample exhibited biocidal performance against both Germs. Silver nanoparticles showed high antibacterial activity the range of ZOIs were measured; from 9 to 12 mm. It can be observed that silver nanoparticle has high activity to *Pseudomonas aeruginosa and* minimum activity against *Staphylococcus aureus* 12-12 and 9-10 mm respectively;

sample name	Content	E.c	Ps.a	S.a	B.s	C.a
AgNPs	100mg/ml	10-12	12-12	9-10	09-11	12-11

B.s *Bacillus subtilis,* **Sa** *Staphylococcus aureus,* **Ca** *Candida albicans*
Ec *Escherichia coli, and* **Psa** *Pseudomonas aeruginosa*
Table 1: *Ag-NPs ZOI results.*

The results were expressed in terms of the diameter of the inhibition zone: < 9 mm; inactive; 9-12 mm; partially active; 13-18 mm; active; >18 mm; very active. The potential antibacterial mechanism of AgNPs against bacteria in the present study can be attributed to the interplay between the nanoparticle and that of the bacterial cell wall. This may work under the effect of electrostatic interactions, hydrophobic effects and van der Waals forces. This may lead to the

adsorption of AgNPs on the cell membrane and the production of silver ions (Ag^+). The released Ag^+ might have damaged the cell membrane by protein coagulation, cell wall pits, inactivation of the respiratory chain, membrane permeability induction and biosorption. Furthermore, adhesion of AgNPs to cell membranes probably produces the reactive oxygen species (ROS) that damage the bacterial cell membrane (Zhang et al., 2016; Kanwal et al. 2019).

Removal experiment methods

Ceramic pottery samples **S1**, **S2**, and **S3** were tested for their ability to remove Cu^{2+}, Zn^{2+}, NO_2, and NO_3^- from aqueous solutions at constant temperature and pH. The adsorption studies were conducted over different times, ranging from 5 to 25 hours. The results (Figure 4) showed clearly that ceramic pot samples have a high ability to remove some cations and anions from aqueous solutions.

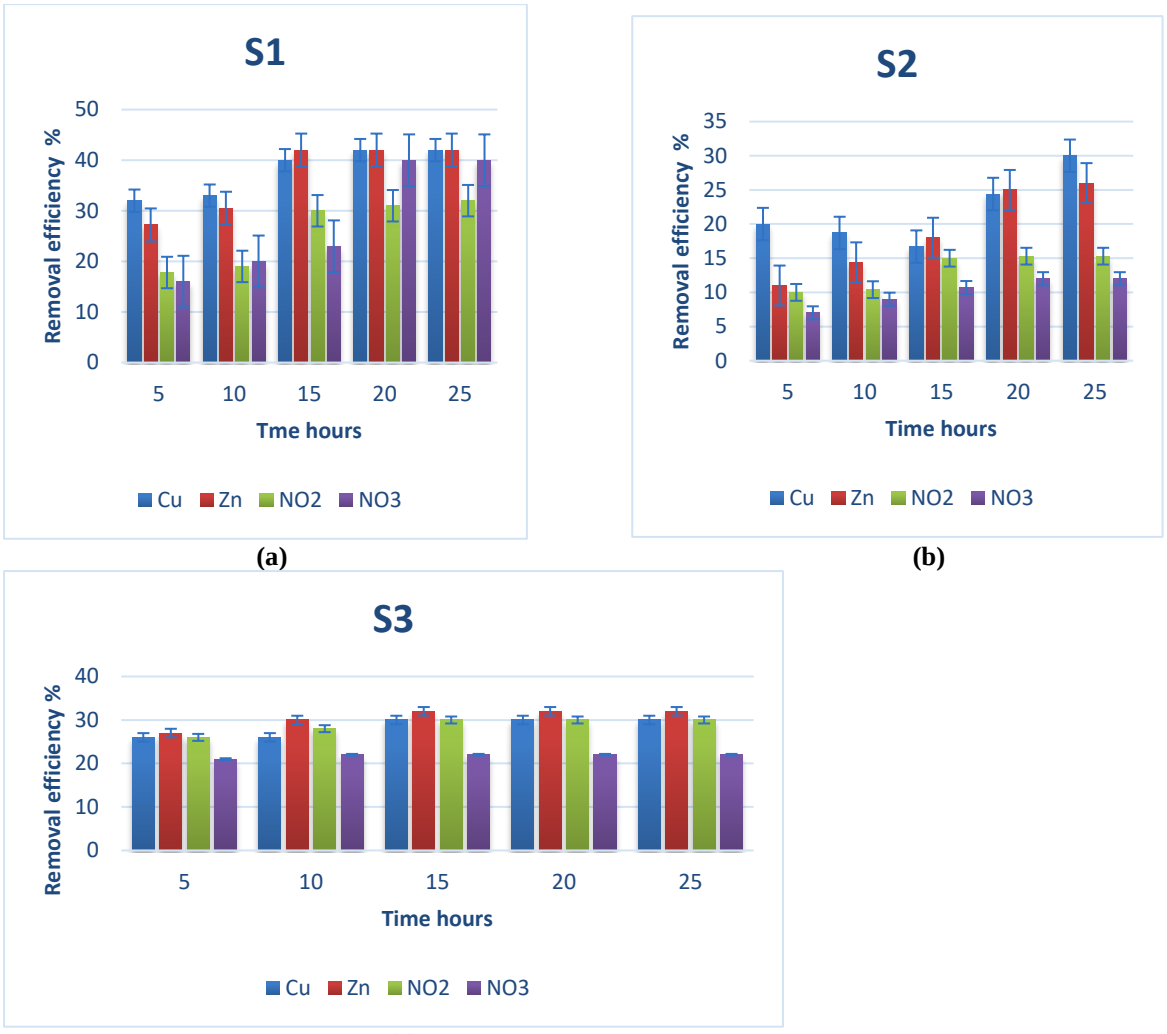

Figure 4: *Removal efficiency percentage of S1, S2 and S3.*

Sample **S1** which contains 70% kaolin, 20% Nile silt clay and 10% sawdust reported a high removal rate of up to 42%, while **S2** 80% kaolin, 10% Nile silt clay and 10 sawdust recorded low removal percentage close to 7% for nitrate ions. As it can be seen, increasing the contact time has improved copper and zinc removal from an aqueous solution. It is clear that the major part of removal by ceramic pot **S1 S2**, and **S3** occurred in the ten first minutes however, the system reached equilibrium quickly at fifteen minutes, due to increasing the collision change

of cations and anions with the active site of adsorbent (Hejri et al., 2019). In addition, the removal behaviour can be explained focusing on the increase in the driving force for transport of ions as the concentration of ions is increased to high levels (Chu, 2002). They studied the ability of pottery jugs to serve as drinking water filters to reduce heavy metals as well as physio-chemical parameters such pH, turbidity and electrical conductivity in water. Sampling and analysis were done before and after filtration, but also inside the pottery jugs, over a 24-hour period. Her results illustrate that pottery jugs which contain a suitable amount of silt and the high quality of clay increased water quality index by reducing heavy metals concentration (Hasballah, 2018). As it is described in literature, due to high adsorption capacity, removal of some heavy metals such as zinc and iron ions through aluminosilicate zeolite powder adsorbent indicated that the mechanism removal plotted by chemical bonds, therefore, removal suggesting homogenous distribution surface, the ions Zn^{2+} and Fe^{2+} bent to the adsorbent by chemical bonds (Ali and Yasin, 2020).

CONCLUSION

The research presented herein demonstrates that ceramic pottery filters manufactured with local materials can significantly improve household water quality. In addition, adhesion of silver nanoparticles, prepared by green methods, facilitated removal of microorganisms. Furthermore, Ceramic filter and ceramic disks were prepared by mixing different local Sudanese clays with kaolin and sawdust and formed by hand molding demonstrated reduction of copper, zinc, nitrite, and nitrate ions from an aqueous solution. Using a higher percentage of local Nile Silt clay improved performance, if the structural integrity of the filter could be maintained. In addition, silver-nanoparticles demonstrated their ability to remove bacteria and fungi from microbially spiked laboratory samples to high levels. This technology certainly offers the possibility of complete microbial removal as well as enhancement of water quality. All evidence suggests that the ceramic pot filter can be a valid solution that should be expanded across rural communities.

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POSTERS

ABSTRACTS

TUTI ISLAND – PROPOSALS OF SUSTAINABLE URBAN DEVELOPMENT

Andrea Dung*, *Martin Speth*, *and* *Clemens Bonnen
Hochschule Bremen, Germany

Abstract

The question of how African cities can be densified and yet still strengthen their identity and cultural heritage was the subject of the joint project work of students from the HSB and the University of Khartoum. In the design for Tuti Island, Khartoum, methodical and process-oriented procedures were used to translate the typological and topological site-specific features into concrete planning proposals that place particular emphasis on the issue of sustainability.

Keywords: Densification of the African city, Tuti Island urban planning, Tuti Island cultural heritage, densification of the African city while preserving its cultural identity.

Conference Topic: Construction and Infrastructure & **Cities and Space**.

IMPROVING INCUBATION PROGRAMS MECHANISMS FOR CREATIVE IDEA TO ENHANCE PRODUCTION PROCESS

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National Information Center, Sudan

Abstract

The paper looks into the concept and importance of creative ideas to help in solving some of the economic and social problems relating to issues of increasing production and job creation. The incubation program is considered one of the necessary methods to improve lifestyle of people by enhancing products, services, and appropriate technology which effect to reduce cost, time, and effort. The paper discusses the issues related to incubation programs represented in techniques, components, benefits, and examples. Moreover, the paper shares some success stories from Sudan reflecting the effect of incubation programs to support transferring creative ideas to actual products and services in the business market. In addition to that, the paper gives summary of the benefits and objective of incubation program for creative ideas and which appropriate mechanisms to guarantee a sustainable increase in job creation and production.

Keywords: Creative Ideas, Incubation programs, Mechanisms, Nafeer, Entrepreneurship.

Conference Topic: Education, Knowledge and Technology Transfer.

GOLD DETECTION USING REMOTE SENSING AND ARTIFICIAL NEURAL NETWORK TECHNIQUES

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Abstract

The main objective of this paper is to evaluate the potentiality of Artificial Neural Network (ANN)) for gold detection based on remotely sensed data acquired by satellite imaging systems. The research also addresses a further objective which concerns the investigating of an appropriate ANN model for gold detection. Wide range of procedures were applied to meet the objectives of this paper. The test was carried out in three phases. Phase one is concerned with the observation and collection of the test data and a set of training and test patterns were generated to build an artificial neural network model. Phase two is concerned with the designing and building of the ANN model. This phase also includes the training session. Experiment was divided into three sessions in which each session included set of models that applied, designed, tested, and trained. In phase three, the performance of the trained model was assessed. This was done by applying the trained model to a set of test patterns that were not included in the training session. The shell output results were statistically analyzed. The Back-Propagation Neural (BPN) network architecture, as tested, was found to be able to predict the gold detection of 50 test patterns with reliability and stability compared to the GRNN (Adaptive and Iterative) models. The Back-Propagation Neural (BPN) model showed better results than the GRNN where standard error was computed as 0.04 ± 0.217 and 0.122 ± 0.298 respectively. The GRNN Iterative model was found to be more accurate than the Adaptive GRNN model. The standard error was found to be 0.122 ± 0.298 and 0.125 ± 0.33 respectively. In learning of time, the Iterative GRNN model was fastest (1:18 minute). The GRNN Adaptive model was faster (1:47 minute) than the BPN model (42:55 minute).

Keywords: Artificial Neural Network, Gold Detection, Back-Propagation Neural, General Regression Neural Network.

Conference Topic: Energy and Materials.

THE USE OF RECYCLED SLAG STEEL POWDER IN FINGER PRINT PROCEDURE AFTER CHEMICAL TREATMENT

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Abstract

This work investigates airfoil self-noise produced by flow separation and reattachment at low frequency around a NACA-0012 airfoil at Reynolds number of 50,000 and 90,000, Mach number of 0.4, and several angles of attack at near stall conditions. Time histories of the lift coefficient show that the flow is fully attached at the stall angle of attack. At angles of attack higher than the stall angle of attack, the lift coefficient exhibits a low-frequency oscillations due to flow separation and reattachment. As the angle of attack is further increased, the airfoil becomes fully stalled and the flow is massively separated with occasional reattachments.

Large eddy simulation data of the flow field was analyzed using Fast Fourier Transform (FFT) to explore the spectrum of the pressure field, and investigate the most dominant frequencies and amplitudes of the generated noise. The spectra exhibit low frequency peaks at the frequency of 0.04Hz representing flow separation and reattachment. Spectral analysis showed that the noise source due to flow separation and reattachment at low frequency is of a dipole nature. The maximum noise level is observed at the angle of attack at which the low frequency flow oscillation has maximum amplitude of oscillations for each Reynolds number.

Keywords: Slag Steel Powder, X-Ray Diffractometer, Scherer's Equation, Crystal Structure, Fingerprinting.

Conference Topic: Energy and Materials.

NUMERICAL INVESTIGATION OF AIRFOIL DIPOLE NOISE DUE TO FLOW SEPARATION AND REATTACHMENT AT NEAR STALL CONDITIONS

Mohamed G. H. Salih, Omer E. K. Mustafa, and Eltayeb M. Eljack
University of Khartoum, Sudan

Abstract

This work investigates airfoil self-noise produced by flow separation and reattachment at low frequency around a NACA-0012 airfoil at Reynolds number of 50,000 and 90,000, Mach number of 0.4, and several angles of attack at near stall conditions. Time histories of the lift coefficient show that the flow is fully attached at the stall angle of attack. At angles of attack higher than the stall angle of attack, the lift coefficient exhibits a low-frequency oscillations due to flow separation and reattachment. As the angle of attack is further increased, the airfoil becomes fully stalled and the flow is massively separated with occasional reattachments.

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Keywords: Wind Energy, Unsteady Aerodynamics, Aerodynamic Noise, Low Frequency Flow Oscillation.

Conference Topic: Energy and Materials.

NUMERICAL SIMULATION OF FLUID FLOW AND HEAT TRANSFER IN A PLANETARY GEARBOX

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Abstract

Power transmission is a crucial process in the production and utilization of energy. Power losses across the transmission is increasingly affecting the efficiency, environmental impact, and reliability of power systems. Fluid flow and heat transfer in gearboxes greatly affect the motion of gears and loss of energy. The lack of understanding of the physics of lubricant flow and heat transfer is hindering the design of optimum power transmission systems. Fluid flow and heat transfer experimental methods and measuring techniques are not feasible for investigating flow of lubricants inside gearboxes. Numerical simulation presents an efficient and accurate means to investigate the flow and heat transfer inside a gearbox. However, the flow configuration and gears motion are challenging to model in CFD. In this study, chimera mesh is used to simulate the fluid flow of lubricant and inside a planetary gearbox of three planets. Structured and body fitted grids are used around the gears' teeth to accurately resolve the boundary layers; thus, predict the fluid flow, Temperature distribution, Volume Fraction of oil, and Velocity Magnitude within the impairing complex configuration of the planetary gearbox with the maximum possible accuracy. The results show that the simulation has indeed captured the flow physics and CFD simulations can visualize the oil flow behavior with a very high degree of detail, realism, stability and reliability which is going to provide a significant benchmark within the state-of-the-art methods for modeling relevant problems.

Keywords: Power Transmission, Wind Energy, CFD, Chimera Mesh.

Conference Topic: Energy and Materials.

IMPROVEMENT OF AERODYNAMIC PERFORMANCE OF STRAIGHT-BLADED DARRIEUS WIND TURBINE USING BLADES EQUIPPED WITH MOVING SURFACE

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Abstract

In the present work, blades equipped with moving surface are proposed to be used to improve aerodynamic performance of Darrieus type Vertical Axis Wind Turbine (VAWT). Adding a moving surface on the blade suction or pressure side increases the lift coefficient, prevents flow separation, and suppresses flow oscillations due to the instability of the Laminar Separation Bubble (LSB). Thus, improving the aerodynamic performance of the turbine. Furthermore, the moving surface minimizes dynamic stall effects on the performance of the turbine.

Numerical simulations of the flow field about the turbine are carried out using Reynolds averaged Navier-Stokes (RaNS) method. The wind turbine operates at Reynolds number of one million based on the turbine diameter and free stream velocity. The flow-field and power coefficient are compared with and without the presence of the moving upper surface of the blades. The results show that the moving walls have indeed improved the aerodynamic performance of the turbine, and the power coefficient has doubled due to the wall motion.

Keywords: Wind Energy, Unsteady Aerodynamics, CFD, Flow Control.

Conference Topic: Energy and Materials.

DESIGN OF A PROSTHETIC KNEE-JOINT BASED ON 4BAR MECHANISM FOR AMPUTEES IN THE DEVELOPING WORLD

Safa Elamin Mahmoud Hamad, Hanna Gasem Ahmed Abdalla, Mona Elemam Ali Sharf Aldeen, Fatima Galal Ahmed Elsayed, Mohamed Ibrahim Salih Fadul, and Altayeb Mobarak Altayeb Babeker
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Abstract

The number of amputees in Sudan as well as in the world is increasing because of several reasons, including illness, wars, and accidents. Inadequacy of prosthetic limbs – high cost, lack of companies, and diversity in the products – leave patients with limited options and in some cases none, because most amputees have no access to providers. In this project, we target amputees to the top of the knee, mostly using local materials to design and manufacture customized 4Bar knee joint that is adapted to the atmosphere, climate, nature of the land, and terrain in developing countries. The motion simulation testing results curve – displacement, velocity and acceleration – showed good stability during knee flexion and extension of the gate cycle.

Keywords: Prosthetic Knee, 4bar Knee, Developing World Amputees, Artificial Limbs.

Conference Topic: Health.

USING OF A LOCAL HERB (*CYMBOPOGON SCHOENANTHUS*) AS APPROPRATE TECHNOLOGY FOR ENHANCE A HEALTH

Salma Mohammed Alameen
Sudan University of Science and Technology, Sudan

Abstract

Cymbopogon schoenanthus is a medicinal herb of genus Cymopogon which is commonly known as Lemongrass. This herb grows wild in many parts of Sudan and it is known as Maharaib in Arabic. As many other herbs, Cymbopogon schoenanthus is rich with some nutritional elements and essential oils, and hence it has medicinal uses for purposes of enhancing health. The importance of this herb in Sudan comes from using it as flavoring agent. Small amounts of this herb are added to drinking water to enhance taste, and for treatment of kidney diseases, as a diuretic. This study was carried out on Cymbopogon schoenathus collected from a field in south Darfour state (Niala City). It aims to determine the nutritional elements in this herb via inductively couple plasma optical emission (ICP-OES) spectrometry and the chemical compositions of the extracted volatile oil by gas chromatography mass spectrophotometric (GC-MS) techniques. (ICP-OES) analysis results showed that Cymbopogon schoenanthus is rich with iodide and many nutritional elements that most people in that region suffer a lack of these elements: Iodide (36.70mg\100g), Magnesium (20.10 mg\100g), Calcium (20.10 mg\100g), Sodium (17.85mg\100g), Zinc (14.36 mg\100g), Potassium (14.55 mg\100g), Copper (13.50 mg\100g), Manganese (00.98 mg\100g), and Phosphorous (00.90 mg\100g). The major constituent in the essential volatile oil was found to be Piperitone (71.35%); the other major constituents were Elemol (7.91%), (+) - 2-Carene (6.92%), Limonine (4.32%), α-Eudesmol (1.43%), β-Eudesmol (1.30%), α-Eudesmol (1.26%).

Keywords: Cymbopogon Schoenanthus, Flavoring, ICP, GC-MS, Health.

Conference Topic: Health.

UNSATURATED FATTY ACID HINDERED *PORPHYROMONAS GINGIVALIS* PATHOGENICITY FACTORS

***Sara Ahmed Eltigani* [1], *Mohamed Mutasim Eltayeb* [2], *and Jiro Arima* [3]**
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[2] University of Khartoum, Sudan
[3] Tottori University, Japan

Abstract

Porphyromonas gingivalis is a major periodontitis pathogen that produces several proteins known as virulence factors, including gingipains and hemagglutinins. These proteins are crucial for P. gingivalis growth and survive through iron and heme uptake by attaching and aggregating host erythrocytes. To prevent the adherence of P. gingivalis to the host tissues, and to block the inflammation in the early stages of infection, we focused on suppressing the virulence factors. Recently, we isolated several compounds with inhibitory activities against P. gingivalis and its virulence's. Of them, fatty acids from Monechma ciliatum seeds showed potent inhibitory activity against the tested assays. In this study, we focused on the effect of fatty acids with eighteen carbon chain and different saturation degrees on P. gingivalis growth and hemagglutination. The unsaturated fatty acids showed less minimum inhibitory concentration (MIC) values compared to that of saturated fatty acids. Sub-MICs dosages of unsaturated fatty acids significantly affected P. gingivalis growth and hemagglutination. The N-terminal of partially purified proteins revealed that six protein bands corresponding to gingipain R1 hemagglutinin, Lysine gingipain, and hemagglutinin genes decreased inversely with the sub-MICs concentrations of unsaturated fatty acids. The results presented here will expand the uses of the fatty acids as safe additives to impede virulence of pathogenic microbes and enlarge their usage in pharmacological manufacturing.

Keywords: Sudanese Medicinal Plants, Fatty Acids, Porphyromonas Gingivalis, Hemagglutinins.

Conference Topic: Health.

A COMMUNIYY-ORIENTED MOBILE APPLICATION MODEL FRAMEWORK TO CONTROL PRODUCTS PRICE

Mathani Hajali
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Abstract

The phenomenon of not controlling goods prices in markets causes merchants to raise prices. In this contribution, a community-oriented mobile application is developed to create a network between consumers to obtain products at the lowest price and the easiest resources. The application aims to reduce consumers living burden and reach closeness at goods prices in markets or even equal in the easiest way. Accordingly, consumers are connected and the goods types with their various brands are clarified, and the prices of the goods in various quantities (total and retail) are listed. Based on the application model framework, the data indicated by the application is filled out by the consumer himself, and then in another stage, the data is filled out by the merchant after reaching effective results from the first stage and creating competition among merchants, at a very advanced stage, the data is filled by the manufacturers. Data flows to the consumer by locating the consumer and the data is shown according to several classifications. The application includes an explanation of the offers and discounts available, and it provides an opportunity for the consumer to express his opinion and experience. Hence, it facilitates the task of controlling goods prices in markets without the need for officials and campaigns to control their price.

Keywords: Community, Market, Mobile Application, Product Price, Consumer.

Conference Topic: Sustainability, Social Inequality, and Human Wellbeing | **Green Economy and Innovation**.

WORKSHOPS

ABSTRACTS & DESCRIPTIONS

PLASTIC-FREE PERIOD: MENSTRUAL CUPS

Marwa Tageldin [1], *Muna Abdelrahman* [1], *Maisaa Dean* [2], *and Aamir Dean* [2]
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Abstract
Period poverty (not having access to period products or information) is a major problem that faces hundreds of millions of girls and women every day. Many reasons lead to it, like ignorance, poverty, or war. Not much light is shed in this area. There are much more products that can be used for menstruation other than pads. For many, the only known period products are cotton and disposable pads. This workshop will shed some light on sustainable alternatives to regular disposable pads. These alternatives are examples of using appropriate technology in the health sector. Samples will be shown to the audience to examine them themselves. Another objective of the workshop is to break the taboo surrounding menstruation by discussing concepts like period poverty, menstrual hygiene management, and sustainable period products. We aim to engage males in the conversation to normalize talking about periods and help bridge the gap between genders and reduce gender inequalities which is goal 5 of the Sustainable Development Goals (SDGs). The workshop will also answer questions that some of the audience may have. Personal reviews of sustainable period products will be shared as well. Attendees will learn more about menstrual cups, menstrual discs, reusable pads, period panties, and how they are used and cared for.

Keywords: Menstrual Cup, Period Poverty, Reproductive Health, Sustainability.

DESCRIPTION:

Objectives
1. Define and discuss the concept of period poverty.
2. Define menstrual hygiene management.
3. Show examples of ways to fight period poverty.
4. Introduce sustainable period products.
5. Share stories of customers using sustainable period products.
6. Involving men in the discussion.

Expected Outcomes
1. Educate about major concepts like period poverty and menstrual hygiene management.
2. Break the taboo of discussing sensitive topics in the community.
3. Normalizing talking about reproductive health and menstrual period.
4. Educate the audience about sustainable products and how they are used.
5. Familiarize the audience with sustainable period products.

Discussion Points
We will be discussing many new concepts to the audience like; period poverty, sustainable products, waste from non-reusable products, menstrual hygiene management.

Conference Topic: Education, Knowledge and Technology Transfer.

HOW TO INCORPORATE A CITIZEN SCIENCE APPROACH INTO AT PROJECTS?

Gada Kadoda, Marwan Adam, Rofaida El Zubair, Safa Mohamed, Rawan Sharfi, Wadah Omer, Fatima Salah, Sahl Yasin, and Dalia Eissa
Sudanese Knowledge Society, Sudan

Abstract
While appropriate technology (AT) is designed and utilized with the purpose of empowering people, citizen science (CS) is an approach for engaging people in research and development in ways that go beyond 'participation'. Both concepts originated and have been popularized in environmental and agricultural fields, but have spread to other disciplines such as peace, security, and governance. At their core, the two concepts are about collaboration and open science, compliance with scientific and ethical standards, and the cultivation of local knowledge. The idea of the "wisdom of the crowd", whether the crowd are the AT project's target community or a collective of communities with similar problems, is intrinsic to CS. This workshop aims to promote the integration of the two concepts as a win-win situation. Whereas the public gains greater understanding of the science and technology involved in the AT project through CS, the AT researcher or practitioner gains from an unlimited human capability and gets access to a self-sustaining resource beyond any project's means with the potential for new discoveries and innovation.

Keywords: Citizen Science, Appropriate Technology Projects, Public Participation, Scientific Research.

DESCRIPTION: Objectives & Outcomes
The main objective of this workshop is to equip participants with an approach to incorporate CS into their AT projects. Participants will learn about the concept and principles of CS, its applications, related fields, and useful skills. They will also be guided towards designing their own CS approach for their AT projects. The workshop is designed around the following activities:

1. Learning about concepts, principles, and applications of CS.
2. Framing projects using a CS approach in relation to the research or project objectives and the level of public participation sought.
3. Crowdsourcing and open data with focus on data classification, lifecycle, quality, and policy.
4. Collecting data using surveys with special focus on geographic data and images.
5. Employing processes and tools for project and knowledge management.

The anticipated output of this workshop is that participants would have acquired sufficient understanding of how to incorporate CS into their AT projects where there is an identified benefit from public participation. If participants register for the workshop beforehand and are already engaged in an AT project or planning one, the practical part of the workshop can be utilized to produce an actual outline of the CS component for their specific project.

Before the end of the workshop, the facilitators' team will discuss with participants whether they are interested in continuing in the development of their CS component after the conference. If there is interest among participants in this suggestion, a mechanism for follow-up work will be agreed upon at the end of the workshop.

Conference Topic: Education, Knowledge and Technology Transfer.

OPEN DATA SHARING PROTOCOL: A SUDANESE EXPERIMENT

Safa Suliman, Marwan Adam, Rofaida El Zubair, and Gada Kadoda
Sudanese Knowledge Society, Sudan

Abstract
Data sharing is a common part of modern governance and the delivery of public services. Government bodies collect large amounts of data from individuals and other organizations in the exercise of their various functions and share these data with other government authorities or researchers. The problems with data sharing between public bodies may originate from a number of causes other than a deficit in substantive law, such as the lack of guidance or knowledge; insufficient technology; cultural barriers; and inadequate organization. In this workshop, we discuss an open data sharing policy that was developed for Dunia al-Madaris (Schools' World) project. Because the project is about engaging citizens with educational issues in new ways towards realizing global goals such as improving access, equity and quality of education, and also to ensure whether data sharing is ethically used, data policy and sharing became a core element of project design to serve the large number of parties that need to use its data.

Keywords: Data Sharing, Open Data Policy, Data Sharing Protocol.

DESCRIPTION:

Objectives and Expected Outcomes

The objective of this workshop is threefold: First, to demonstrate the importance of sharing data by discussing different data types, their value, and criticality; second, to discuss various laws that govern data sharing and legal aspects in data policies as well as their ethical considerations; and third, to highlight components of a data sharing policy (protocol and discuss the various processes required for developing one such as establishing responsibilities, getting approvals, etc.

The expected outcome of this workshop is for participants to gain a broad understanding of the issues pertaining to open data and policy development as well as share their views and experiences with possibilities of forming a regional community-of-interest to stem from the 10th ICAT towards fostering a paradigm shift in governments' thinking about development data.

Discussion Points

In the most part, this workshop is intended as an open discussion session where interventions by participants are given the bulk of the time. However, a number of clauses in *Dunia al-Madaris protocol* (exhibited in the Tech-Fair) will be shared to enrich the discussion and draw on the insights of participants towards improving it. Areas of discussion include data access and security, privacy and safety, and the various issues pertaining to data sharing, making it open, yet, overseen and ethical.

Conference Topic: Governance | Policy, Standards, and Ethics.

SCIENCE, TECHNOLOGY AND INNOVATION APPLICATION TO BUILD GRAND HYDROELECTRIC GENERATION DAMS IN AND FOR AFRICA: THE CASE OF GERD

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Tshwane University of Technology, South Africa

Abstract
Africa has biggest dams that can hold rich water storage capacity in the world. Kariba Dam in Zimbbawe and Akosombo Dam in Ghana are classified and included in the ten leading biggest dams in the world. The Grand Inga Dam in the DRC Congo, if it is built successfully is expected to produce from 40-70 GW that will make it as the largest power station in the world; expected if it can be done to cover 60 % of the electricity needs of the whole of Africa. There are 980 large dams in Central, Western, Southern and Eastern Africa with 589 in Southern Africa. The Grand Renaissance Dam is expected to be the generator of the largest hydroelectric power plant in Africa and possibly also to be included in the 20 largest ones in the world. The dam has started generating electricity. The key challenge is that there is still no binding agreement between Egypt, Ethiopia and Sudan. The three states should agree how to address the challenges together to share the benefits from the successful completion of the GERD. Africa has also wind and solar energy. If Africans learn how to agree and value the resources they are endowed with, no one will lack any electricity and water at all. The objective of this workshop is to bring together stakeholders to discuss the much missing engineering hydropower mega projects by focusing mainly on the Grand Renaissance Dam.

Keywords: Grand Renaissance Dam, Energy and Electricity Production, Engineering Solutions and Collaboration Avenues.

DESCRIPTION:

There are three main areas planned for discussion that map to the main objective of the workshop which is to provide a platform where a diverse set of stakeholders discuss engineering solutions and collaboration avenues in Dam construction across borders.

1. **Engineering Solutions**: For example, for the filling of the dam and discovering the appropriate and agreed highway to avoid water loss; for examining the weather condition and climate, e.g., space satellites with remote sensing communications; for dealing with the water flow value chain from Blue Nile upstream and downstream countries in a way that saves water being lost due to evaporation; and for storing the heat from the sun during hot seasons, using solar panels, to retain the green zone on the ground and retain water.
2. **Pro-collaboration Approaches**: For example, by applying rigorous scientific research and valuing science-based evidence and not political opinions; as well as exploring mutually beneficial sustainable relations to bring people to unity rather than conflict.
3. **Principled Relations between Riparian Countries**: For example, by producing science anchored solutions—collaboratively; and by implementing mutually beneficial solutions to generate policy learning; and by learning to settle whatever differences countries have without external interference.

Conference Topic: Governance | Policy, Standards, and Ethics.

TECH-FAIR

ABSTRACTS & ESCRIPTIONS

DUNIA AL-MADARIS: A PROJECT BLENDING APPROPRIATE TECHNOLOGY AND CITIZEN SCIENCE

Gada Kadoda, Marwan Adam, Rofaida El Zubair, and Safa Mohamed
Sudanese Knowledge Society, Sudan

Abstract
Dunia al-Madaris is a citizen science (CS) project that was launched in January 2021. It was initially envisioned by two members from the Sudanese Knowledge Society (SKS), and was implemented in collaboration with Sudan Federal Ministry of General Education (FMGE) by a team from SKS. The project aims to engage citizens with educational issues in new ways, and draws its core values from FMGE's policy towards improving access, equity, and quality of education (SDG 4). By combining a CS approach that involves public participation and open data policy with existing data management processes, as well as by utilizing a variety of opensource software; the project provides an inexpensive way to support the Ministry in closing data gaps, integrating datasets, and improving information access, flow and cycle for government and citizens. Not only the project realizes the goals of appropriate technology, such as, few resources are required and the system can be easily maintained; it also empowers the people which is relevant to the enduring democratization process and the quest for social justice in Sudan.

Keywords: Citizen Science, Education, Appropriate Technology Projects, Public Participation.

DESCRIPTION

Objectives & Outcomes
The main objective of the team is to show that citizen science approaches open a unique opportunity for vibrant information communities to grow by responding to the increasing demand from citizens for more transparency, in Sudan and elsewhere. Visitors to this Tech-Fair section will be presented with an experience of open school data where they can explore and discuss with the team the various categories of data that can be considered for sharing such as school profile, efficiency and performance, and parent and pupil satisfaction, etc., as well as about the variety of risks associated with, and barriers to, the introduction of open school data initiatives, particularly in Africa.

We hope this demo will represent a proof of concept and show the possibilities, but also highlight issues that deserve critical attention from scholars, practitioners, and policy makers, about new roles for citizens, and for science, towards producing accessible knowledge.

Display Items
The display consists of two sections, the first is on the main project (*Dunia al-Madaris*) and the second is on projects that emanated from it. In the first section, visitors are presented with an interactive map of schools' locations and can explore their profiles; and in the second, students' projects on data quality, computer vision, and prediction models are presented. With this set-up, we are demonstrating the application of CS and AT towards the vision of *Dunia al-Madaris* project towards data openness and knowledge production.

Conference Topic: Education, Knowledge and Technology Transfer.

CONTROLLING FLOOD AND BENEFITING IN IRRIGATION PURPOSES AND IN GENERATION ELECTRICITY IN THE RIVER NILE

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Abstract
Floods are considered a catastrophe that threatens humanity. Floods occur from heavy rainfall, which leads to an increase in the volume of water in the watercourse and it exceeds some or most of the limits of nature and affects its resources from the destruction and waste it causes, delays the movement of development and progress in the area, damage to crops and erasing the geography of the region. To reduce the risk of these floods, dams have been used, but the threat continues to threaten humanity and its resources. As an example of the floods that occur are that in the Nile River, where the countries that share the Nile River are called the Nile countries, it springs from the south and flows to the north. Nile River extends from latitude 4 to latitude 35 north. The flood occurs from April to October, and its peak is in August. To turn the flood disaster into a wealth that can be utilized in generating power, the model of structural basins is divided into two sections in a way that this it generates electricity, thus reducing the consumption of national electricity and providing it locally in the flood zone.

Keywords: Flood،Turpin, River Nile.

DESCRIPTION

Objectives and Expected Outcomes

The main purpose is to establish a hydroelectric station aimed at supplying the neighboring regions with electric power, to cover the deficit by:

1. Decreasing River Nile flooding.
2. Supplying flood water to irrigation canals for use in agriculture and other uses to meet the demand.

One of the secondary goals is to achieve peace and population sustainability. In the area and reduce displacement, so that when flooding is controlled, residential areas are inundated and their features are erased, people are safe and benefit from what constitutes a threat to him in the development and reconstruction of the area.

The discussion of the model that is exhibited aims to generate new ideas making use of flood water after the flood period throughout the year.

Conference Topic: Energy and Materials.

ONLINE ELECTION DASHBORAD FOR CANDIDATES VOTING

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Abstract
The existing manual Voting System consumes more time for giving a vote. In the traditional scenario the Voter has to wait for a Vote polling station to vote for the right candidate. On the other hand, the Election Officers have to check the Voters one by one; inappropriately, this Voter can vote more than one time, then the Voter ID will present in the Voters list many times, this is the main restriction on our solution; no one can vote more than once. In the aforementioned traditional process, the Voter had to stand in the queue to cast his/her vote. Moreover, all the work is done in a paper manner; so, it is very hard to locate a particular candidate's votes, some voters cast their votes for all Candidates. In addition to, Corona pandemic make paper election difficult. So, to overcome of all these obstacles the need to implement a web application raised, which is helpful for Voting anytime anywhere. The objective of this dashboard is a replacement of the traditional process that is in existence. Not only the solution reduces the time for voting but also the system is reliable, easy to use, user friendly and faster in getting election results from different point of views, different representations; in conformance to candidates and voter groups, departments, associations and so on. Online Election dashboard for Candidates Voting is a web-based application. which has a centralized database to keep records of basic information about all Voters and Candidates and the final results. This dashboard is based on one-time activation link, that is to be sent to Voters via registered email for confirmation of Voter's identity and eligibility to vote, after that he/she can login and vote for his/her preferred Candidate, if he/she is not eligible, the System will block him.

Keywords: Online Election, Voter, Candidate, Dashboard.

DESCRIPTION

The demonstration will show the online election dashboard for candidates voting system, which is a web application that has been developed to enable organizations, groups, associations and individuals to conduct their votes in a secure manner with high quality and availability and accessibility; not only that, but also the system workflow is done in a secure manner. The main functions and processes in the system that are highlighted include:

1. The processes of counting of votes for each elected candidate, which gives the election result in multiple representations according to business requirements.
2. The functions that are available to system users, voters and election committee, in terms of verification processes for access rights, system security, and voting result accuracy.

The discussions with visitors revolve around, but is not limited to, the following:

1. The benefits of using a web application to solve the issues related to traditional voting process, such as people crowding, erroneous voting results and other problems related to manual and paper-based processes.
2. While this solution has been tested with more than three beneficiaries, ideas are sought to enhance or make the process more intelligent and adapted to different of user's requirements.

Conference Topic: Technology R&D I **Services Industry**.

INVITED WORKSHOPS

ABSTRACTS & ESCRIPTIONS

10th ICAT Program Partners who contributed to this section include:

Passion of Hope International, USA

Joint Educational Facilities, USA

A GLOBAL ETHICS FOR APPROPRIATE TECHNOLOGY

Organizers
Charles Verharen [1], John Tharakan [1], Gada Kadoda [2], George Middendorf [1], and David Schwartzman [1]
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[2] Sudanese Knowledge Society, Sudan

Abstract
This workshop will discuss a set of specific LEED-like ethical principles as a foundation for a global system of ethics for appropriate technology. LEED is the acronym for Leadership in Energy and Environmental Design. The LEED organization offers a green building rating system deployed throughout the world. Modeled on LEED certification, the discussion will start with the ethical principles of the Songhaï ecovillage model developed by Godfrey Nzamujo: autochthony (rooted in the physical and cultural soil of the ecovillage community); autonomy (relying on green energy and excluding chemical fertilizers and pesticides); and authentic (responsible for the survival and flourishing of all community members with outreach to surrounding communities). Building upon these three principles, the workshop will consider their compatibility with the United Nations Declarations of Universal Human Rights. The workshop's conclusion will discuss whether a LEED-like ethical system for appropriate technology applications should be produced consensually by appropriate technology practitioners. While any given set of ethical principles may be a springboard for reflection, changing global circumstances call for constant revaluation of ethical principles capable of confronting contemporary existential crises such as catastrophic climate change and the sixth mass extinction.

Objective
This ethics workshop is designed to complement the INAT ethics initiative on an ethics of appropriate technology. Its main objective is to build a consensus on methodology for producing a set of global ethical principles for appropriate technology applications.

Expected Outcome
Reshaping cultural convictions about the status of ethical foundations.

Discussion Points
1. Comparison of LEED principles and ethical systems.
2. Professor Godfrey Nzamujo's proposed 3 ethical principles.
3. Comparison with the Indian Muni Seva Ashram's ethical principles.
4. Examination of the foundations of the United Nations declarations of human rights.
5. The possibility of a universal system of ethics for appropriate technology applications.

Conference Topic: Governance | **Policy, Standards and Ethics**.

WORKING WITH UNDERREPRESENTED GROUPS TO INFORM TECHNOLOGY GOVERNANCE & POLICYMAKING

Organizer
Lassana Magassa
University of Washington, USA

Abstract
Although developing policies and technologies that are informed by the life experiences of underrepresented groups can reduce the likelihood of harm, it can be difficult to get started. Diverse Voices is a method developed to increase the probability that technologists and policymakers can integrate feedback from marginalized communities before an artifact is finalized. This in turn avoids, or at least reduces the likelihood of underrepresented groups being disproportionately harmed. This workshop will introduce the method, describe the method's effectiveness, and provide hands-on experience with key aspects. Attendees will briefly explore how Diverse Voices can be used to generate feedback on proposed sustainable community wellbeing initiatives.

Objectives

1. To introduce the Diverse Voices method to attendees.
2. To give attendees an opportunity to practice key parts of the method.
3. Explore how the method can be used in the work attendees are currently involved in.

Expected Outcomes

1. Attendees will understand what gaps the Diverse Voices method is intended to fill.
2. Attendees will be able to perform key aspects of the method.
3. Attendees will explore how the method can be used in their local context.

Discussion Points

1. Technology is often developed without the circumstances and needs of underrepresented communities in mind.
2. Technology policymakers mean well, but sometimes fall short and create policies that disproportionately harm underrepresented communities.
3. To properly consider how a particular technology or policy would negatively impact the life experiences of underrepresented communities.
4. Diverse Voices accomplishes this by holding three to four expert panels, each with 3 to 6 participants on a mature draft of a policy document or technology.
5. Panels that are convened after developing a list of all possible underrepresented groups that might be negatively impacted and finalized after discussion about who is least likely to be represented in conversations.
6. Each panel will have a minimum of 2 people with lived-experience in addition to people (for example friends, family, lawyers, community aid workers, etc.) who support their experiences. 6. In preparation for panel sessions, short videos and comic strips demonstrating the promise and peril of a technology or class of technologies are identified.
7. Panel sessions are recorded, facilitated by two people, and transcribed.
8. The transcribed audio files are analyzed with the discussed technology in mind. A synthesis document is prepared and shared with the author(s) of a policy document or technology.

Conference Topic: Governance | **Policy, Standards and Ethics**.

SUSTAINABLE COMPUTING USING THE RASPBERRY PI PLATFORM

Organizers
Jesse Bemley*, *Bryan Bemley*, *Anthony Adedoyin*, *and* *Olaoluwa Adewoye
Joint Educational Facilities, USA

Abstract
Since the dawn of the technological age, computers have enabled the human race to achieve major milestones in all aspects of our lives. However, the digital divide, the gulf between those who have ready access to computers and the internet, and those who do not, has been a constant factor in areas around the world with limited resources. Organizations such as the Raspberry Pi foundation are developing the means to provide a bridge over this divide by providing low-cost equipment and resources for people who want to learn more about technology and its applications to society. This presentation will introduce the Raspberry Pi platform as a sustainable technology platform, and attempt to inspire people to embrace this platform to learn more about technology. Additionally, the following Raspberry Pi models will be explored with multiple use-cases for sustainable technology and everyday use: Raspberry Pi, Raspberry Pi 2, Raspberry Pi 3, Raspberry Pi 4, Raspberry Pi 400, and Raspberry Pi Zero.

Objectives
1. To introduce the Raspberry Pi platform.
2. To identify the current Pi models that are available.
3. To provide a few use cases where this platform can excel.

Expected Outcomes
1. Participants will be able to discuss the components of a Raspberry Pi system.
2. Participants will be able to identify and discuss the several Raspberry Pi Models.
3. Participants will be able to discuss how they can use a Raspberry Pi.

Demonstration Areas
There will be a PowerPoint presentation, as well as visual aids showing multiple Raspberry Pi models, and a Raspberry Pi 400 Demonstration at the end of the presentation.

Conference Topic: Education, Knowledge and Technology Transfer.

COLLABORATIVE DESIGN AND CONSTRUCTION WORKSHOPS BUILD LOCAL CAPACITY IN SOLAR OVENS AND SMALL WIND TURBINES ON SUMBA ISLAND, INDONESIA: USEFUL OUTCOMES FOR AUTONOMOUS RENEWABLE ENERGY GENERATION?

Organizer
Tim Frodsham
Appropriate Technology International, Australia

Abstract
This work was undertaken to support local demand for improvements in utility, replicability and affordability for small scale hybrid energy for off-grid use in isolated settlements, with particular focus in Eastern Indonesia, serving as a test case for wider applications in similar remote off-grid contexts in low-income areas. Surveys undertaken by partner researchers (Sumba Renewable Energy Group) as well as collaborative design and construction workshops were conducted to build local capacity for both renewable energy technology and more balanced gender function. The collaborative design sought to improve and diversify generation and storage of two forms of renewable energy, respectively – wind power, and solar thermal energy, in the form of a box style solar oven. These systems were subjected to a six-week trial, to ascertain baseline data for user behaviour and expectations, as well as basic functionality.

Objectives
1. Improvements for small scale hybrid energy for off-grid use in isolated settlements.
2. Collaborative design and construction with balanced gender participation.
3. Acquire baseline data for user behaviour and expectations, as well as basic functionality.

Expected Outcomes
1. Improvements for small scale hybrid energy for off-grid use in isolated settlements.
2. Collaborative design and construction with balanced gender participation.
3. Acquire baseline data for user behaviour and expectations, as well as basic functionality.

Demonstration Areas
1. Effectiveness of the use of local materials.
2. Implications of gender balanced participation.
3. User behaviour – constraints versus opportunities.

Conference Topic: Energy and Materials.

ECOLOGICAL APPROACHES TO FOOD SECURITY AND PEACE IN THE SAHEL FROM THE SMALL HOLDER FARMER UP

Organizers
Brian Stephenson [1]**,** ***Mariam Olorundare*** [2]**,** ***Marwan Awad*** [3]**, and** ***Enayat Mohaker*** [4]
[1] Passion of Hope International, USA
[2] Maripha Empowerment Foundation, Nigeria
[3] Sudanese Knowledge Society, Sudan
[4] University of Bahri, Sudan

Abstract
The expansion of farming in traditional pastureland has resulted in desertification in the Sahel region with implied climate change and socio-economic instability. This has impacted the resilience of pastoral livelihoods and weakened regional livestock markets which rely on unrestricted mobility of herders. In turn, conflict-related crises have escalated, including violent extremism and forced displacement in some countries. This workshop will bring together a divers set of stakeholders in the Sahel regional economy, including small-holder farmers, cattle herders, commercial-scale farmers, traders, students, financial institutions, and government policy makers.

Objectives
This workshop intends to bring key stakeholders into dialogue in addressing the issues which underline these regional instabilities. The objectives of the workshop are to explore the role governments should play in regional agricultural policy and land use management.

Expected Outcomes
1. Discussion between farmers and cattle herders which leads to collaboration and peaceful economic co-existence.
2. Recommendations on agricultural policy and land use management to government which are environmentally sustainable, support regional economic resilience, increase food security, and minimize existing tensions between key stakeholders.
3. Introduction of appropriate technologies which embrace regenerative agriculture, peer-to-peer cooperation, and value-addition for increased financial success.
4. Facilitation of ongoing constructive discussions between key stakeholders which promotes environmental and economic stability in the Sahel regions and beyond.

Discussion Points
1. How can appropriate technology knowledge reach rural farmers?
2. Creating value for farm products and getting it to the market
3. Financial opportunities for farmers and how it can be accessed.
4. Agricultural sustainability through forestry recovery.
5. Risk of rain distribution and floods.
6. Water harvesting model.

Conference Topic: Environment, Agriculture and Ecovillages.

3D PRINTING FUNDAMENTALS: GETTING STARTED ON PRINTER CONFIGURATION, TROUBLESHOOTING, AND CAD FILE TO OBJECT STEPS

Organizers
Jephias Gwamuri [1] ***and William Goriwondo*** [2]
[1]National University of Technology, Great Zimbabwe University
[2]National University of Technology

Abstract
This workshop aims to empower participants who own (or intent to) with the basic skills to enable them to derive the most value out of their 3D Printers. Among the topics to be discussed are: introduction to 3D printing, general; procedures for troubleshooting and CAD file development to physical object. The workshop will be help online and all participants are expected to have access to PC in addition to a reliable internet connection.

Objectives
To capacitate participants with basic 3D printing skills.

Expected Outcomes
Increased adoption and usage of 3D printing technologies by universities and communities.

Discussion Areas
1. Why 3D Printing?
2. Who should own a 3D Printer?
3. Selecting CAD Software. What should one consider?

Conference Topic: Manufacturing.

WASH (WATER, SANITATION AND HYGIENE) IN ELFASHER

Organizers,
***Mustafa Omer Mohammed*, *Mehad Khalil Adam Mohammed*, *Mayada Yousif Ibrahim Mansur*, *Mustafa Abdoalrhman Mohamed*, *and* *Saif Elislam Adam Musa Abdelkareem*,**
El Fasher University, Sudan

Abstract
The population growth of El Fasher city and the war that broke out in the Darfur region and caused the displacement of a large number of citizens inside El Fasher city exacerbated the problem of the lack of clean water suitable for drinking and use. Which led the citizens to save water in different ways to store water and reuse it in periods of water scarcity and water supply interruption from the main line. As a result, diseases and epidemics spread due to water pollution, in addition to some societal and behavioral practices of individuals related to the method of transporting and storing water and the cleanliness of the used containers, in addition to environmental reasons related to the nature of untreated water in the area, which is used by citizens directly without purification. This workshop aims to discuss common diseases associated with the use of impure water, as well as identifying environmental causes and societal practices that increase impure water and cause its pollution, and technical solutions to address and purify the water problem in the region.

Objectives
Discussing the water problem and its impact on the health aspect, and identifying community practices to reduce the water problem Diseases caused by the use of impure water.

Expected Outcomes
Finding solutions for water treatment focusing on the health, environmental, technical and social aspects.

Discussions Points
1. Causes and water sources in the city
2. The impact of water scarcity on society and how to deal with it.
3. Diseases and the effects resulting from these habits.
4. Suggested technical solutions that include all dimensions.

Conference Topic: Water and Sanitation.

SPECIAL SESSIONS

ABSTRACTS

10th ICAT Program Partners who contributed to this section include:

Northern California Council of Black Professional Engineers, USA

Sudanese Knowledge Society, Sudan

STEM Sudan

TECHATHON

Mjumbe Poe
International Network on Appropriate Technology

The INAT Techathon is an opportunity for college and university students to design and build a solution in accordance with the values of Appropriate Technology. Teams will have several weeks to choose a project, design or construct a detailed prototype, and pitch the solution. The projects will be evaluated based on the clarity and potential impact of the problem, the implementation plan, the pitch presentation, and the overall relevance of the project to appropriate technology. The best projects will be awarded cash prizes.

This session is the official start of the Techathon. We will go through the details of the rules, the schedule, and meet the people involved.

WOMEN IN STEM AND AT

Gada Kadoda ***and*** *Hattie Carwell*
International Network on Appropriate Technology; Sudanese Knowledge Society, and Northern California Council of Black Professional Engineers

The AT Manifesto and INAT's Declaration on AT, where women are not seen as optional, but rather essential and critical for Appropriate Technology success, serve as the premise for this forum. The first part involves showcasing (1) a number of projects that transpired from recent activities by STEM Sudan (NGO) that engaged young women graduates in mobile applications development for social purposes; and (2) the work of a set of women innovators and entrepreneurs whose work exhibits much of AT values, such as small-scale, affordable, labor intensive, etc. The examples mirror the theme of the forum because they required excellence in STEM fields and addressed real-world problem solving through appropriate technology. They are meant to remind us of what is possible to think about how to have more of it. The second part of the forum involves a number of scholars and practitioners in exploring approaches for closing the gender disparity in STEM, which is a prerequisite to enter the tech industry, and therefore be in a position to influence it; and for inculcating AT values in the new generations of women innovators, which is a prerequisite to design technologies that attend to the least empowered, where women are dominant.

PANEL ON KNOWLEDGE PRODUCTION AND INNOVATION IN AFRICA

Gada Kadoda ***and*** *Marwan Adam*
International Network on Appropriate Technology, and Sudanese Knowledge Society

The relationship between knowledge and innovation is often described as inseparable and cyclical because innovation involves learning something new or producing knowledge. Critics of the accepted order of "knowing and doing things" argue that the categories and structures that have exercised a generative power over the production of knowledge about the world over the last three centuries have failed to acknowledge the importance of (and sometimes subdued) indigenous or local systems of knowledge. For a rooted knowledge society, one that does not only acquire, but creates knowledge, the fundamental task of education becomes one to acculturate the youth into this "knowledge-creating" society and help them find a constructive and personally satisfying role in that culture. Reforming education systems to address the knowledge society challenge is of interest to national governments, regional, and global bodies. This panel aims to explore the intersection of the production of knowledge and the pursuit of innovation, with a focus on the context of developing countries. It is precisely in times of social and economic crises that local knowledge should be cultivated, learning accelerated, and efforts devoted to innovation technological, educational and cultural. We will discuss social, ethical and political factors that are relevant to the reform debate, think about "education for sustainability" and policies and systems that should be in place to support innovators we see every day.

SCHOOL STUDENT EXHIBITION

Hassan Baba
STEM Sudan

As part of its educational community contributions and within its medium and long-term projects in the field of science dissemination in schools, the STEM initiative works on two lines. The first engages young girls in the age group 10 to 16 years old working on Scratch Programming System to design educational programs for young children in the fields of science and mathematics in an easy and attractive way for school children. The second is a group of university students and recent graduates who work in teams on projects to apply AR (Augmented Reality) technology to be used in schools by simplifying the components and equipment used in schools and in a way that facilitates their work and implementation in schools easily with simple and available tools.

The exhibition includes STEM Innovations for children under 16 years featuring a 13-year-old from Ad-Damazīn City, Blue Nile State. He built a solar power system using junk, recycled batteries, and small solar panels, to set-up street lights for his village (50 km away from the city). Other featured projects involve robots and electronic circuits using Arduino.

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