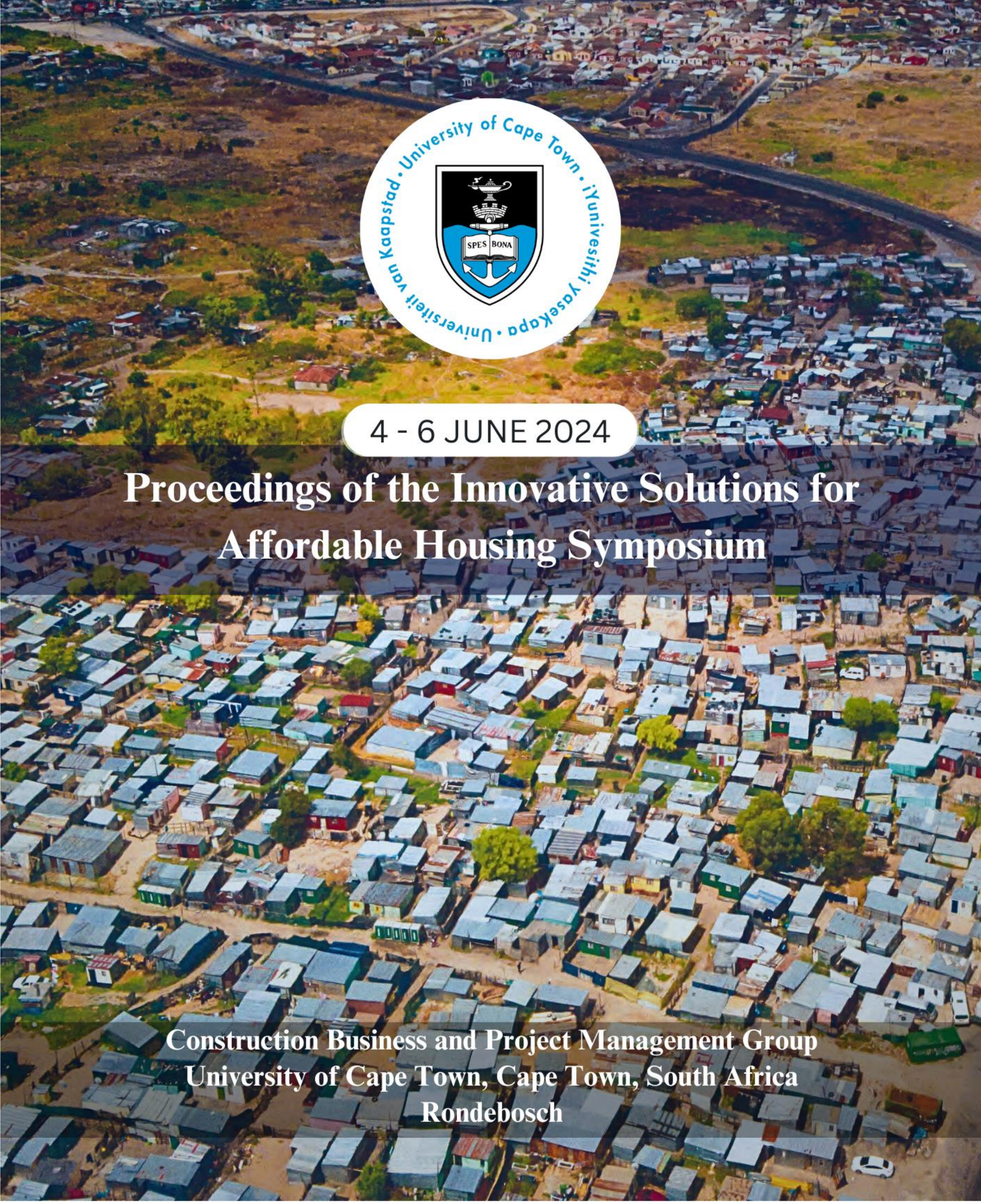

4 - 6 JUNE 2024

Proceedings of the Innovative Solutions for Affordable Housing Symposium

Construction Business and Project Management Group
University of Cape Town, Cape Town, South Africa
Rondebosch

Royal Academy of Engineering
Edinburgh Napier University
City of Cape Town / Isixeko Sasekapa / Stad Kaapstad
National Home Builders Registration Council (NHBRC)
Central University of Technology, Free State

Proceedings of the Innovative Solutions for Affordable Housing Symposium
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Professor Fidelis Emuze – Central University of Technology, Free State, South Africa
Professor Francesco Pomponi – Edinburgh Napier University/Cambridge University, United Kingdom

DECLARATION

Thirteen submissions were received and accepted for presentation at the Symposium from authors based in 16 Universities and 1 College of Technology, located in Nigeria, Uganda, United Kingdom, and South Africa. All full papers in this publication went through a double-blind peer-review process which involves submission of full papers, review of full papers by the Scientific Review Committee, feedback to authors on full papers submitted which included a decision on acceptance and evaluation of the revised papers by the Scientific Review Committee to ensure the quality of the content.

Instituitional Affiliation	Count of Affiliation	Affiliation%
Cranefield College of Project and Programme Management, South Africa	1	3%
Durban University of Technology, South Africa	3	9%
Federal University of Technology, Akure, Nigeria	1	3%
Global Institute of Property Studies, Uganda	1	3%
Joseph Ayo Babalola University, Ikeji, Nigeria	2	6%
Obafemi Awolowo University, Nigeria	2	6%
Stellenbosch University, South Africa	3	9%
University of Cape Town, South Africa	5	15%
University of Cross River State, Calabar, Nigeria	1	3%
University of East London, United Kingdom	1	3%
University of Ibadan, Nigeria	5	15%
University of Stellenbosch, South Africa	1	3%
University of the Witwatersrand, South Africa	5	15%
Yaba College of Technology, Lagos, Nigeria	1	3%
Cambridge University	1	3%
Central University of Technology, Free State	1	3%
Total	**34**	**100%**

PREFACE

On behalf of the organizing committee of the Innovative Solutions for Affordable Housing (ISAH) 2024 Symposium, I extend a heartfelt welcome to everyone joining us, whether in person or remotely, over these three days. We are thrilled to see both familiar faces from past events and new participants who are attending this symposium for the first time. This year's symposium is dedicated to exploring groundbreaking solutions and sustainable practices in affordable housing.

We are honoured to host this significant gathering at the UCT Graduate School of Business in Cape Town, South Africa, where practitioners, policymakers, researchers, and community stakeholders come together to push the boundaries of what is possible in affordable housing. Our gratitude extends to the Scientific Review Committee and Local Organizing Committee whose tireless efforts have ensured the high quality and impactful nature of this event. Your relentless dedication to rigorous peer-review processes and seamless organization has been foundational to the symposium's success.

Our keynote speakers this year, including distinguished personalities like Prof. Francesco Pomponi, Mr. Craig Makapela, Prof. Ayodeji Aiyetan, Ms. Xoliswa Daku, Mr. Barry Lewis, Mr. Pragasan Chetty, Prof. Johannes John-Langba, Prof. Stephen Ogunlana, and Mr. Robert Plattner promise to deliver thought-provoking insights that are sure to stimulate discussions and inspire innovations. We are also excited about the various workshops and parallel sessions spread across the programme, focusing on critical areas such as Alternative Building Technologies (ABTs), public-private partnerships, sustainability, and community engagement.

We are proud to announce that thirteen submissions were accepted for presentation at the symposium, hailing from thirteen universities and one college of technology. These submissions have undergone a rigorous double-blind peer-review process, contributing significantly to the body of knowledge that will benefit policymakers, practitioners, and the academic community.

Reflecting on the previous editions of our workshops, we see a steady growth in both participation and the depth of shared knowledge. This year's edition builds upon past successes, marked by insightful presentations, robust panel discussions, and engaging workshops. Notably, the unveiling of a prototype re-imagined informal house using ABTs will highlight the practical applications of our collective efforts in affordable housing.

As we embark on this journey of knowledge exchange, I urge all participants to actively engage in intellectual debates, learn from each other, and foster collaborations that will extend beyond the symposium. Your presence and contributions are vital to the success of this event and the ongoing quest for innovative sustainable housing solutions.

I warmly welcome you all to the ISAH Symposium 2024.Should you have any queries or require assistance, please feel free to reach out to me or the organizers.

Thank you very much for your attention.

June 4th, 2024

Professor Abimbola Windapo
Chair, Innovative Solutions for Affordable Housing (ISAH) 2024 Symposium

SCIENTIFIC REVIEW COMMITTEE

Prof. Abimbola Windapo	University of Cape Town, South Africa
Prof. Fidelis Emuze	Central University of Technology, South Africa
Prof. Francesco Pomponi	University of Cambridge, United Kingdom
Dr. Lindelani Matshidze	University of Witwatersrand, South Africa
Dr Salie Mahoi	Fourah Bay College, Sierra Leone
Dr. Kehinde Alade	University of Cape Town, South Africa

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Fabio Companie	University of Cape Town, South Africa
Sizolwenkosi Mthethwa	University of Cape Town, South Africa
Darmarajan Chinasamy	Secretary, University of Cape Town, South Africa

THE PEER REVIEW PROCESS

All the full papers in this publication went through a rigorous two-stage blind peer review process by no less than two acknowledged experts in the subject area to ensure that high-quality scientific papers were produced and included in the proceedings.

The submitted full papers were first of all checked to ensure papers are aliggned to the symposium themes, then for originality and inappropriate copying using the Ithenticate software. After that, the papers were assigned to experts in the field based on their areas of expertise for review. The full papers were reviewed in terms of relevance to the originality of the material; technical writing; academic rigour; contribution to knowledge; pertinent literature review; research methodology and robustness of analysis of data; empirical research findings; and overall quality and suitability of the paper for inclusion in the proceedings.

Evidence was required relative to specific actions taken by the authors regarding the reviewers' comments. Final papers were only accepted and included in the proceedings after satisfactory evidence was provided that the paper had met all the conditions for publication. Thirteen papers were finally accepted and included in the ISAH-Symposium proceedings.

At no stage was any member of the Scientific Committee, Review Panel or the Organising Committee, or the Editors of the proceedings involved in the review process related to their own authored or co-authored papers. The role of the editors and the scientific committee was to ensure that the final papers incorporated the reviewers' comments and to arrange the papers into the final sequence as captured on the USB memory stick and Table of Contents.

Professor Abimbola Olukemi Windapo
Chair, Scientific Committee ISAH 2024 Symposium

COMMUNIQUÉ OF THE INNOVATIVE SOLUTIONS FOR AFFORDABLE HOUSING SYMPOSIUM

04-06 June 2024

Overview:
The Innovative Solutions for Affordable Housing Symposium, held over three days, brought together more than 100 key stakeholders from government, academia, the private sector and civil society to address the significant challenges facing affordable housing development. The discussions revolved around issues in informal settlements, innovative building technologies, community empowerment, and sustainability in housing development and construction practices.

Day 1 Summary:
The first day featured workshops and academic presentations exploring the construction strategies used by informal builders and the challenges of housing construction in informal communities. The challenges identified include financial constraints, lack of materials, and the need to recognize community-driven solutions. The presentations examined community engagement, alternative construction methods, and the importance of localized solutions, emphasizing training and awareness for informal builders on innovative construction methods and materials. The workshops focussed on engaging participants in discussions around practical solutions for addressing overcrowding, safety and community cohesion. The workshop also focussed on hands-on construction techniques using the Sandbag and Eco-beam eco-friendly building materials, highlighting the interplay between technical training and community participation.

Day 2 Highlights:
The second day included keynote presentations and panel discussions on the high costs of building materials, the role of public-private partnerships, and the integration of academia and industry to engender collaboration towards sustainable housing development. The keynote presentations highlighted the innovative use of local building materials and technologies while advocating for community-driven housing initiatives, emphasizing women's empowerment in construction and the need for inclusive planning processes.

Day 3 Summary:
The final day further explored the intersection of academia and industry in affordable housing, innovative building material solutions, and scholarly presentations outlining sustainable construction strategies, process management, and construction technologies applicable to housing. The focus was on bridging knowledge gaps that prioritize community involvement and regulatory reform.

Conclusion:
Based on the presentations, panel discussions, and workshops, it can be concluded that sustainable and inclusive solutions that address housing needs can be implemented through collaboration between the government, communities, regulators, building material suppliers, and NGOs. The success of these initiatives will rely on funding and embracing local community-based construction practices.

Recommendations:
The following are the recommendations for stakeholders based on the findings:

1. **For Government:**
    - Implement policies that support community-led housing initiatives.
    - Allocate resources for training workshops that educate informal builders on innovative and sustainable construction techniques.
    - Enhance support for Public-Private Partnerships (PPPs) aimed at affordable housing developments, ensuring transparency and community engagement.

2. **For Regulators:**
    - Reform regulations to facilitate the adoption of alternative building materials and methods.
    - Streamline approval processes for innovative building technologies to encourage their adoption.
3. **For Building Material Manufacturers:**
    - Invest in research and development of cost-effective, sustainable materials accessible to low-income communities.
    - Create partnerships with local communities to educate them about alternative materials and construction techniques.
4. **For Communities:**
    - Develop grassroots initiatives to address housing challenges, utilizing local resources and knowledge.
    - Organize community workshops to empower residents through education on sustainable construction practices and self-help initiatives.
5. **For Non-Governmental Organisations (NGOs):**
    - Advocate for policies prioritising affordable housing and engaging in community capacity-building efforts.
    - Facilitate dialogue between communities and government to address housing needs while promoting sustainability.

We look forward to your feedback and thank you for your participation and commitment to advancing solutions to enhance affordable housing!

ENDORSEMENTS

The Innovative Solutions for Affordable Housing Symposium is funded by the Royal Academy of Engineering and supported by the National Home Builders Registration Council, Development Action Group, National Research Foundation, UBU and the Journal of Construction Business and Management.

Royal Academy of Engineering

NATIONAL HOME BUILDERS NHBRC REGISTRATION COUNCIL

DAG Development Action Group

NRF

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JCBM Journal of Construction Business and Management OPEN UCT PUBLICATIONS

https://journals.uct.ac.za/index.php/jcbm/login

KEYNOTE SPEAKERS

The ISAH 2024 Organising Committee would like to thank our keynote speakers for accepting the invitation to come and share their presence and thoughts on innovative solutions to affordable housing debacle with housing stakeholders, end-users and the academic and professional community.

PROFESSOR FRANCESCO POMPONI

Francesco Pomponi is the Senior Associate at the Institute for Sustainability Leadership at the University of Cambridge, an Honorary Professor at the University of Cape Town, and Visiting Professor at Edinburgh Napier University, where he previously held the Chair of Sustainability Science and led the Resource Efficient Built Environment Lab (REBEL).

His academic expertise lies in life cycle assessment, embodied and whole life carbon, and the circular economy.

Within the built environment his work revolves around low-carbon buildings, measurement, management and mitigation of environmental impacts, and passive design. He has published more than 120 peer-reviewed outputs and advised national governments and international bodies around sustainability in the built environment. He holds a PhD in Life Cycle Assessment, and MSc in Engineering Management and a BEng in Industrial Engineering. Professor Pomponi is also a Fellow of the Royal Society of Arts and of the Higher Education Academy. Currently is career is at the interface of academia, entrepreneurship and innovation, and non-profit organisations to create the trusted tools and data for the transition to a Net Zero built environment.

MR CRAIG MAKAPELA

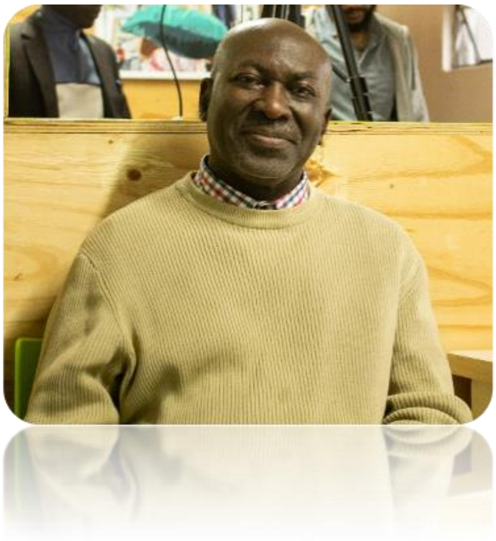
Craig Makapela, the Executive Manager of Engineering and Technical Services at the National Home Builders Registration Council (NHBRC), has been employed in the construction industry since 2001. He holds a BSc. Eng (Civil) degree from the University of Cape Town (UCT).

Mr. Makapela's academic accolades are also from the University of Pretoria in B. Eng (Hons) (Geotechnical Engineering) and M. Eng (Engineering Management), respectively.

Makapela's contribution to the human settlements value chain through organisations such as Mariswe (formerly known as UWP Consulting), Transnet, as well as the NHBRC has seen him playing an advisory role to municipalities and provincial departments through risk analysis in the home building industry, advising, and providing guidance on the structural warranty to new homes and residential housing designs as well as approval of construction sites and the assessment of geotechnical reports.

As a registered engineering professional, Makapela's memberships include the South African Institution of Civil Engineering (SAICE), Engineering Council of South Africa (ECSA), and the South African Council for the Project and Construction Management Professional (SACPCMP).

PROFESSOR AYODEIJI OLATUNJI AIYETAN



Professor Ayodeji Olatunji Aiyetan is a Senior Lecturer and Head of Department of Construction Management and Quantity Surveying at the Durban University of Technology, Durban. D Aiyetan holds the following qualifications: B.Sc. Building (1986), M.Sc. Construction Management (both at A.B.U Zaria, Nigeria) and Ph.D. Construction Management 2011 (NMU, PE, South Africa). Dr Aiyetan has published DHET accredited Journal and Conference papers at both National and Internationally.

MR BARRY LEWIS

Barry Lewis, an architect and the founder of Ubuhle Bakha Ubuhle (UBU), collaborated with The Warehouse NGO in Wetton, Cape Town. A program was implemented in the informal community of Sweet Home Farm in Philippi.

During the initial three years, the primary objective was to establish relationships rather than construct homes. Barry and Siya James, who would later serve as the community's leader and factory manager at UBU, established and operated a soccer club known as "The Superstars of Sweet Home Farm."

UBU was established in 2012, and although it was legally recognized as a business, its primary objective was to establish a facilitated building methodology and to assist the UISP (Upgrade of Informal Settlements Program) project in the community, which is administered by the City of Cape Town.

MS XOLISWA DAKU

Successful business leadership, legal passion and corporate governance specialist - these are some of the attributes that one can use to describe the property mogul that is Xoliswa Daku. She is the Founder and CEO of DAKU (PTY) Ltd, a 20-year-old privately held entity with subsidiaries in property, law and energy.

Daku Properties focuses on property development, facilities, and asset management. Her property development vision is to develop corridors of excellence, turn small towns into economic hubs, and redevelop underutilized properties. Whilst Daku Legal focusses on mergers and acquisitions and Daku Energy specializes on investment in energy efficiency and development.

She is an astute lawyer with 26 years of experience, Chair of SEDA and Deputy Chair of the University of the Western Cape, holding LLM, EMBA, and various international post grad business diploma in her bag. Daku has served on various boards for the past 26 years specializing on governance, institutional framework, FDI, trade and industry. Her company footprint is nationwide and carries an international flavour. She has worked with multinationals globally, seeking opportunities for the growth of the country. Her generosity and community development approach describes where she comes from.

MR PRAGASAN CHETTY

Pragasan Chetty is the CEO of Modular Innovative Building technologies (MIBT). MIBT are manufactures of structurally insulated lightweight concrete panels (SIP Technology).

Modular Innovative Panel (Mi Panel) is one of the highest certified Agrément systems in Africa. Agrément is the international certification authority for alternative building systems and is administered by the CSIR in SA, under the auspices of the DPW. Mi Panel is approved by all major banks for EDGE end user bonds as well as development funding. Mi Panel is a load bearing and structural walling system that exceeds the physical strength of a 9-inch clay brick wall Ito vertical compression as well as shear capacity - we can hang 740 kgs of load off Mi Panel walls.

Mi Panel has a higher R value Ito of thermal insulation properties than a 9-inch clay brick wall. Mi Panel is a rapid construction system with zero water consumption on site and is both EDGE (IMF AND IFC certification) and LEED -US Green Building Council approved technology.

SIP technology is the most prevalent building technology in the world now in terms of increased usage and is only going to be more dominant in the future. Mi Panel walling system is easy enough to use that the system can be taught to most people who have never worked on a construction site, necessitating the need to employ local labour with a SAQA accreditation for training and development.

PROFESSOR JOHANNES JOHN-LANGBA

Johannes John-Langba, Ph.D., MPH is Professor of Social Work in the School of Applied Human Sciences and Director of the College of Humanities Doctoral Academy at the University of KwaZulu-Natal (UKZN) in South Africa. Prof John-Langba holds PhD (Social Work) and Master of Public Health (Behavioural and Community Health) degrees from the University of Pittsburgh (United States) and a Master of Social Work (MSW) from Howard University (United States).

Prof John-Langba is the recipient of a number of scholarly awards including the Dr Inabel Burns Lindsay Social Work Education Leadership Award from Howard University (United States), for outstanding leadership in social work education and the promotion of social justice in Africa and an Excellence in Teaching Merit Award from the University of Cape Town (South Africa).

He is the current Regional Vice President-Africa of the World Federation for Mental Health (WFMH) and also serves as Vice President and Mental Health Ambassador of Cape Mental Health (CMH) in South Africa. Prof John-Langba serves as co-chair of the Data Ethics Working Group of the International Science Council’s Commission on Data (CODATA) and is a member of the KwaZulu-Natal Provincial Substance Abuse Forum in South Africa.

PROFESSOR STEPHEN OGUNLANA

Professor Ogunlana graduated with an honours degree in Building from University of Ife, Nigeria in 1981. He also obtained a master's degree in construction management from the same university in 1984.

He was a partner in TOS Associates, a firm of project management consultants and a staff of the Department of Building, University of Ife, between 1982 and 1986. He obtained a PhD in Construction Management at Loughborough University in the UK. He joined the Asian Institute of Technology (AIT) as assistant professor in 1990 and was promoted to associate professor and full professor in the same institute.

Professor Ogunlana, a renowned researcher in system dynamics simulation, has a strong international reputation for his work in construction projects and organizations. He has been the Chairperson for the academic senate in AIT from 2005 to 2007 and later Chair of Construction Project Management at Heriot-Watt University. He is currently the director of Elim Project Systems Limited and has authored over 250 scholarly publications. His research has been funded by various organizations, including the Canadian International Development Agency, European Union, Thai National Housing Authority, UNOCAL, Japanese Government, and British Council. Ogunlana is also the joint coordinator of the CIB W107 Commission on Construction in Developing Economies and a member of the Editorial Board for over 10 internationally refereed academic journals.

MR ROBERT PLATTNER

Robert Plattner, co-founder of the Hydraform group in 1988, has over 38 years of technical expertise in building technology. The group is based in Johannesburg. He is the creator of the Hydraform building technology, which has been implemented in more than 70 countries worldwide. In 2012, Robert was appointed as the company's managing director.

Hydraform is a South African company renowned for its innovative building technology utilizing hydraulic block-making machines. Hydraform has become a global leader in the manufacture and distribution of construction machinery for building affordable, eco-friendly housing solutions.

The Hydraform blocks eliminate the need for traditional mortar during construction, allowing for faster and more cost-effective building processes. Hydraform's technology is particularly well-suited for low-cost housing projects, rural development initiatives, and sustainable construction practices. Hydraform's mission is to provide innovative solutions for sustainable building practices, addressing the challenges of affordable housing, infrastructure development, and environmental sustainability. Through partnerships with governments, non-profit organizations, and private enterprises, Hydraform has contributed to the construction of thousands of homes, schools, clinics, and community facilities in over 70 countries worldwide.

With a commitment to quality, efficiency, and social impact, Hydraform continues to pioneer the usage of locally available earth as a construction raw material and transforming the earth into interlocking dry stacking high quality building blocks which are produced on the building site. This advancement in ancient construction linked up with the Hydraform technology is empowering communities to build better futures through accessible and sustainable housing solutions.

ISAH 2024 WORKSHOP

PRESENTERS

Darmarajan Chinasamy

UCT Master Student researching the supply chain issues of sustainable building technologies designed for low carbon and affordable housing in South Africa.

Dr Kehinde Alade

Expert in sustainable construction, project management, and construction disciplines. Collaborates with diverse teams in UK and Africa, managing risks, budgets, and quality. Committed to solving global challenges through research, teaching, and professional practice.

DAY 1 04 June 2024: WORKSHOP SYNOPSIS

The workshop section of the Symposium explored the construction strategies employed by informal builders, challenges faced to housing construction in informal communities, and the importance of community engagement, awareness and training on the use of alternative construction techniques in housing construction. The session consisted of both academic presentations and a hands-on workshop that involved building a prototype structure using sandbags and eco-beams. The audience engaged in activities including discussions, quizzes, Question and Answer sessions and learned from each other.

The session began with introductions by Prof. Abimbola Windapo followed by a presentation by Darmarajan Chinasamy titled Construction strategies, techniques and specifications used by dwellers of informal settlements. Darmarajan showcased case studies centered around three informal settlements in South Africa, specifically, Franschhoek, Ocean View, and Khayelitsha. He proceeded to emphasize the historical context, construction methodologies, and various types of housing built within these informal communities. He summarized the construction techniques used by informal builders, the observed specifications for internal configuration, and the essential amenities needed by the residents. He suggested several methods to enhance the construction strategies of informal builders. These include offering comprehensive training to builders, establishing standardized practices in the shack construction market, and raising awareness among clients to improve the quality of shacks. Ultimately, he proposed several theories that are underestimated in informal communities. These include the notion that informal settlers have the financial capacity to enhance their buying power, the advantage of utilizing ABT to offer alternative housing choices and encouraging the construction of permanent structures through the promotion of security of tenure.

The second presentation by Dr Kehinde Alade titled Limitations and challenges to housing construction in informal communities focussed on identifying the various challenges in informal settlements, from resource access to technical building issues, and advocating for community-driven, sustainable solutions. The presentation opened with a reminder of the importance of community engagement and grassroots discussions in solving housing issues in informal settlements. Dr. Alade emphasized the vast number of people living in informal settlements worldwide, particularly in Sub-Saharan Africa, underlining the critical need for sustainable solutions. He highlighted that about one in five South Africans live in informal settlements, reflecting a significant housing challenge that aligns with sustainable development goals (SDGs) aiming for inclusive, safe, resilient, and sustainable human settlements. He described informal settlements as urban areas developing without formal state control, characterized by a lack of adequate living conditions, health, and nutrition, and noted that despite the deprivation, these settlements are places of creativity where people find innovative ways to handle their living conditions. By engaging with informal settlement builders and community leaders he identified the challenges and limitations to housing construction in informal communities as access to resources – financial constraints and access to construction materials; lack of formal training of informal builders in management skills, safety standards and technical know-how; and technical challenges – the structural durability and resistance of the homes to the weather are often compromised due to poor construction techniques and materials. The context set by these presentations by Darmarajan Chinasamy and Dr. Kehinde Alade highlighted the complexity of informal settlements and the necessity for innovative solutions that match their unique socio-economic and geographic challenges.

Following the presentations, the Workshop Session facilitated by Dr. Amanda Filtane, Dr. Salie Mahoi and Barry Lewis, focuses on understanding and resolving the complexities surrounding informal settlements, particularly the issues of housing, community dynamics, and sustainable building practices. The discussion is framed around community engagement and the practical use of alternative construction techniques. The panellists invited audience members to contribute further ideas and questions emphasizing the workshop's goal to generate actionable solutions rather than merely discussing theoretical frameworks to practical, actionable solutions for making informal settlements more liveable. The intent is to recognize the existing informal structures' resilience and creativity and to bolster these with informed technical and material support. The key problems identified included the necessity of secure tenure, community-based design solutions, and how community self-help initiatives can be effective. A significant point was how political and economic challenges affect housing. Others include:

1. **Displacement and Community Connections:** Residents often refuse housing relocation due to loss of community ties and increased distance to essential services like schools and clinics.
2. **Overcrowding and Limited Space:** Families living in informal settlements often find the government-issued houses inadequate due to space constraints, prompting a need for extensions.
3. **Temporary Nature and Perpetuity of Informal Settlements:** The misunderstanding that informal settlements are temporary, whereas many residents have lived in such conditions for decades.
4. **Safety, Noise, and Infrastructure Issues:** Concerns include crime, noise disturbances due to proximity, and structural issues like leaking roofs and unstable doors.
5. **Economic Activity Spaces:** The need for integrated working spaces within homes for informal economic activities.

The informal builders and end-users were aware of the drawback of the materials used for informal housing construction – Zinc, which is used for the roof and walls however, due to its temperature conduction, it makes homes very hot. They also noted that they have limited understanding of alternative materials. The following alternative materials were proposed – sandbags (good for temperature regulation but requires proper cladding); Bamboo **(**grows rapidly, structurally sound, but climate-dependent); Thatch and Mud (traditionally used but might need modernization for durability); Steel Structures (quick to build but energy-intensive and costly). It was concluded that emphasis should be on using locally available materials tailored to the environment and economic situation of the end-users. Other solutions proffered are as follows:

1. **Design Solutions:** Community members voiced the need for secure, soundproof, expandable homes that consider safety and proximity to services.
    - Use of soundproofing materials in Zinc housing construction.
    - Develop modular designs that can be expanded horizontally or vertically.
    - Integrate economic spaces within housing plans.
2. **Community and Leadership Dynamics:**
    - Regular rotation and accountability in community leadership to prevent corruption and ensure the welfare of the community.
    - Establishing rules around noise and safety tailored to the community's context.

3. **Material Education and Training:** The experts provided detailed explanations on the properties and viability of various building materials and proposals for integrating modern building technologies with traditional practices:
    - Training residents on using alternative building technologies effectively.
    - Community-based initiatives to recycle and reuse materials innovatively.
4. **Long-term Planning and Inclusivity:**
    - Efforts to secure land tenure and legalize informal settlements to provide a stable foundation for improvements.
    - Collaborative planning involving residents, technical experts, and policymakers to ensure sustainable and accepted solutions.

Charles a community leader's immediate offer to visit and assist with a leaking roof of a community member demonstrates the practical and immediate support required in such communities. The session effectively transitioned from identifying issues to formulating practical steps, with a strong emphasis on collaborative efforts among community members, technical experts, and governmental support.

The practical session demonstrated by Barry Lewis the CEO of UBU on building with sandbags and eco-beams. This was designed to showcase a hands-on approach where participants could learn the construction technique by engaging directly with the materials. Main components of the sandbag construction included eco-beams made from galvanized steel and timber, sandbags made from recycled plastic, and techniques to ensure the structural integrity of the walls. Discussion on materials stressed the importance of using locally available resources to keep costs low and sustainability high. Participants learned the differences between various types of sand and underlined the importance of moisture content in the sand to ensure compactness and durability. Numerous questions from both in-person and online participants were addressed. Topics included the structural integrity of sandbag walls, flood resistance, the challenges of building in various geographic locations, and how to engage communities in construction projects. The importance of educating local builders and involving community members in the entire construction process was highlighted.

The workshop was highly interactive and aligned community needs with technical expertise to advance the dialogue on sustainable housing solutions. The use of sandbags in construction was established as a viable, cost-effective, and sustainable method that could address some of the most challenging aspects of housing in informal settlements such as structural durability, fire, floods, crime and heat.

KEYNOTE ADDRESS

Quantifying Sustainability: What matters where?

Professor Francesco Pomponi

Prof. Francesco Pomponi, the first presenter, delivered a thought-provoking talk on the true meaning of sustainability, exploring the fundamental principle of meeting present needs without compromising the ability of future generations to meet theirs, emphasizing the need to understand local contexts and needs rather than adopting broad, universal solutions. He critiqued the inefficacy of current language and terminologies used in discussions of informal housing and proposed a more human-centric approach. His presentation explored various aspects of housing adequacy, showing how terms and standards often differ vastly between regions, thus needing unique, context-specific solutions. The presentation highlighted the socio-economic and cultural contrasts between the Global North and the Global South, particularly in the realm of housing. Prof. Pomponi pointed out the pitfalls of conventional terminology such as "informal settlements" and "refugee camps," advocating for a shift towards more inclusive and dignified language. Prof. Pomponi also pointed out the significant disconnect between policymakers' strategies and the actual needs of communities, advocating for a more participatory approach where communities are actively involved in designing and implementing housing solutions. Prof. Pomponi's talk aimed to inspire a rethinking of sustainable development practices, underscoring the richness of local solutions in achieving broader sustainability objectives.

The session also saw interactive discussions with the audience, who raised pertinent questions about the viability and effectiveness of social housing, the role of regulatory bodies, and the need for community empowerment in housing projects. Prof. Pomponi responded by highlighting the importance of ownership, community-driven initiatives, and learning through failure as critical components in achieving sustainable housing solutions

Public-Private Partnerships in Housing Development: Leveraging Resources for Mass Housing Projects.

Ms Xoliswa Daku

Xoliswa Daku's presentation focused on the challenges and opportunities in Public-Private Partnerships (PPPs) for community-driven development projects in South Africa. She highlighted her experience working on projects that involve complex land and community dynamics. Xoliswa introduced PPPs as collaborations between the public sector and private entities aimed at developing public assets or services. She highlighted that these partnerships are rooted in South Africa's Public Finance Management Act (PFMA) and Municipal Finance Management Act (MFMA). Ms. Daku provided Case Studies and Project Examples to support her presentation. Xoliswa discussed a development project involving 43 hectares of land in the Eastern Cape. The project faced issues such as land claims and community resistance. Despite plans for varied housing types including RDP (Reconstruction and Development Program) units, community demands altered the initial plans to focus solely on RDP housing. Another example involved a long-term lease with Prasa (Passenger Rail Agency of South Africa) to create mixed residential apartments. The goal was to provide affordable housing near transport hubs, thus integrating them into the broader public transport system. She highlighted plans for a ten-storey building that would house 1,000 apartments aimed at creating an inclusive community living closer to their workplaces in the Woodstock Development. This project emphasizes high-density living and the use of innovative building technologies.

Ms. Daku discussed the various challenges faced in land development to include Planning and Land Audit - Issues with land audits and title deeds often reveal unanticipated complexities such as additional land claims and outdated land use records. These factors can significantly delay project timelines. Also, Community Resistance - Community demands sometimes diverge from original plans, requiring negotiations and amendments to ensure the project's success while satisfying community expectations. Xoliswa emphasized the need for durable and cost-effective building technologies to manage infrastructure costs. These technologies should also be adapted to high-density developments like those planned in the Woodstock development. She also highlighted the importance of viewing housing developments not just as construction projects but as opportunities to enhance the socio-economic status of communities. This involves creating inclusive environments that contribute positively to residents' health, education, and employment. A significant portion of the discussion revolved around women's empowerment in the construction industry. Xoliswa stressed the necessity of including women at all levels of these projects, from labour to leadership roles, and ensuring they benefit from the opportunities created.

Several questions addressed the themes of women empowerment, the inclusion of rural women in these projects, and the need for more accessible information and support structures for aspiring female developers. The sustainability and affordability of housing for all community segments, including the unemployed, were also discussed. The key takeaways from her presentation included: Inclusive Planning – emphasis on community involvement and flexible planning to meet local needs; Women Empowerment with focus on creating opportunities and support systems for women in the construction industry; leveraging innovative and cost-effective building technologies to enhance project feasibility and sustainability; and Holistic Development - ensuring that housing projects contribute to the broader social and economic well-being of communities.

Potential of Innovative Building Technologies (IBTs) in addressing the housing backlog and improving construction standards in South Africa.

Mr Craig Makapela

Craig Makapela, representing the NHBRC (National Home Builders Registration Council), provided a comprehensive overview of the potential of innovative building technologies (IBTs) in addressing the housing backlog and improving construction standards in South Africa. The presentation covered several key points, including the benefits, challenges, and necessary policy support for IBTs.

Makapela began by highlighting the significant housing backlog estimated at 2.4 million units, exacerbated by rapid urbanization and the limitations of traditional brick-and-mortar construction methods. He noted the inability of current methods to meet the demand, thus necessitating the adoption of more efficient IBTs. He explained that IBTs, which include advanced materials such as nanotechnology, lightweight steel panels, and concrete innovations, can accelerate construction processes, reduce costs, and improve energy efficiency and thermal performance of homes. These technologies also offer durability and fire resistance, critical for informal settlements prone to fires. Furthermore, Makapela discussed the value of adaptive technologies like additive manufacturing, which can print construction elements on-site, thereby saving time and labour. He emphasized the importance of aligning these technologies with local conditions and educating communities about their benefits.

Challenges addressed included the initial higher costs of IBTs compared to traditional methods, the need for skilled labour to handle new technologies, and resistance to change due to familiarity with conventional building techniques. He urged for greater government support, including policy adjustments, financial incentives, and the continuation of the NHBRC's role in educating housing consumers and ensuring quality assurance. Makapela concluded by urging the incorporation of IBTs in human settlement plans and the development of guidelines to assist municipalities and provincial departments in adopting these technologies, ensuring sustainable, affordable, and safe housing solutions across South Africa.

The High Cost of Building Materials and Promoting Innovation in the Construction Industry.

Professor Ayodeji Aiyetan

Prof. Ayodeji Aiyetan's presentation focused on the significant issue of rising building material costs in the construction industry and explored innovative solutions to mitigate these costs and improve project feasibility. Prof. Aiyetan noted that Building material costs constitute a significant portion of project expenses, often cited as 70-30 or 60-40 ratios compared to labour costs, and that high material costs complicate project completion within budget, leading to financial difficulties for developers and contractors. He identified 29 factors affecting the high cost of building materials, narrowing them down to nine major factors: Exchange rates of country currency; Government policies and regulations; Costs of raw materials; Inadequate infrastructural facilities; Scarcity of building raw materials; Costs of transportation and distribution; Interest rates and costs of finance; Costs of labour and plant; and Seasonal changes and political interferences. He noted that the adoption of new technologies and construction methods - robots and drones, 3D Printing can help mitigate high material costs. It was recommended that for the construction industry to remain sustainable and cost-effective, it must embrace new technologies, collaborative practices, and innovative materials, while encouraging knowledge sharing and collaboration among stakeholders such as consumers, government authorities, and complementary industries for industry growth and stability. Prof. Ayodeji Aiyetan emphasized the need for innovation and collaboration in the construction industry to address the high costs of building materials. He noted that the industry can improve project feasibility and deliver higher quality outputs within budget constraints by adopting new technologies, sustainable practices, and efficient project management methods.

Reviving Indigenous Architecture: Using Local Materials and Techniques for Affordable Housing.

Mr Barry Lewis

Barry Lewis's presentation emphasized the ethos of UBU ("Ubuhle Bakabantu Bakha Izinto Ezinhle" - Beautiful People Build Beautiful Things), emphasizing the empowerment of local communities to build their own homes, in using local materials, fostering inclusive building processes, incremental building and maintaining ongoing dialogue with communities. Barry rejected the notion of "reviving" indigenous architecture as it implies it was dead. Instead, he highlighted the ongoing presence and relevance of indigenous practices. He highlighted the practical application of these principles in current and future projects, particularly focusing on sandbag technologies for affordable housing. Barry showcased a project in rural Zimbabwe where communities used available materials like sand and empty feeding bags to build structures and highlighted the importance of using what is readily available to ensure sustainability and affordability and where everyone, including children and elders, participated. He stressed the importance of involving the community at every step to ensure successful and sustainable building practices. He emphasized that building together fosters community ownership and pride. He discussed the concept of incrementalism, where houses are built and improved over time as resources become available and highlighted that the of Sandbag Building Technology is cheaper, more flexible, and allows for continuous improvement and customization.

Barry introduced a current opportunity via a new tender by the City of Cape Town for building emergency housing using alternative building technologies and discussed how UBU plans to use sandbag technology to build these emergency houses incrementally, involving community members in the construction process. He focused on the pilot project in Sweet Home Farm, a site where UBU had previously worked. He mentioned the bureaucratic hurdles and the time taken for such projects to gain approval and start and highlighted health and safety considerations, particularly when building multi-story structures with sandbags. Barry emphasized the importance of training and continuous community involvement to ensure safety and durability. He addressed questions about scalability and safety of sandbag constructions for multi-story buildings and acknowledged the limitations and emphasized that community safety and practicality are prioritized.

Maximizing Sustainability in Affordable Housing: Embracing innovative Building Technologies to Reduce Embodied Energy and Avoid Greenwashing

Mr Pragasan Chetty

Pragasan Chetty's presentation highlighted the critical need for innovation in the construction industry to meet the massive demand for affordable housing while ensuring sustainability. He explained that affordable housing touches on 14 of the 17 United Nations Millennium Development Goals and highlighted the massive demand for affordable housing due to high urbanization rates and insufficient supply. He explained that the average cost of a new build in South Africa is between R600,000 and R650,000 and that an affordable house must provide dignity, security, and allow families and communities to grow. He emphasized the role of modular construction in achieving these goals and warned against greenwashing where companies misrepresent their products or practices as more environmentally friendly than they are, emphasising that genuine sustainability requires transparency and proper implementation of green principles. He shared case studies of successful projects in various contexts such as building affordable houses in five days and modular housing structures in Zambia designed to be relocated with minimal wastage. Using various visual aids, including photos of innovative housing projects and construction sites, Pragasan illustrated successful implementations of modular construction. The presentation concluded with an interactive session where audience concerns about affordability and regulatory challenges especially the role of regulatory bodies in promoting alternative building technologies were addressed.

Education and Research: Bridging the Gap between Academia and Industry for Housing Development.

Professor Johannes John-Langba

Prof. Joannes John-Langba's presentation focused on the pivotal role of education and research in bridging the gap between academia and the construction industry for sustainable housing development. He underscored the necessity of effective collaboration between universities and industry players in order to achieve sustainable development goals (SDGs), particularly those related to housing. Prof. Langba emphasized that social scientists have a significant role to play in projects traditionally dominated by engineers and illustrated this by referencing his ongoing project on a shelter prototype for refugees, conducted in collaboration with engineers. Langba highlighted the well-documented "disconnect" between academia and industry, stressing that universities provide vital workforce training and innovative ideas while industries focus on practical application and profit. He noted that effective collaboration could enhance industry performance and help achieve SDG 11, which aims at making cities and human settlements inclusive, safe, resilient, and sustainable and which calls for ensuring access for all to adequate, safe, and affordable housing and basic services. On the definition of "adequate housing," he emphasized that what is deemed adequate varies and must involve community consultation for context-specific solutions.

Prof. Langba presented the Triple Helix Model as a potential solution for fostering innovation-friendly environments. The model advocates for close interactions among universities, industry, and government and aims to address the gap by facilitating regulatory compliance and reducing bureaucratic barriers. By working together, these entities can compensate for each other's shortcomings, thereby promoting evidence-based innovations that are crucial for sustainable housing developments. He acknowledged the challenges in academia-industry communication and collaboration, proposing that solutions lie in mutual understanding and transparent engagement. Prof. Langba also stressed the importance of revamping academic curricula to be relevant to industry needs, thus ensuring that students are well-prepared to join the workforce and contribute meaningfully. Addressing the issue of industry reluctance to share data with researchers, Prof. Langba suggested that it is a matter of building trust and understanding the confidentiality concerns of industry partners.

Prof. Langba concluded that bridging the gap between academia and industry through collaborative frameworks like the Triple Helix Model is essential for achieving sustainable housing and urban development. He advocated for continued engagement, multidisciplinary approaches, and inclusive dialogue to meet the housing needs and challenges of the 21st century effectively.

Building Beyond Cement: Exploring Alternative Construction Materials and Technologies for Cost Effective Housing Solutions.

Professor Stephen Ogunlana

Professor Stephen Ogunlana, a construction management expert with strong international recognition, particularly in systems dynamic simulation in construction projects. His presentation focussed on building with and beyond cement using innovative construction technologies developed at the Asian Institute of Technology (AIT) in Bangkok, Thailand. His presentation focused on the innovative Habitech interlocking stabilized soil block technology, highlighting its cost effectiveness, sustainability, and community benefits. With successful implementations across various countries and applications, the technology presents a promising alternative to traditional cement-based construction, particularly suitable for low-cost housing in developing economies. He noted that the Research Centre was tasked with researching and developing low-cost, sustainable construction technologies, disseminating research through educational programs and demonstration projects. The Habitech Building System was noted to provide end-to-end solutions for constructing walls, door frames, and roof systems using locally available materials. Its main focus are the interlocking stabilized soil-cement blocks (SSBs) for building walls, with minimal cement usage (less than 10%). These blocks differ from conventional bricks; interlock without the need for mortar. It is produced using basic, manual or hydraulic press machinery and its advantages include the use of local soil, job creation, reduction in transportation costs and emissions, minimal use of cement, energy-efficiency, minimal wastes, and ease of construction with local labour. Despite the initial cost for equipment, the overall project costs is noted to reduce significantly (typically 30-50% savings). It is also noted to enhance living conditions and provide durable, long-lasting structures.

Prof. Ogunlana noted that the Habitech Building System can be used for residential buildings, schools, clinics, community centers, offices, resorts, and rapid response housing developments and that the system has been implemented successfully in several countries including Thailand, Myanmar, Nepal, Indonesia, and Nigeria. In conclusion, Prof. Ogunlana notes that the Habitech system offers a viable, sustainable alternative to conventional building methods, particularly suited for developing economies and encouraged adoption and further projects in Africa, noting the minimal current penetration in Africa compared to other regions.

Building Beyond Cement: Exploring Alternative Construction Materials and Technologies for Cost Effective Housing Solutions.

Mr Robert Plattner

Mr. Robert Plattner, co-founder of the Hydraform Group, presented on the innovative building technology and its applications, particularly focusing on housing development and rural initiatives. Hydraform specializes in interlocking stabilised soil-cement blocks (SSBs), which are particularly suitable for low-cost housing and rural development. Hydraform blocks are made from soil stabilized with a small amount of cement. They are produced by pressing the soil-cement mix in Hydraform machines. The blocks interlock, eliminating the need for mortar between them. The blocks are produced on-site using local materials and are cured for 5-7 days before they can be used for building. The advantages of this technology according to Mr. Plattner is that it promotes local job creation because of its simplicity, reduces construction costs by up to 30%, and utilizes local resources. Mr. Plattner emphasized the importance of engaging the community in housing projects. Communities can take part in the construction process, making decisions on their housing needs and preferences.

Mr. Plattner noted that Hydraform blocks are suitable for building houses, schools, storage facilities, and even high-rise buildings and has a global footprint. Although Hydraform is based in Johannesburg, its technology is used worldwide, including in Africa, South America, and Asia. Surprisingly, it has not been widely adopted in the Western Cape of South Africa. He noted Housing projects in Tanzania and Mthatha, South Africa. The University project in Nigeria and an impressive hospital project in Abidjan, Ivory Coast. The Hydraform blocks align with the requirements of Green Technology because the blocks have a low carbon footprint compared to conventional building materials and provide excellent thermal properties, ensuring houses remain warm in winter and cool in summer. Mr. Plattner called for the promotion of local materials and community-driven projects to maximize the impact of affordable housing initiatives.

In conclusion, Mr. Robert Plattner's presentation highlighted the innovative Hydraform technology as a viable and sustainable solution for low-cost housing. Emphasizing the importance of community involvement and the use of local materials, he showcased the global success of Hydraform projects and called for greater adoption within South Africa to better serve local communities.

PANEL DISCUSSION

The ISAH 2024 Organising Committee would like to thank our Panel Discussants and Moderators for accepting the invitation to come and share their presence and thoughts on innovative solutions to affordable housing debacle with housing stakeholders, end-users and the academic and professional community

Panel Discussion I: Challenges and opportunities related to sustainable humana settlements and the adoption of Innovative Building technologies (IBTs), moderated by Fabio Companie

The first panel discussion on sustainability in the symposium was moderated by Fabio Companie and featured a diverse group of panellists, including Craig Makapela from the NHBRC, Dr. Amanda Filtane, Mr. Craig Makapela, Professor Babafemi, and Professor Francesco Pomponi. The discussion centered around the challenges and opportunities related to sustainable human settlements and the adoption of Innovative Building Technologies (IBTs).

The key points discussed centred around sustainable human settlements, challenges with IBTs, Role of regulatory bodies and community involvement. Regarding **Sustainable Human Settlements:** Craig Makapela underscored the importance of creating human settlements that align with the United Nations Sustainable Development Goals (SDGs). He emphasized the necessity to design communities where people live close to their workplaces to minimize travel. Dr. Amanda Filtane stressed the importance of using locally available materials and understanding the local context when defining sustainability. She also questioned why certain materials, like zinc sheets, are predominantly used despite not being locally produced. Professor John Babafemi advocated for the use of locally sourced and waste materials as viable alternatives to traditional, high-carbon construction materials like cement.

Regarding the **Challenges with IBTs,** Professor Pomponi noted that the challenge isn't necessarily with the materials themselves but rather their overuse and the lack of adaptation to various contexts. Professor Babafemi mentioned the need to ensure that alternative building materials are structurally sound and durable, while Dr. Amanda Filtane highlighted the issue of achieving economies of scale for alternative building technologies. She stressed that the initial cost of these technologies might be higher, but their long-term benefits could outweigh traditional methods. Craig Makapela emphasized the need for social acceptability and consumer education. He noted that people often resist new technologies in favor of familiar ones like brick and mortar.

Concerning the **Role of Regulatory Bodies**, there was a significant discussion about the role of regulatory bodies like the NHBRC. Craig who works for the regulator emphasized that the NHBRC's role is to ensure quality and safety through education and regulation. However, concerns were raised about the NHBRC's effectiveness in promoting and adopting IBTs, with some audience members expressing frustration over perceived inefficiencies. Furthermore, multiple speakers, including audience members, stressed the importance of **Community Involvement** in the planning and implementation of housing projects. This involvement ensures the acceptability and sustainability of new technologies.

The session concluded with an emphasis on the need for a holistic approach to sustainable settlements. This involves collaboration between regulators, developers, and communities, focusing on local resources and long-term benefits. The importance of education and patience in overcoming initial resistance to new technologies was also highlighted. The key takeaways from the session are that:

- Sustainability is context-specific; understanding and utilizing local materials is important.

- Consumer education and community involvement are vital for the adoption of IBTs.
- Achieving economies of scale for new technologies requires strategic planning and patience.
- Regulatory bodies play a critical role in ensuring quality and safety but need to be more proactive in promoting innovation.

Panel Discussion II: High Cost of Building Materials and Promoting Innovation in the Construction Industry, moderated by Dr. Kehinde Alade

The second panel discussion on the high cost of building materials and promoting innovation in the construction industry was moderated by Dr Kehinde Alade featured a diverse group of panellists:

- **Prof. Fidelis Emuze:** Central University of Technology, Built Environment, Sustainability.
- **Prof. Ayodeji Aiyetan:** Durban University of Technology, Innovation in Construction.
- **Craig Makapela (NHBRC):** Regulation, Managing costs and innovation.
- **Zama Mgwatyu (Community Development):** Development Action Group, grassroots engagement.
- **Melita Molala:** CEO, Vibrant Construction Company, Johannesburg.

The discussion highlighted the multifaceted challenges in the construction industry, emphasizing the need for collaborative efforts among researchers, regulators, industry players, and communities to drive down costs and promote the adoption of innovative building technologies. The session concluded with a commitment to address the identified barriers and work towards practical, sustainable housing solutions.

Melita Molala emphasised the importance of embracing Innovative Building Technologies (IBTs) to address the housing backlog (2.4 million) in South Africa and advocated for the inclusion of women in the construction industry and the implementation of the 30% government spend target on women-owned businesses. She highlighted that IBTs work globally and questioned why South Africa is slow to approve and adopt these technologies and encouraged local manufacturing of building materials to drive down costs and create jobs.

Zama Mgwatyu highlighted the socio-political challenges, including extortions in townships, affecting construction and stressed the need to understand and support the informal sector, which comprises significant construction activity. He called for clearer communication and education on planning laws and the use of alternative technologies for community-based builders and advocated for access to capital and alignment of governmental systems with on-ground realities to foster sustainable development.

Prof. Fidelis Emuze suggested the use of evidence-based research that addresses real problems and influences policy and encouraged collaboration between researchers and communities to ensure practical and impactful research outcomes He proposed the adoption of methodologies like design science to build solutions with end-user participation. Prof. Ayodeji Aiyetan identified scarcity of raw materials and high production costs as major factors driving up the cost of building materials and emphasised exploring renewable materials and innovative technologies to replace traditional building materials. He also highlighted the need for research focused on durability, fire resistance, and other properties of new materials.

Craig Makapela of the NHBRC acknowledged the need for better communication and education about IBTs to builders and housing consumers and admitted that there has been a gap in sharing information and facilitating adoption of approved technologies. He stated that the NHBRC is committed to working closely with stakeholders to educate and train on the benefits and implementation of IBTs.

The audience raised concerns about the risk of project abandonment and the need for better planning and execution with the high cost of building materials. There was criticism regarding the slow adoption of innovative technologies by the government and the persistence of traditional methods despite available alternatives. There were also concerns about land classification and ownership changes that impact community settlements and housing developments. Notable points from the panel and audience interactions were the need for alignment between research outcomes, governmental policies, and community needs, advocacy for faster approval and implementation of IBTs to address housing deficits, and emphasis on creating sustainable, cost-effective housing solutions through local manufacturing and innovative technologies.

Panel Discussion III: Indigenous Architecture and Affordable Housing, moderated by Prof. Abimbola Windapo

The third panel discussion for Day 2 on Indigenous Architecture and Affordable Housing was moderated by Prof Abimbola Windapo featured a diverse group of panellists:

- **Dr. Iruka Anugwo:** Senior Lecturer, Durban University of Technology
- **Prof. Philippa Tumubweinee:** Associate Professor, University of Cape Town
- **Dr. Salie Mahoi:** Structural Engineer
- **Ms. Bernadette Rossouw:** Community Activist, Ocean View

The panel highlighted the importance of leveraging indigenous architecture principles using modern techniques to create affordable, sustainable housing that resonates with contemporary needs. This requires a shift in perception, educational curriculum changes, community involvement, and policy adjustments. The key themes drawn from the panel discussion revolved around indigenous architecture and the modern context; perception vs reality; practical implementation in communities; sustainability and education; and combining traditional and modern techniques.

Dr. Salie Mahoi emphasized the importance of perception when it comes to building materials. He highlighted those materials like adobe (mud bricks) and thatch, still used in wealthy areas like Constantia and Camps Bay, are considered premium, whereas in other regions, they are perceived as inferior. The conversation focused on the need for education and the demonstration of well-built structures using indigenous materials to change these perceptions. Concurring with the views of Dr. Mahoi, Ms. Bernadette Rossouw**,** representing the informal community of Ocean View, spoke about how she uses locally available materials to build their homes. She mentioned the importance of having a solid base due to the windy environment they live in and highlighted the practicality and necessity of using what is available. She also emphasized the need for policy changes to support such grassroots construction efforts.

Prof. Philippa Tumubweinee discussed how indigenous architecture is more about principles rather than appearance. She noted that using local materials isn't about recreating historical structures but adapting ancient principles to modern needs. She stressed that resistance to such materials often comes from misconceptions rather than practical shortcomings. The need for practical education came up, particularly the importance of getting construction and architectural students to engage in hands-on projects that utilize indigenous materials. Prof. Tumubweinee suggested that students learning by building shelters and other structures themselves is invaluable and should be incorporated into their formal education. This would bridge the gap between theoretical knowledge and practical application especially as it concerns indigenous architecture. Dr. Iruka Anugwo introduced the idea of creating hybrid construction practices that combine traditional and modern methods. This merges the durability and local adaptability of traditional materials with modern construction standards, potentially improving affordability and sustainability within the housing market.

The key points discussed centred around incremental building, spaces for dialogue and regulatory changes. Incremental building allows communities to construct their homes overtime, adding improvements as resources become available. Creating spaces for continuous community dialogue, which is crucial for sustainable development, noting that only through open dialogue can the real needs and effective solutions of the community be addressed. There are calls for a shift in policy to accommodate and recognize indigenous architecture and methods as viable options for urban housing. However, the mainstream acceptance of such methods requires support from both academic and regulatory bodies.

Panel Discussion IV: Bridging the Gap Between Academia and the Industry for Housing Development, moderated by Dr Kehinde Alade

Dr. Kehinde Alade moderated a dynamic panel discussion focusing on bridging the gap between academia and the industry for housing development. The session featured contributions from Dr. Amanda Filtane, Prof. Joannes John-Langba, Mr. Fabio Companie, Dr. Iruka Anugwo, and Mr. Mochelo Lefoka.

The key contributions from the panellists centred around Engaged Scholarship, Publication Practicality, Interdisciplinary Collaboration, the Triple Helix Model, Practical Experience, Generational Understanding, Project Based Learning, Community Engagement, Mentorship and Technical Skills. Dr. Amanda Filtane discussed her experience with UCT's Engaged Scholarship programme, which aims to link classroom activities with societal impact. The programme requires academics to translate their research into accessible formats, like infographics and pamphlets, to ensure the general public and communities understand and benefit from the research findings. She stressed the importance of disseminating academic knowledge in ways that communities can understand and use, emphasizing that publishing alone is not enough. While Prof. Langba highlighted the need for interdisciplinary collaboration, pointing out that social scientists and engineers must work together. He shared examples from his own research and involvement in projects that needed social science input to be effective. He reiterated the importance of the Triple Helix Model, which connects academia, industry, and government to facilitate innovation and overcome individual shortcomings.

Mr. Fabio Companie emphasized the importance of understanding the community's needs and the practical problems they face. He mentioned the necessity of improving informal settlements incrementally and understanding the local context for effective interventions. He supported a multi-generational approach to tackling housing issues, which focuses on long-term affordability and sustainability. Dr. Iruka Anugwo advocated for project-based learning as a means to bridge the gap between theoretical knowledge and practical skills. He shared his experience of assigning live projects to students, which helps them develop real-world problem-solving skills. He emphasized the need for students to engage with communities, suggesting that curriculum review sessions with industry practitioners could enhance the relevance of academic programmes. Further, Mr. Mochelo Lefoka discussed the importance of mentorship in bridging the gap between academia and industry. He highlighted how aligning students with mentors in the industry can significantly enhance their practical learning experiences. He pointed out the disparity in valuing technical skills and emphasized the need to respect and improve the training of tradespeople to ensure the construction of adequate housing.

A participant emphasized the distinction between adequate housing and satisfactory housing, noting that regulations often define adequacy, but community satisfaction is driven by subjective perceptions and local context. A comment from an online participant addressed the stigma attached to graduates from certain institutions, suggesting that academics should work to break down these barriers for a more inclusive industry. The panel concluded that effective collaboration between academia, industry, and communities is crucial for developing sustainable housing solutions. Emphasizing experiential learning, respecting technical skills, and ensuring community engagement were identified as essential steps in bridging the gap between theoretical research and practical application.

Panel Discussion V: Practicalities and challenges of implementing Alternative Building Technologies (ABTs) in South Africa and beyond, moderated by Prof. Fidelis Emuze

The panel featured experts including both academic and industry professionals, bringing diverse perspectives on the adoption and challenges of ABTs for low-cost housing. The experts include: Pragasan Chetty,Robert Plattner, Michael Chikwava, John Matthews and Bob Hindle. Prof. Fidelis Emuze introduced the session, highlighting the need to address the gap in the adoption of alternative building technologies (ABTs), particularly technologies developed locally but implemented more successfully abroad.

Key topics that emanated from the discussions centred on Community involvement and Technology Acceptance' Regulatory Challenges, Economic and Business Considerations; Educational and Industry Integration; Infrastructure and Implementation; and exposition of Practical Examples and Success stories. Pragasan Chetty emphasized that many townships already use ABTs (albeit informally) and highlighted the importance of involving the community in decision-making to foster acceptance. While Bob Hindle raised the point that communities should decide what they need, implying that top-down approaches often fail to meet local needs effectively. Several panellists indicated that current regulations are rigid and act as barriers to implementing ABTs. A shift towards performance-based regulations was suggested. They discussed the role of regulatory bodies like Agrément South Africa and the need for these bodies to be more open and supportive of ABTs.

Robert Plattner discussed the challenges his company, Hydraform, faces locally compared to broader success internationally. He emphasized the commercial decision to operate where business is more feasible. Challenges were raised about government tender requirements and the lack of flexibility in emergency housing specifications, which often mirror those of permanent structures, thus nullifying cost benefits. John Matthews stressed the importance of educating both the community and professionals on the benefits and practicalities of ABTs, while Michael Chikwava highlighted resistance within professions like architecture and civil engineering, where there is little incentive to deviate from traditional materials and methods. Panellists raised points about the need for adequate infrastructure to support the use of ABTs. For instance, ensuring proper soil types and mixes could significantly impact the longevity and durability of structures built using ABTs. Prof. Ogunlana mentioned the importance of having demonstration projects to showcase the benefits and practicality of ABTs in local contexts. Thereafter, the panel discussed various successful implementations of ABTs in different regions, highlighting the conditions and factors that contributed to their success including the importance of involving communities in the design and construction process to ensure that the end product meets their needs and gains their acceptance.

Members of the audience inquired about the suitability of different soil types for making blocks, and concerns were raised about the practical implementation of ABTs in various environmental conditions. Further, audience members and panellists discussed the role of government in facilitating the adoption of ABTs through regulatory flexibility and financial incentives. Finally, there was a call for more robust mechanisms to empower communities to dictate the types of structures that best suit their needs, especially when it comes to informal settlements. The panel discussion concluded with a consensus on the need for a more flexible regulatory environment, better educational outreach to both communities and professionals, and a collaborative approach that includes government, industry, and academia to streamline the adoption of alternative building technologies. The session underscored the importance of aligning technological innovation with community needs and regulatory frameworks to achieve broader acceptance and implementation of ABTs in housing development.

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ACADEMIC PAPERS: SESSION I

Sustainable Construction Strategies, Process Management and Innovations applicable to Housin

Exploring the Contribution of Real Estate Investment Trusts (REITs) to Achieving Sustainable Development Goals (SDGs) in Sub-Saharan Africa.

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Abstract
Despite high-income inequality, Sub-Saharan Africa (SSA), like the rest of the world, is making efforts toward Agenda 2030. This paper examines how the REIT, a dynamic financial instrument, can support SDG progress in Sub-Saharan Africa. The potential of REITS to finance sustainable construction projects, create jobs, and drive economic growth is explored. The research methodology used is a literature review, including peer-reviewed papers from 2016 to 2024 from academic databases. It was found that while REITs impact sustainability by encouraging transparency and responsible investment, they are also faced with legal risks and are affected by regulatory dynamics that are accountable for their structure, which affects their adoption and growth. There is enormous potential for REITs to align with SDGs by raising funds to support affordable housing and infrastructure to support the achievement of SDGS 9(Industry, Innovation, and Infrastructure), 11(Sustainable Cities and Communities), and 8(Decent Work and Economic Growth) in SSA.

Key Words: REITS, Construction, SDGs, Sub-Saharan Africa, Financing Solutions.

1. Introduction

With a rich and diverse socio-economic landscape, income inequality is prevalent in Sub-Saharan Africa (Fuje et al., 2022; Odusola et al., 2019). However, like other regions across the globe, SSA too is striving to achieve the SDGs before the 2030 deadline, a feat whose attainment will require creative approaches, primarily recruiting the support of the private sector in overcoming development obstacles (Buckley & Bower, 2020; Mawdsley, 2015). The UN SDGs are a detailed framework deliberately crafted to support sustainable development, some of which include SDG 11(Sustainable cities and communities), SDG8(Economic Growth)and SDG9(Industry, Innovation and Infrastructure) (United Nations, 2015), reinventing development efforts (Caballero, 2019).

With a largely youthful demographic and abundant natural resources (Okada & Shinkuma, 2022), Sub-Saharan Africa has enormous potential but also faces considerable hurdles, such as the “resource curse” (Wegenast & Schneider, 2017), infrastructural challenges, and not to mention conflict in some parts of the region (Calderon & Zeufack, 2020; Coulibaly et al., 2019). Unexpected challenges have further curtailed progress towards Agenda 2030 such as the COVID-19 pandemic, which brought a heavier debt burden, and the Ukraine war (United Nations, 2023).
The private sector, governments, and civil society must work together if the SDGs are to be realized (Ionaşcu et al., 2020). The strengths offered by the private sector revolve mostly around specialized skills, high efficiency and resources (Scheyvens et al., 2016). Given how closely real estate and infrastructure relate to SDGs 8,9, and 11 as key drivers

of economic growth and social well-being, strategic investments in critical sectors are necessary. Real estate greatly contributes to achieving the objectives through job creation, financing green (Mariani et al., 2018), construction (Fei et al., 2021), and more.

REITs, by definition, is a financial instrument that pools resources from various investors and then invests in a portfolio of income-generating real estate assets (Keke & Emoh, 2019), presenting an avenue for mobilizing resources towards SDG-aligned projects like affordable housing (Diala, 2021; Zou, 2017), infrastructural development (Ishak et al., 2022; Wang et al., 2023), thus fostering economic growth. Fei et al. (2021) found that the construction industry has a crucial role in furthering all 17 SDGs, as has been demonstrated successfully in countries such as China and Malaysia in financing infrastructure (Wang et al., 2023; Ishak et al., 2022).

REITs, with proven resource mobilizing abilities and high productivity in the real estate sector (Ma, 2020), might offer a reprieve to SSA countries, given the heavy debt burdens(Calderon & Zeufack, 2020) many carry, yet this has not yet been widely explored for SDG financing. There is a need for region-specific research to understand how REITs can support the achievement of SDGs in SSA. This may be valuable academically and practically for implementation as 2030 approaches.

2. Literature Review

2.1 REITS Adoption and Economic Growth

REITs, according to a National Association of Real Estate Investment Trusts (NAREIT) study, have, over a period from February 2005 to December 2021outperformed both bonds and stocks as reflected below, the REIT compound annual growth rate (CAGR) of 6.9% (FTSE EPRA/Nareit Global Index) while the broader stock market at 5.4% (MSCI EAFE), private real estate at 5.4(NCREIF) and finally global bonds at 3.1% (Bloomberg Barclays Global Aggregate bond index) (Funari, 2022).

REITs have received widespread adoption globally, providing capital for real estate development. Over the years, their number has grown to 865 REITs in 41 from a paltry 31 in 1990, contributing up to $72 trillion(85%) to global GDP by 2020(Bertoldi et al., 2021), as reflected in the comparative statistics above. SSA has, however, experienced slower growth due to underperforming capital markets, as well as regulatory challenges(Diala, 2021), and yet (Gogineni et al, 2022), in a study across 32 jurisdictions, found common themes in REIT regulation all across, despite some variations. Only five African countries, including Kenya(1), Tanzania(1), Ghana(1), Nigeria(4), and South Africa(44) have operational REIT structures (Joseph et al., 2020). This indicates the need for legislative and real estate market reforms for REITs to grow in SSA.

2.2 Social and Environmental Impact

A study on ESG ratings and REIT performance in the US revealed a positive relationship, with social factors more significant than environmental factors in the implementation efforts (Brounen & Marcato, 2018). Sustainability practices have been found to increase profitability in real estate, as evidenced by European REITs (Mariani et al., 2018), and even operational performance benefits from green building certifications (Morri et al., 2020), a good motivator for investment in sustainable development. Economic growth (SDG8) can be further boosted by promoting community engagement and SDGs, increasing even the REIT value (Minh Hiep et al., 2021; Feng & Wu, 2022). GCB securities in Ghana are fulfilling their social mandate by partnering with the National Housing and Mortgage Fund, Ghana (NHMF) to provide affordable rental homes for public sector workers in a 15-20 year rent-to-own model at lower rates (11.9 to 12.5 per cent) compared 24 per cent market rate (CAHF, 2020). Mortgage REITs can also enhance home buyers' affordability (Ndung'u & Onyuma, 2020). However, some REITs, even with diligent ESG reporting, have been found to lack actionable sustainability strategies (Ionaşcu et al., 2020), while other REITs only prioritize social reporting to appease the stakeholders (Zahid & Ghazali, 2015). This highlights a gap in actionable practices that render REITs contributing to sustainable development.

2.3 Regulation and Policy

The role of regulation and policy on the growth of REIT markets is emphasized in the literature. A Spain-based study on REITs demonstrated REIT regulatory practices good governance and transparency in addition to their tax-efficient nature as a way to promote commercial real estate markets and macroeconomic factors such as employment rates, contributing to economic growth (SDG8) (Indrawan & Wahyuningsih, 2021; Marzuki & Newell, 2018). Equity REITs are mandated by law to be listed on the stock exchange, which gives access to raising capital for infrastructural development, especially since REIT regulation in some jurisdictions allows for a broader definition of REITs to include even cellphone towers like American Tower (Habbab & Kampouridis, 2024), as well as electric and gas distribution systems (Deloitte).

On the other hand, a Chinese study on utilizing the REIT financing model for infrastructure investment to alleviate pressure on government funds revealed legal and policy-related challenges. Therefore while REITs offer a sustainable financing option for infrastructure in developing countries, risk management strategies should be put in place (Wang et al., 2023). Furthermore, Deb (2020) posits that the relationship between governance and sustainable development is complex as there is a positive and negative relationship between governance and sustainable development, even though governance is a prerequisite for sustainable growth.

2.4 Progress Towards SDG Achievement in SSA

Studies have discovered that the construction industry is a potential contributor to all 17 SDGs, although more directly than ten goals (Fei et al., 2021). This further emphasizes the need for joint concerted efforts by the government and partners, as recommended by(Ionaşcu et al., 2020), to adequately address the 17 SDGs. However, with the varied REIT adoption pace across the globe, more established REIT markets are already experiencing progress toward SDG in the form of the enormous REIT contribution to the GDP at 85% ($72 trillion) as of 2021 (Bertoldi et al. 2021). On the other hand, SSA only has five countries with operational REITS (Joseph et al., 2020), and even then, only South Africa has about 33 REITs and only a handful of the rest. This points to a huge gap in leveraging the financial instrument to support SDGs in SSA, where there is still significantly high informal employment at 89%, manufacturing employment at 6% (United Nations, 2020), with small-scale industries receiving significantly less business financing than the rest of the world (United Nations, 2022); major infrastructural shortages to the point of nearly 300 out of 520 million rural dwellers lacking reliable road access (World Bank, 2019); the acute need for affordable housing and infrastructure due to rapid urbanization, with up to 51% of the urban population SSA living in slums (World Bank Data, 2019).

In comparison, some Asian REITs have aligned their strategies with specific SDGs, and this provides a model of how REITs may be effectively used to achieve sustainable development, for instance, Singapore's AIMS APAC REIT(SDGs 3,7,8,9)[1], Malaysia's ALSALAM REIT(SDGs8,9,11,13,16)[2], and UAE's TPL REIT (SDGs 3,6,9,11)[3]. REITs, therefore, can invest in infrastructural development, including telecommunications, transportation networks as well as commercial property, triggering economic growth (Wang et al., 2023; Turner, 2023).

Nonetheless, there are conflicting views as to whether or not REITs can substantially contribute to sustainable development, with some studies highlighting their ability to mobilize resources for sustainable projects (Bertoldi et al.,2021; Funari,2022), others stress the market condition and regulatory challenges (Diala,2021; Wang et al.,2023) hindering REIT adoption and performance. This showcases the need for a robust study on the long-term socio-economic impact of REITs in SSA, assessing the impact on SDGs, considering that the current literature focuses more on the financial performance aspect.

3.0 Research Methodology

The research methodology employed a literature review to assess current knowledge on the role of REITs in furthering sustainable development. Academic databases such as Google Scholar, Research Gate, and Academia. Edu, Emerald and JSTOR were explored to retrieve relevant literature. Search keywords used in the study included "REITs", "SDGs", "ESG", "Sustainable development", "Construction", "SSA", and "Sub-Saharan Africa"

Inclusion criteria were peer-reviewed journal articles and reports from reliable sources such as the World Bank, United Nations, and the Nations Association for Real Estate Investment Trusts from 2016-2014 that particularly addressed the topic of sustainable development. Relevant information was extracted and synthesized to create a clear picture of current knowledge and expose gaps for further study.

4.0 Findings and Discussion

The overlap between the real estate and construction sectors and sustainable development should be addressed. Goubran (2019) suggests that 17% of the SDG targets directly require the construction industry to achieve, and indirectly, another 27%. Goubran & Cucuzzella (2019), in a case study of a Quebec-based building, showed that it is possible to integrate all 17 SDGs into building projects by leveraging futuristic building designs and cutting-edge technologies(Qi et al., 2021), such as integrating IoT and BIM technologies (Nguyen, 2016) to create smart buildings that streamline maintenance reducing energy consumption and operational costs(SDG9). Construction technology companies like Giatec use IoT to create sensors to monitor emissions from concrete (Giatec, 2024). This is characteristic of the technology-powered intelligent REIT (REIT) (Hu, 2017) provides actionable ways to implement SDGs in the REIT sector.

Fei et al. (2021) highlighted the construction industry's potential toward the SDGs, which can be manifest in resource mobilization. REITs, aside from having access to capital on the stock exchange (Deloitte), are now exploring new financing mechanisms such as green bonds. For example, Acorn Holdings Ltd, a Kenyan-based REIT, has the Acorn green bond (Acorn Holdings Limited, 2019).

Poor REIT adoption in Africa has been attributed to regulatory challenges(Diala,2021) and market conditions. REITS have had widespread adoption and success in the US on the other hand (Moobelaa et al., 2022). Benchmarking (Dai & Kuosmanen, 2014) regulatory practices from such successful markets can help SSA countries streamline their regulation for more successful REIT markets, which can in turn partner with governments to address affordable housing challenges as is the case in Ghana (CAHF, 2020), or even independently provide the same as has been done the Acorn Holdings REIT in Kenya which specializes in Student accommodation and now affordable housing (Acorn, 2024) for young professionals, to promoting social equity and supporting SDGs 8 and 11.

Many REITs focus on growing their profit margin through sustainability practices that lower costs through energy efficiency and retrofits (PRI.nd; Borchersen-Keto, 2022). Governments can create collaborative Sustainable Urban Development Projects, for example, by working with REITs to restore old government buildings and repurpose them to provide affordable housing options that promote sustainable urban living because of reduced commutes.

5.0 Conclusion and Further Research

The government alone would take much longer to achieve SDGs. Beyond paying taxes, citizens mobilized a civil society organization, and the private sector had to do its bit in a concerted effort. REITs have been used to finance even infrastructure in Malaysia, China, and the US, and therefore a version of these results can be replicated in SSA to at least achieve the SDG that is most directly related to the real estate and construction industry, SDGs 9 and 11, with a ripple effect of economic growth (SDG8) through job creation An example of effective collaboration, is Rwanda's self-help model, where the government and some private organizations collaborate with women's groups to build affordable housing for the group members. As such, it is crucial to put in place capacity-building initiatives to enhance stakeholders' understanding of REITs and open minds to their potential impact on sustainable development.

A policy framework in Sub-Saharan Africa should be designed to support REITs and the real estate sector, with a focus on investment in areas aligned with SDGs like affordable housing and infrastructure. The framework should also focus on building technological infrastructure to support the sector, for example, smart cities, exploring the intelligent REIT (iREIT) model. There is a clear need for additional research to explore the role of REITs in advancing SDGs in SSA.

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[1]https://www.aimsapacreit.com/sustainability-framework.html
[2]https://www.insage.com.my/ir/interactiveAR/ALSREIT/interactiveAR2022/88/
[3]https://tplfunds.com/esg/

7.0 References

Acorn. (2024). Retrieved from https://acornholdingsafrica.com/integrated-real estate/#realestateinvestment

Acorn Holdings Limited. (2019). Acorn Holdings Limited Green Bond Framework. Nairobi: Acorn Holdings Limited.

Akhter, A., & Sangmi, M.-u.-D. (2015). Stock Market Awareness among the Educated Youth: A Micro-level Study in India. *The Journal of Business Perspective*.

Amos O. Arowoshegbe, & Uniamikogbo Emmanuel. (2016). Sustainability and Triple Bottom Line: An Overview of Two Interrelated Concepts. *Igbinedion University Journal of Accounting*, 2(January), 1–40.

Borchersen-Keto, S. (2022). Retrieved from NAREIT: https://www.reit.com/news/podcasts/retrofitting-buildings-seen-essential-step-reaching-net-zero-emissions-goals

Bertoldi, A., Prof, R., Viruly, F., & Ureru, U. (2021). Role of Residential Real Estate Investment Trusts (REITs) in Sub-Saharan Africa.

Boshoff, D., & Bredell, E. (2013). Introduction of REITs in South Africa: Transformation of the Listed Property Sector. Pretoria: University of Pretoria.

Bower, J. R. (2020). Housing Policies in Rwanda; Riding the Urbanisation Wave. IGC.

Brounen, D., & Marcato, G. (2018). Sustainable insights in public real estate performance: ESG scores and effects in REIT markets. *Berkeley Lab*.: Berkeley, CA, USA. https://buildings.lbl.gov/sites/default/files/ESG measures FinalVersion.pdf

Buckley, R., & Bower, J. (2020). Housing policies in Rwanda. *Policy Paper S-19108 RWA-1*, January 4.

CAHF. (2020). Affordable housing in Ghana: Market shaping indicators. South Africa: *Centre for Affordable Housing Finance in Africa*.

Caballero, P. (2019). The SDGs: Changing How Development is Understood. Global Policy, 10(January), 138–140. https://doi.org/10.1111/1758-5899.12629

Calderon, C., & Zeufack, A. G. (2020). Borrow with Sorrow? The Changing Risk Profile of Sub-Saharan Africa's Debt. Borrow with Sorrow? The Changing Risk Profile of Sub-Saharan Africa's Debt, January. https://doi.org/10.1596/1813-9450-9137

CFI. (2021). Random walk theory. A mathematical model of the stock market. Retrieved from www.corporatefinanceinstitute.com

Cletus Moobelaa & Nalumino Akakandelwab & Mutale Katyokac & David Manased & Wilfred Matipae & Dingayo Mzyechef & Victor Samwingag & Sambo Zuluh, 2022. "Barriers And Success Factors To The Adoption And Implementation Of Real Estate Investment Trusts (REITs) In African Real Estate Markets," AfRES 2022-030, *African Real Estate Society* (AfRES).

Coulibaly, B. S., Gandhi, D., & Senbet, L. W. (2019). Africa_Sovereign_Debt_Sustainability. 1–16.

Dai, X., & Kuosmanen, T. (2014). Best-practice benchmarking using clustering methods: Application to energy regulation. *Elsevier*.

Deb, A. (2020). *Governance and Sustainable Development Goals (SDGs): Exploring The Relationship Between Governance and SDGs Using an International Comparative Perspective*. Texas: Thesis submitted to the University of Texas Rio Grande Valley graduate college in partial fulfilment of the requirements for the Master of Public Affairs degree. 14.

Diala, O. A. (2021). Affordable Housing Ambidexterity of Real Estate Investment Trusts: SWOT Analysis for N-REITs. *European Journal of Business and Management*, 13(12). https://doi.org/10.7176/ejbm/13-12-02

Deloitte. (n.d.). REITs and infrastructure projects.

Fei, W., Opoku, A., Agyekum, K., Oppon, J., Ahmed, V., Chen, C., & Lok, K. (2021). The Critical Role of the Construction Industry in Achieving the Sustainable Development Goals (SDGs): Delivering Projects for the Common Good. *MDPI*.

Feng, Z., & Wu, Z. (2022). Local Economy, Asset Location, and REIT Firm Growth. *Journal of Real Estate Finance and Economics*, 65(1), 75–102. https://doi.org/10.1007/s11146-021-09822-8

Fuje, H., Ouedraogo, R., Yao Jiaxiong, Diaby Mohamed, & Ouattara Franck. (2022). Regional Inequalities in Sub-Saharan Africa.

Funari, N. (2022, 02 28). Nareit Study Shows the Growth and Benefits of Global REIT Adoption. Retrieved from *NAREIT*: https://www.reit.com/news/blog/market-commentary/nareit-study-shows-growth-and-benefits-global-reit-adoption

Giatec. (2024, 6 1). Retrieved from https://www.giatecscientific.com/products/

Gogineni, Sridhar and Jain, Pawan and Upadhyay, Arun. (2022). REIT Regulations and Valuation: A Global Perspective. Available at *SSRN*: https://ssrn.com/abstract=4310581 or http://dx.doi.org/10.2139/ssrn.4310581

Gondo, N. (2019). How to Invest: Exactly How Much Daily Volume Should You Look For In A Great Stock? Investors Business Daily.

Goubran, S. (2019). On the Role of Construction in Achieving the SDGs. *Journal of Sustainability Research*, 1(2), 1–52. https://doi.org/10.20900/jsr20190020

Goubran, S., & Cucuzzella, C. (2019). Integrating the Sustainable Development Goals in Building Projects. *Journal of Sustainability Research*, 1(2). https://doi.org/10.20900/jsr20190010

Habbab, F. Z., & Kampouridis, M. (2024). An in-depth investigation of five machine learning algorithms for optimizing mixed-asset portfolios, including REITs. *Science Direct*.

Hu, S. (2017). Intelligent REITs in the information age. *Research Gate*.

Indrawan, I., & Wahyuningsih. (2021). Literature Review on REITs and Islamic REITs and Lessons Learned for. Unpublished.

Ionaşcu, E., Mironiuc, M., Anghel, I., & Huian, M. C. (2020). The involvement of real estate companies in sustainable development analysis from the SDGs reporting perspective. *Sustainability* (Switzerland), 12(3), 1–24. https://doi.org/10.3390/su12030798

Ishak, S. Z., Nusa, F. N. M., Ahmad, R., & Shafien, S. (2022). *The Comparison of Malaysian Real Estate Investment Trusts (M-REITs) and Islamic REITs with China-REITs (C-REITs) and Japan Infrastructure Fund for Railway Infrastructure Development in Malaysia: A Review*. *2022* IEEE International Conference on Automatic Control and Intelligent Systems, I2CACIS 2022 - Proceedings, June, 152–157. https://doi.org/10.1109/I2CACIS54679.2022.9815484

Joseph, D., Olanrewaju, O., Wayne, J., & Diouf, W. (2020). The Potential for Developing a Residential Real Estate Investment. *Centre for Affordable Housing Finance in Africa*.

Keke,V;Emoh, F. I. (2019). Real Estate Investment Trusts (Reits) and Mortgage-Backed Securities (Mbs) as Emerging Trends for Financing Real Estate Development in the Nigerian Capital Market. *International Journal of Civil Engineering, Construction and Estate Management*, 15(2), 9–25. www.eajournals.org

Ma, X. (2020). *Future Development Trends of REITs in Mainland China*. E3S Web of Conferences, pp. 218, 1–5. https://doi.org/10.1051/e3sconf/202021802011

Mariani, M., Amoruso, P., Caragnano, A., & Zito, M. (2018). Green Real Estate: Does It Create Value? Financial and Sustainability Analysis on European Green REITs. *International Journal of Business and Management*, 13(7), 80. https://doi.org/10.5539/ijbm.v13n7p80

Marsden, J. H., & Wilkinson, V. A. (2018). *Big data analytics and corporate social responsibility: Making sustainability science part of the bottom line*. IEEE International Professional Communication Conference, 2018-July, pp. 51–60. https://doi.org/10.1109/ProComm.2018.00019

Marzuki, M. J., & Newell, G. (2018). The emergence of Spanish REITs. *Journal of Property Investment and Finance*, 36(5), 495–508. https://doi.org/10.1108/JPIF-05-2018-0032

Mawdsley, E. (2015). DFID, the Private Sector and the Re-centering of an Economic Growth Agenda in International Development. *Global Society*, 29(3), 339–358. https://doi.org/10.1080/13600826.2015.1031092

Minh Hiep, P., Hoang Tien, N., Paul Dana, L., Rafal Kuc, B., Van Tien, N., Chi Minh City, H., & Vu Xuan Ha, V. (2021). Enhancing Social Responsibility and Sustainability in Real Estate Industry. *Turkish Journal of Computer and Mathematics Education*, 12(14), 4999–5013.

Morri, G., Anconetani, R., & Benfari, L. (2020). Greenness and financial performance of European REITs. *Journal of European Real Estate Research*, 14(1), 40–61. https://doi.org/10.1108/JERER-05-2020-0030

Ndung'u, D., & Onyuma, S. (2020). Financing Affordable Housing Through Real Estate Investment Trusts in Africa. *Africa Growth Institute*.

Nguyen, H. (2016). *Integration of BIM and IoT to Improve the Building Performance for Occupants Perspective*. Stockholm: Masters Thesis: Royal Institute of Technology.

Odusola, A., Cornia, G. A., Bhorat, H., & Conceição, P. (2019). Income Inequality Trends in Sub-Saharan Africa Divergence, Determinants, and Consequences: Introduction, Motivation and Overview. *In Nations Development Programme (UNDP) Africa Reports*.

Okada, K., & Shinkuma, T. (2022). Transparency and natural resources in sub-Saharan Africa. *Resources Policy*, 76(February), 102574. https://doi.org/10.1016/j.resourpol.2022.102574

PRI. (n.d.). A Strategy For Investing In Sustainable Reits. Retrieved from https://www.unpri.org/download?ac=6411

Qi, B., Razkenari, M., Costin, A., Kibert, C., & Fu, M. (2021). A systematic review of emerging technologies in industrialized construction. *Journal of Building Engineering*.

Scheyvens, R., Banks, G., & Hughes, E. (2016). The Private Sector and the SDGs: The

Need to Move Beyond 'Business as Usual.' *Sustainable Development*, 24(6), 371–382. https://doi.org/10.1002/sd.1623

Turner, D. (2023). A Tailwind for Towers: A Closer Look at the Cell Tower REIT Sector.

United Nations. (2020). Economic and Social Council-SDG REPORT (Vol. 06176, Issue April).

United Nations. (2021). Economic and Social Council -SDG REPORT. 05814(April), pp. 1–27.

United Nations. (2022). Economic and Social Council-SDG (Vol. 2017, Issue April).

United Nations. (2023). The-Sustainable-Development-Goals-Report-2023.pdf.

UNSD. (2020). Global indicator framework for the Sustainable Development Goals and targets of the 2030 Agenda for Sustainable Development. Work of the Statistical Commission about the 2030 Agenda for Sustainable Development, pp. 1–21. https://unstats.un.org/sdgs/indicators/Global Indicator Framework after 2019 refinement_Eng.pdf%0Ahttps://unstats.un.org/sdgs/indicators/Global Indicator Framework_A.RES.71.313 Annex.pdf

The 'Massive, Little' Houses: 'Prefabs', A Solution for Informal Settlement Housing Crisis in South Africa! A Scoping Review

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Abstract:

Unlike most continents, Africa still grapples with urban informality, where housing shortages affect most people living in substandard conditions. Prefabricated housing (PH) presents an alternative option that provides a quicker and cheaper housing supply, although it currently lags behind demand. This paper examines whether 1) informal settlements can be upgraded using prefabricated/modular houses, 2) these housing types are desirable to occupants, and 3) alternative houses should receive as much emphasis and policy support as possible, particularly considering the challenges experienced during the COVID-19 pandemic. Based on a comprehensive literature survey utilising a scoping review methodology, the paper indicates that stakeholders such as developers, financiers, and occupants of prefabricated housing increasingly embrace PH despite its challenges. The literature unanimously agrees that substantial efforts are required to catalyse more investment in PH regarding further research, education, supply chain improvements, and enhanced communication and collaboration among industry stakeholders. Additionally, numerous research gaps need addressing, including in-depth examinations of PH's contextual feasibility and performance across different geographical areas. The paper recommends that South African governments adopt PH as an alternative housing solution, as it is faster and cheaper, thereby aiding in achieving the 2030 Sustainable Development Goal 11.

Keywords:

Informal settlements, Modular housing, Prefabricated housing, Sustainable development, Urbanisation

1 Introduction

Adequate housing encompasses a set of minimum criteria, including legal security of tenure, affordability, availability of services, materials, facilities, infrastructure, habitability, accessibility, location, and cultural adequacy (Maphumulo, 2016). Providing sustainable and affordable housing remains a global challenge, and Africa is no exception to this crisis. Despite some progress, reducing the affordable housing backlog has been formidable since 1994 (Turok & Visagie, 2018). The challenges of affordable housing delivery arise from various market spheres, including political, socio-economic, and environmental factors. Consequently, these multifaceted challenges have no singular solution (Turok & Visagie, 2018). Current mechanisms for affordable housing delivery predominantly focus on conventional 'brick and mortar' solutions. However, modular alternatives, proven viable over decades, account for only a negligible portion of efforts to address the housing deficit despite their recognition for being more environmentally friendly, cost-effective, faster to develop, and of higher quality than traditional construction methods (Turok & Visagie, 2018). The limited adoption of modular housing solutions highlights the need for a broader, more innovative approach to housing policy and practice.

Extensive research conducted globally, and to a lesser extent in South Africa and other African countries such as Nigeria, generally identifies prefabricated housing (PH) as a viable alternative to affordable housing (Maphumulo, 2016). Researchers from other developing countries, including India and Malaysia, advocate exploring PH to meet their affordable low-cost housing targets (Husain & Shariq, 2018). However, some studies, such as those on shipping container homes in Lagos, have found that costs can be comparable to, or even exceed, those of conventional buildings when similar standards are applied (Sholanke et al., 2019). Unlike most continents, Africa struggles with urban informality, where housing shortages affect most people living in substandard conditions. The provision of housing in Africa remains slow and costly, posing significant challenges to meeting the 2030 Sustainable Development Goal 11, which aims to make cities and human settlements inclusive, safe, resilient, and sustainable (Weaich et al., 2023).

In the past decade, there has been significant debate across Europe regarding the housing crisis, primarily focusing on issues of affordability. However, there has been limited discussion about 'tiny, manufactured houses' as a potential solution. Given the more severe challenges it faces concerning urban informality, housing provision, and affordability (Simbanegavi et al., 2021), South Africa could benefit significantly from this debate.

2 Literature Review – How Best to Deliver Prefabricated Housing

The most effective approach to overcoming knowledge barriers related to prefabricated housing (PH) is targeted training. These barriers primarily stem from limited experience, skills, and understanding of PH processes (Jiang et al., 2020). A crucial barrier is the limited comprehension of the PH business model, which includes understanding the business framework, tools, stakeholder roles, PH approaches and inspections, PH designs and module installations, and the associated costs across the entire supply chain (Gan et al., 2018a). A significant knowledge barrier in developing countries is the lack of on-site experience. This includes a shortage of experienced technicians, collaborative groups, manufacturers, designers, PH component suppliers, and skilled operators, such as crane operators, alongside a general lack of specialised expertise (Wuni & Shen, 2020). Given the relative newness of the modern PH industry, one of the more challenging barriers to overcome is the objective determination of value-added benefits (Arif et al., 2017).

There is a need to standardise prefabricated housing (PH) to address technical barriers effectively. Complex interfacing between modules, extended lead times, highly restrictive tolerances, and other technical anomalies differentiate the design and engineering of PH from conventional construction methods. PH is less forgiving and more costly regarding error rectification (Wuni & Shen, 2020). Design changes are inflexible due to the inability to modify designs once inaccuracies are identified on-site (El-Abidi & Ghazalia, 2015). Additional design barriers include insufficient integrated design capacity, transportation restrictions, poor cooperation between multi-interface components, and issues such as leakages, cracks, and joining problems. Designs also necessitate the repetition of consistent layouts to achieve greater efficiency and economic feasibility (Wuni & Shen, 2020). The lack of standardised components, research centres, research information, development centres, technology, and testing institutes, coupled with insufficient manufacturing and supply capacities, further complicates the situation (Gan et al., 2018a). While improvements in handling strong winds and other turbulences, such as earthquakes, have been reported, they still need to be validated with certainty, preventing large-scale implementation (Wuni & Shen, 2020).

Innovative financing mechanisms are essential to overcoming financial barriers in prefabricated housing (PH). These barriers include challenges related to project costs, risks, cash flows, and financial decision-making in PH projects. The most significant barrier is PH's high initial capital cost, which encompasses establishing modular factories, securing yards, hiring specialised labour, and managing exorbitant fixed overheads and sunk capital costs in factories (Wu et al., 2019). These high initial costs translate to higher bidding prices by contractors, leading small to medium enterprises to opt for lower bids instead of value-added benefits (Wuni & Shen, 2020).

Due to the uncertain demand for prefabricated housing (PH), developers may face prolonged periods of holding onto properties post-completion, making it challenging to achieve economies of scale and secure quicker returns on investment (Wuni & Shen, 2020). Breaking even or realising returns on substantial initial capital investments can take an extended period, which serves as a significant disincentive for developers and complicates the process of obtaining finance for PH projects (Wuni & Shen, 2020). The necessity for early commitment and upfront payments is a significant deterrent for banks; typically, clients or banks must make a full payment before the modules leave the factory, leaving them without a tangible asset as collateral (Feutz, 2019; Harikrishnan, 2019). In some countries like New Zealand, banks will not release funding until the modules are assembled on-site. Although the rapid construction process of PH can facilitate faster solvency and cash flow generation, the fragmented supply chain and the complex network of stakeholders complicate contractual payment terms for banks (Wuni & Shen, 2020).

In some countries with limited manufacturing capacity, exorbitant logistics costs arise from the necessity of transporting prefabricated housing (PH) components from neighbouring countries (Wuni & Shen, 2020). Additionally, many countries lack innovative financing mechanisms tailored to the PH process (Feutz, 2019). While PH can achieve cost savings through reduced labour requirements, these savings are often offset by the higher wages associated with the specialised and high-skill labour needed (Wu et al., 2019). Further, the unexpected costs related to redesigning, additional planning, and error rectification further complicate PH's financial feasibility and adoption (Wu et al., 2019).

Prefabricated housing (PH) can be positioned as a cheaper and more robust alternative if researchers and project managers focus on analysing, modelling, configuring, and optimising the supply chain to achieve cost minimisation (Wu et al., 2019). Identifying, quantifying, and monetising the intangible benefits of PH can enhance the existing cost-benefit analysis framework, thereby strengthening the case for PH as a cost-effective solution (Wuni & Shen, 2020). To improve lending for PH projects, innovative financing vehicles tailored to the specific processes of PH could be developed, such as long-term loan schemes provided in advance to developers and contractors (Feutz, 2019). Additionally, public-private partnerships should be considered as potential financing sources and investment vehicles for PH (Gan et al., 2018).

Optimising supply chain management strategies for prefabricated housing (PH) is crucial due to the inherent conflicts with conventional construction processes. The PH supply chain involves a longer value chain, a complex web of stakeholders, and intricate procurement and contractual arrangements (Wuni & Shen, 2020). PH's unique, relatively nascent, unintegrated, and untested business model presents multi-layered barriers that intertwine with other challenges, slowing the industry's adaptation (Gan et al., 2018). Transportation logistics pose additional overlapping barriers, affecting both financial and technical aspects. These include cross-border logistics, insufficient modes of transporting larger modules, load restrictions, and damages incurred during transportation, significantly hindering the PH process (Jiang et al., 2020). Adequate storage of modules, whether on-site or offsite, can also be challenging if schedules are not meticulously managed and synchronised (Salama et al., 2018). The frequent need for mobile cranes to hoist modules and components further complicates operations, especially in underdeveloped areas. A lack of standardisation, collaborative contracts, information and communication platforms, best management practices, training, labour upskilling, and capable managers exacerbates these challenges (Wuni & Shen, 2020).

Supply chain management strategies must be optimised through the collaboration of research institutions and industry practitioners (Gan et al., 2018a). Reducing the complexity of project management and ensuring the collaboration of all stakeholders from the early stages of projects are essential to prevent PH processes from becoming a legitimate barrier (Gan et al., 2018a). Enhancing coordination and communication between fragmented parts of the supply chain can be achieved by leveraging various smart technologies and integrated project delivery models, such as Building Information Modelling (BIM) and electronic file transfers, to decrease risk and improve project performance (Jiang et al., 2020). Additionally, the industry should consider prefabricating modules closer to construction sites, where feasible, to mitigate transportation logistics challenges (Wuni & Shen, 2020).

Broad regulatory systems and government support are essential to guide, ignite, and regulate the implementation of valuable innovations in the prefabricated housing (PH) industry (Jiang et al., 2020). The absence of standards and regulations presents significant barriers. The lack of government incentives, subsidies, and preferential tax policies are major policy obstacles to investment in the PH sector (Aziz & Abdullah, 2015). Additional barriers include the lack of technical guidance and information, design codes and standards, and inadequate policies and regulations. However, countries such as Japan, the United States, Sweden, and the United Kingdom, where the investment in PH is highest, have made significant advancements in these areas (Gan et al., 2018). Restrictive and unfavourable planning and building regulations further challenge the adoption of PH in some countries. Therefore, most countries need to establish regulatory frameworks to implement, assess, rate, and certify PH systems (Wuni & Shen, 2020).

Governments and developers, possessing the highest degree of power and centrality, must ensure the establishment of comprehensive policies, guidelines, and regulations in developing countries (Jiang et al., 2020). Governments should act as catalysts for changing perceptions by investing in prefabricated housing (PH) projects, stimulating the market through incentives for developers, and establishing PH tenders (Aziz & Abdullah, 2015). Legal, regulatory, and technical support structures should include risk aversion measures, design codes and standards, technical guidance, best practice manuals, and success factors for industry practitioners (Wuni & Shen, 2020). These efforts should also extend to novice developers and potential clients who may be interested in PH but need to be more informed about the technology (Gan et al., 2018). The COVID-19 pandemic has underscored the importance of alternative housing solutions, highlighting the need for these to receive equal emphasis and policy support.

Nurturing a cultural shift is essential to overcoming industry barriers in developing more prefabricated housing (PH) projects. The industry's historical reputation for being conservative and slow to adopt new and innovative solutions is a primary recurring barrier (Wong et al., 2018). This barrier is further reinforced by the dominance of established conventional systems, with stakeholders fearing structural industry change (Wuni & Shen, 2020). Additionally, the lack of standardisation in PH forces the industry to cost modules using standard measurement methods from conventional construction, further hindering progress (Jiang et al., 2020). One of the most frequently cited overlapping barriers is the unfavourable organisational systems of PH and its fragmentation at both the industry and project levels (Steinhardt et al., 2019).

Product demand uncertainty and supplier availability exacerbate risk aversion among clients and banks in the prefabricated housing (PH) industry. The monopoly of construction techniques by prominent manufacturers and suppliers is another counterproductive tactic, as it hinders knowledge dissemination and slows down investor and developer interest in utilising PH. Turok and Visagie (2018) also highlight the challenge posed by the quality and quantity of retiring shipping containers relative to demand. Suppose the technology were to be rapidly adopted. In that case, it is unlikely that the number of retiring containers would meet the demand, and even if the supply were sufficient, there would be concerns about whether these containers are of habitable quality (Turok & Visagie, 2018).

Nurturing a cultural shift in the prefabricated housing (PH) industry is a collaborative effort that requires investment from governments, researchers, and industry practitioners. This collaborative effort is crucial for raising awareness, changing perceptions, and improving investment in PH (Wong et al., 2018). Governments should take the lead in stimulating demand, as demonstrated in some Asian countries and the UK (Wuni & Shen, 2019). Additionally, technical and research institutions need financial support to pursue innovative technologies, such as Building Information Modelling (BIM), and to develop inventions that address current technical challenges, including structural solutions for natural disasters and severe weather conditions like typhoons (Jiang et al., 2020).

To overcome aesthetic barriers, with designs often referred to as 'brutalist architecture', less monotonous designs and structures are essential in the prefabricated housing (PH) industry. There is a perceived fear that PH leads to monotonous designs and structures, resulting in urban fabrics with poorer aesthetics and standardised cities of blandness and uniformity, breeds scepticism toward PH (Wuni & Shen, 2020). Concerns also exist regarding PH's flexibility and customisation capabilities, as customisation and flexibility of modules often come at a financial loss for those specific units (Agatsiva, 2019). Additionally, space and height limitations are frequently cited as challenges (Nduka et al., 2018). Social acceptance poses a significant barrier, with associations of the raw steel aesthetic of containers being perceived as 'poor' and lower-value housing (Zaki & Danraka, 2015). These perceptions negatively affect clients' acceptance of shipping container housing as a viable construction alternative to traditional building methods (Kamara, 2018).

However, architects, contractors, designers, and engineers have already begun pushing boundaries with groundbreaking design options. Improved engineering and module design can further enhance this progress. Turok and Visagie (2018) documented that while 60% of users initially reject the method due to its steel aesthetic, 88% of participants are swayed to accept it when cladded with other materials to resemble conventional housing methods. This approach also addresses concerns of monotony in appearance, as various materials can be used to create diverse and appealing designs.

3 Research Methodology

This research study employs a scoping review methodology to map the key concepts, types of evidence, and research gaps related to upgrading informal settlements using prefabricated/modular houses. Scoping reviews are beneficial for examining emerging areas, clarifying concepts, and identifying the types of available evidence in a given field (Arksey & O'Malley, 2005). The primary research question guiding this scoping review is: "What is the current state of research on upgrading informal settlements using prefabricated/modular houses?" This question aims to uncover the breadth of research available, key themes, and gaps that must be addressed. A comprehensive literature search was conducted across multiple databases housed by Google Scholar. The search terms included combinations of keywords such as “prefabricated housing,” “modular construction,” “informal settlements,” “sustainable housing,” and “upgrading.” The search was limited to peer-reviewed articles, conference papers, and published dissertations or theses focusing on relevant literature published in English over the past ten years.

Inclusion criteria:

- Studies focused on using prefabricated or modular housing for upgrading informal settlements.
- Research articles, review papers, and case studies.
- Publications in English.

Exclusion criteria:

- Studies not focused on housing or informal settlements.
- Articles not available in full text.
- Publications in languages other than English.

Data was extracted from selected articles using a standardised data extraction form. The form was used to capture information on the author(s), year of publication, study location, objectives, methodology, key findings, and conclusions. This process ensured consistency and comprehensiveness in capturing relevant data from each source. The extracted data was analysed thematically. Themes were identified based on the recurring concepts and findings across the studies. This thematic analysis aided in mapping out the key areas of focus in the existing literature and identifying gaps where further research is needed (Braun & Clarke, 2006; Weaich et al., 2024). The results are presented in a narrative format. The narrative discussed the main themes identified, the types of evidence available, and gaps in the research. This presentation provides a clear and comprehensive overview of the current state of knowledge on the topic. As this is a review of existing literature, no primary data collection involving human subjects was conducted. This methodology ensures a systematic and comprehensive approach to reviewing existing literature, providing valuable insights into using prefabricated housing for upgrading informal settlements.

4 Findings and Discussion

Theme 1: Why Prefabricated Housing Can Be an Alternative for Informal Settlements.

Terms such as offsite, prefabricated, and modular construction are often used interchangeably to describe various systems and approaches to offsite construction. Modular construction specifically involves the creation of standardised, complete modules offsite (typically in a factory), which are then transported to and assembled on-site to form more significant buildings, such as townhouses, apartments, and high-rise offices (Thompson, 2019). Modular construction is widely recognised for its significant cost, time, and energy savings. Feutz (2019) states that recent modular projects have demonstrated a "solid track record of accelerating project timelines by 20-50 per cent," while achieving 20 per cent and above construction cost savings. Offsite/modular construction is experiencing a revival and driving a paradigm shift to revolutionise the real estate sector. The industry has grown significantly due to numerous global real estate challenges (Feutz, 2019). Many researchers believe modular construction could address some of the industry's long-standing challenges if fully realised (Wuni & Shen, 2020). Despite the construction industry's general conservatism and slow adoption of progressive innovation, modular construction offers various benefits, including repeatable structures, transportable unit sizes, quality control, affordability, and consistency (Thompson, 2019). Prefabricated housing (PH) also enhances workplace safety, as high-rise buildings can be constructed at ground level and in safer factory environments (Thompson, 2019).

The following continuum of prefabrication construction methods and components enables the realisation of these benefits. Complete/mobile prefabrication comprises factory-completed buildings delivered to a building site (Thompson, 2019). Pods are smaller volumetric units (such as toilets or kitchens) connected to larger structural units on-site (Wuni & Shen, 2020). Panels are non-volumetric frames, such as timber/steel-framed, structural insulated, and precast concrete panels, joined on-site to form volumetric units (Thompson, 2019). Finally, subassembly components, such as doors, windows, and trusses, are pre-cut or preassembled and are not feasible to produce on-site; these components are essentially part of the conventional construction industry (Steinhardt et al., 2019).

Theme 2: Investments into Prefabricated Housing – Challenges and Risks

Investment in prefabricated housing (PH) is occurring at much slower rates globally than expected, especially considering its well-documented benefits over conventional housing. These benefits include lower running costs, faster all-weather turnaround times due to factory production, safer working environments, and better environmental outcomes due to minimised waste (Steinhardt et al., 2019). Consequently, tiny, manufactured housing offers a quicker and cheaper housing supply, lagging behind demand in most African cities. Despite these advantages, stakeholders such as developers, financiers, and occupants of modular/prefabricated housing face significant challenges. Given the overwhelming benefits and feasibility claims, the global consensus is that the development of PH as a viable alternative is progressing too slowly (Gan et al., 2018).

The sluggish uptake of PH has prompted researchers to document the barriers contributing to slow investment. Wuni and Shen (2020) highlight how uninformed perceptions, conservatism, and scepticism among stakeholders unduly hinder investment in modular construction. Since its modern resurgence in the 1990s, modular construction (PH) has faced poor attitudes, low confidence, negative mindsets, and stigmas from the construction industry, and these long-standing barriers persist today (Wuni & Shen, 2020). Claims that modular homes have lower values and are too expensive lead to poor social acceptability due to suspicions around quality and value. Additionally, perceptions that rapid uptake will limit design creativity and negative sentiments from past failures hinder acceptance (Wuni & Shen, 2020). Despite numerous global examples contradicting these perceptions in recent decades, the belief that PH is more expensive than conventional housing remains one of the longest-standing barriers. This perception is particularly difficult to dispel given the many factors that must be considered, such as size and quality (Arif et al., 2017).

Theme 3: Minimising the Risks Associated with Prefabricated Housing

Though variable, the supply chain of PH consists primarily of four stages: planning, modular design, and statutory approval; concurrent site preparation and offsite manufacturing of modules/components; temporary storage and transportation of modules to the destination; and on-site installation and assembly of modular units to form the finished building. This prefabrication process affords numerous benefits to all stakeholders involved, central to the contracting firms and the supply network (Sooriyamudalige et al., 2019). Three classes of firms are involved in modular construction: integrated firms that manufacture products and perform site installations, manufacturing firms that only produce products, and builder firms that only conduct on-site installation of prefab products (Steinhardt et al., 2019). Other central stakeholders include designers and engineers, flanked by end-users, investors, and developers who commission the project and use the final product (Gan et al., 2018). Supporting these central stakeholders are regulatory and institutional frameworks and other technical support institutions that provide the macroeconomic, environmental, technical, regulatory, social, and other industry-related policy frameworks that enable the prefabrication industry (Steinhardt et al., 2019).

Developers often avoid affordable housing due to insufficient returns, complex financing processes, and a lack of sustainability (Thompson, 2019). Some consider offsite manufacturing a panacea to traditional affordable housing construction challenges, and researchers have documented its benefits for decades to support this narrative (Harikrishnan, 2019). While the uptake has yet to be at the expected rates, several

developed and developing countries are beginning to embrace alternative construction methods to alleviate their severe affordable housing deficits (Husain & Shariq, 2018). Modular construction has gained popularity globally due to challenges such as rising construction costs, unprecedented housing demand, and tight labour markets. The sector grew by 62% in the US to reach $3.3 billion in 2016 alone (Feutz, 2019).
Some sceptics of modular construction have valid arguments against its adoption in specific contexts. For example, some container housing programs, though well-intentioned, end up compromised due to political interference. In Shanghai, container housing has created class and social divisions, with policies evicting unwanted social groups into inadequate conditions under the guise of public safety and urban planning (Ling, 2020). Such practices reinforce social hierarchies and contribute to a lifetime aversion to container housing among those affected.

The Shanghai example mirrors the experiences of many African citizens enduring inadequate housing conditions. Agatsiva (2019) notes that Kenyan survey participants view non-brick housing as second-grade. Social status is attached to the steel aesthetic of container housing, which is considered less trendy, leading people to prefer what is popular (Sholanke et al., 2019). In Lagos, Sholanke et al. (2019) advocate that shipping container houses should only be considered once they are made cheaper and trendier. Similar findings apply to Nigeria (Nduka et al., 2018). Social acceptability is a significant barrier to adopting shipping containers as housing alternatives in most developing countries. In Malaysia, there is a 45% acceptance rate for container housing, while in South Africa, the acceptance rate is 40%. However, studies confirm that many participants who reject the raw corrugated finish are swayed when the container is clad to resemble conventional buildings (Kamara, 2018). Maphumulo (2016) found that shipping containers are more accepted in rental housing typologies in Johannesburg but not for permanent homes. Turok and Visagie (2018) suggest that cost savings in container housing only manifest with repetition, and single-story developments are often more expensive than conventional housing equivalents.

Despite the modular industry's benefits, global growth, and momentum, even the most progressive countries face unique hurdles (Feutz, 2019; Harikrishnan, 2019). Some attitudinal barriers are valid and more challenging to shift, requiring stakeholders' time, education, and training. Risk aversion among clients who view modular homes as "untested" technology perpetuates poor attitudes and sentiments (Wuni & Shen, 2020). Addressing attitudinal barriers requires collaboration among all key real estate practitioners to change mindsets and stigmas associated with PH (Aziz & Abdullah, 2015). As the most significant construction clients, governments should lead by initiating PH projects and demonstrating the feasibility of PH, as seen in Hong Kong, the UK, Singapore, Sweden, and China (Jiang et al., 2020; Wuni & Shen, 2020). Researchers can use their platforms to disseminate knowledge about PH and eliminate unwarranted stigmas. Knowledge barriers can be overcome through collaborations between educational institutions, engineers, and leading industry practitioners, offering more seminars, courses, and training programs to improve the skills and knowledge of developers, contractors, lenders, and end-users (Sholanke et al., 2019; Jiang et al., 2020).

5 Conclusion and Further Research

The literature consistently identifies prefabricated housing (PH) as a viable alternative for individuals living in informal settlements, primarily due to its affordability. Research unanimously agrees that significant efforts are required to catalyse more investment in PH, including enhanced research, education, supply chain improvements, and better communication and collaboration among industry stakeholders. The paper recommends that African governments adopt PH as a strategy to achieve the 2030 Sustainable Development Goal 11, which aims to make cities inclusive, safe, resilient, and sustainable. PH is recommended due to its lower construction costs and the critical need for faster delivery in an increasingly urbanised world. Expediting investments in PH could significantly contribute to eradicating housing informality in many African countries. From a research perspective, numerous gaps still need to be addressed, including the need for in-depth examinations of the contextual feasibility and performance of PH across different geographical areas.

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7 References

Agatsiva, C.K., 2019. *An Assessment of Cargo Containers Used to Provide Affordable Housing in Kenya: A Case of Embakasi West Constituency, Nairobi County* (Doctoral dissertation, University of Nairobi).

Arif, M., Killian, P., Goulding, J., Wood, G., & Kaushik, A. (2017). *Barriers and Challenges for Offsite Construction in UK Housing Sector.* Salford: University of Salford.

Arksey, H. & O'Malley, L. (2005). 'Scoping studies: towards a methodological framework', *International Journal of Social Research Methodology*, 8(1), pp. 19–32. doi: 10.1080/1364557032000119616.

Aziz, S., & Abdullah, M. R. (2015). *Modular Construction System in Malaysia: Issues for Research in Sustaining an Affordable Home Project*. Perak: Universiti Teknologi MARA.

Braun, V. & Clarke, V. (2006). 'Using thematic analysis in psychology', Qualitative Research in Psychology, 3(2), pp. 77–101. doi: 10.1191/1478088706qp063oa.

Creswell, J. W., & Creswell, D. J. (2018). Research Design (Fifth Edition Ed). Los Angeles: *Sage Publications*.

El-Abidi, K. M., & Ghazalia, F. E. (2015). Motivations and Limitations of Prefabricated Building: An Overview. *Applied Mechanics and Materials*, 802(1), 668-675.

Feutz, D. (2019). The Hurdles to Financing Modular Development. *Cornell Real Estate Review*, 17(23), 106–111.

Gan, X., Chang, R., & Wen, T. (2018). Overcoming Barriers to Offsite Construction through Engaging Stakeholders: A Two-Mode Social Network Analysis. *Journal of Cleaner Production*, 201(1), 735-747.

Gan, X., Chang, R., Zuo, J., Wen, T., & Zillante, G. (2018a). Barriers to the Transition Towards Offsite Construction in China: An Interpretive Structural Modelling Approach. *Journal of Cleaner Production*, 197(1), 8-18.

Harikrishnan, U. S. (2019). PREFABRICATED HOUSING IN AUSTRALIA: IDENTIFYING THE FINANCIAL BARRIERS. *International Journal of Civil Engineering and Technology*, 10(3), 488–493.

Husain, S. F., & Shariq, M. (2018). Low-Cost PH - A Review. Uttarakhand: *ResearchGate*.

Jiang, W., Huang, Z., Peng, Y., Fang, Y., & Cao, Y. (2020). Factors affecting prefabricated construction promotion in China: A structural equation modelling approach. *PLOS ONE*, 15(1), 1-19.

Kamara, H. (2018). *A Market Research for the Development of Container Housing Units for the Asheshi Community*. Applied Project Report, Asheshi University College: Asheshi.

Ling, M. (2020). Container housing: Formal informality and de-territorialised homemaking amid bulldozer urbanism in Shanghai. *Urban Studies*, 00(0), 1–17.

Maphumulo, M. (2016). *Implications for Using Shipping Containers to Provide Affordable Housing*. Research Report, University of the Witwatersrand: Johannesburg.

Nduka, D. O., Mosaku, T., Omosa, O. C., & James, O. D. (2018). Unit (ISBU) For the Provision of Habitable Homes: Enablers and Challenges. *International Journal of Mechanical Engineering and Technology*, 9(13), 340-352.

Salama, T., Moselhi, O., & Alhussein, M. (2018). *Modular Industry - Character & Barriers to its Increased Market Share.* Hollywood: University of Alberta Library, Edmonton, Canada.

Sholanke, A. B., Opoko, A. P., Onakoya, A. O., & Adigun, T. F. (2019). Awareness Level and Adoption of Modular Construction for Affordable Housing in Nigeria: Architects' Perspective. *International Journal of Innovative Technology and Exploring Engineering*, 8(9), 2278-3075.

Simbanegavi, P., Chigwenya, A. & Poshayi, P. P (2021). *Innovative Investments: Revitalise Townships into Sustainable Human Settlements in South Africa*. The Economic Forum Conference Proceedings on International Research and Innovation, Johannesburg, South Africa: In 'Creating Sustainable Built Infrastructure, Moving forward through research & innovation' Dlamini, S (ed) 15-16 July 2021. ISBN: 978-0-620-92829-8 (e-book) pp. 83-94

Sooriyamudalige, N., Domingo, N., Childerhouse, P., & Shehzad, W. (2019). *Supply Chain of Prefabricated Housing Construction: A Case Research of New Zealand*. Queensland: Central Queensland University.

Steinhardt, D., Manley, K., Bildsten, L., & Widen, K. (2019). The structure of emergent prefabricated housing industries: a comparative case research of Australia and Sweden. *Construction Management and Economics*, 38(6), 483-501.

Thompson, J. (2019). Modular Construction: A Solution to Affordable Housing Challenges. *Cornell Real Estate Review*, 17(21), 90–97.

Turok, I., & Visagie, J. (2018). Inclusive Urban Development in South Africa: What Does It Mean and How Can It Be Measured? *IDS Working Paper*, 512(1), 1-45.

Weaich, M., Simbanegavi, P., Ndlovu, P., Rikhotso, T., Ntshangase, N., 2023. Willingness of End Users in Embracing Sustainable Housing in South Africa. https://doi.org/10.5281/zenodo.10199519

Weaich, M., (2024). Mapping the Novel Nexus of Young People, Digitalisation, and Sustainability in the Global South: A Bibliometric Approach to Reviewing Literature for Future Studies. https://doi.org/10.31235/osf.io/b6fmr

Wong, P. S., Whelan, B., & Holdsworth, S. (2018). Are Contractors Ready for Greater Use of Prefabrication in Projects? An Empirical Analysis on the Role of Unlearning and Counter-Knowledge. *International Journal of Construction Management*, pp. 1–16.

Wu, H., Qian, Q. K., Straub, A., & Visscher, H. (2019). Exploring transaction costs in the prefabricated housing supply chain in China. *Journal of Cleaner Production*, 226(1), 550-563.

Wuni, I. Y., & Shen, G. Q. (2020). Barriers to the adoption of modular integrated construction: Systematic review and meta-analysis, integrated conceptual framework, and strategies. *Journal of Cleaner Production*, 249(1), 1–17.

Zaki, B. M., & Danraka, M. M. (2015). *Potentials of Shipping Container Buildings and The Implication to Nigeria Housing Challenges*. Kwara State: University of Ilorin.

Key Environmental Construction Technologies and Innovations Revolutionising the Construction Industry: A Systematic Review

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Abstract:
The Construction Industry faces immense criticism for the lack of change in the traditional methods of construction and is required to adopt sustainable practices because the industry consumes over 40% of global energy yearly and generates 20% of fossil fuel gas emissions. This literature review explores key environmental technologies shaping the industry's future. The study uses databases like Web of Science and Google Scholar to identify 76 articles on construction environmental innovations that address consumer, governmental, and organisational needs. The paper examines ten themes under technologies and innovations driving sustainability in construction, including specifics such as robotics, green building materials, big data, the Internet of Things (IoT), 3D printing, energy-efficient buildings, Renewable energy technologies Energy-efficient, LED lighting, solar panels, Water conservation technologies, Air monitoring and purification technologies, Virtual and augmented reality, Artificial intelligence (AI) chatbots, and smart building management systems. The study suggests that adopting these technologies and innovations enhances efficiency and safety and reduces environmental footprints. As technology evolves, more ground-breaking solutions are expected to emerge, compelling sustainable development in the construction industry further. Therefore, the industry must embrace technological advances and invest in a more sustainable built environment.

Keywords:
Construction materials, Environmental innovations, Environmental technologies, Sustainable construction

1 Introduction

In any vocation, excellence and innovation are critical for sustainable growth and success, but the contrary is true in the building construction industry about building sustainably. The World Economic Forum’s (2018) report on "Environmental Sustainability Principles for the Construction Industry" declares that the industry consumes over 40% of global energy yearly and approximately 40% of the world's raw materials and generates 20% of global greenhouse gas emissions. Technology plays a critical role in driving construction sustainability through various innovative solutions. These technologies, which are energy-efficient, smart construction applications and technologies, are critical in the creation of sustainable development. Smart construction technologies engender effective energy usage and operational costs and minimise the environmental impact of construction activities. Thus, as technology advances, more innovative solutions can foster sustainable construction development. Innovations specifically related to the environment, or eco-innovations, may be defined as (1) the development of new ideas, behaviour, products and processes, application or introduce them, and (2) a contribution to a reduction of environmental burdens or to ecologically sustainability targets” (Reenings, 2000: 322 cited in Torre Ruiz, 2012). Further, eco-innovations are those innovations that attempt to lower the negative environmental impact of some business activity. Therefore, environmental innovation aims to improve environmental and economic performance within the construction industry, which is a seemingly win-win situation (Hall and Vredenburg, 2003, cited in Torre Ruiz, 2012). The Construction Industry has been tagged as one of the late adopters of technological advances as it still relies on traditional construction delivery methods. Recently, technology has been at its cusp and provides construction development opportunities for timely deliveries, optimising the construction cost and contributing to its sustainability.

2 Research Methodology

The analysis highlighted the primary and secondary needs of four key construction stakeholders. These include consumers, agents and associations, complementary industries, and government and regulatory authorities. The search methods used in this study were keyword searches, screenings, and categorisation. The search terms used included "Construction Industry environmental technologies," "Construction Technologies," "Smart Construction," "Construction Technology," "Environmental Technology in Construction," and "Environmental Management technologies." The search tool engines consist of Google Scholar and Web of Science databases. The articles selected were all written in English, and the articles excluded were those in editorials, notes, errata, letters, or comments.

3 Results and Discussion

Technology is an important driver of innovation, but not all technological advances necessarily result in innovation (Freeman & Soete, 1997). According to the OECD (2005), innovation can take various forms, including product, process, organisational, and marketing. Product innovation involves the development of new or improved products that meet customers' needs. Process innovation refers to improving existing production processes to increase efficiency and reduce costs. Organisational innovation involves the development of new management practices, organisational structures, or business models that enhance the organisation's performance. Key construction environmental technologies and innovations for the construction sector

The construction environmental technologies and innovations identified address the needs of four key stakeholders: consumers, agents and associations, government and regulatory authorities and complementary industries (Sivunen et al., 2013). These Technology and Innovation themes identified in construction are listed in Table 1 and discussed.

Table 1: Technology and Innovation Themes

S/No	Technology Themes
A	Technology (waste, conservation)
B	Building management technology
C	Renewable Energy
	Innovative Themes
D	Radical construction innovations
E	Sustainable design
F	Construction method - prefabrication

A. TECHNOLOGY (WASTE, CONSERVATION)

Robotics and drones

Drones afford a birds-eye view of a construction site, allowing surveyors to map out inaccessible areas (AlRushood et al., 2023). Drones are used to detect deviations from plans, allowing rectification by crews to correct problems that may result in stoppages of construction activities. Further, Drones improve safety by allowing construction managers to monitor sites without being physically on-site. In addition, drones are used to deliver construction materials, thereby reducing the amount of vehicle traffic at the construction site. This lowers carbon emissions, reduces fuel use, and improves efficiency. Surprisingly, most companies and sites still conduct visual inspections, not automatically. Visual inspection is labour-intensive, consumes much time, and can put employees at risk (Patrick et al., 2020). Drones eliminate climbing high structures, reaching difficult areas or putting people in potentially dangerous positions. Visual inspection is a time-consuming and tedious task. Monitoring work in real-time helps minimise overall downtime (Shehhi & Maflahi, 2021).

Robots contribute immensely towards improving construction sustainability through the variability of tasks and full environmental control. However, recently, the Construction Industry has become much more technologically advanced. Some companies use robots for repetitive tasks on their sites, like painting, masonry and bricklaying. This can improve both the speed and quality of the work, leading to a safer environment while conserving energy. VR and AR, SaaS, 3D scanning, drones, AI and robotics, and wearable techs can help with referrals, networking, and reputational enhancements for construction professionals and stakeholders (Ullah et al., 2018).

Big data

Big data can be used to predict weather patterns, business activity, traffic, and more. Construction managers often use big data to determine optimal timing for construction activities (Kassem et al., 2017). This minimises downtime, reduces waste, and improves construction efficiency. Big data can evaluate vast amounts of data and uncover behavioural patterns, unknown correlations, and hidden trends (Khosravi & Ahmed, 2018; Jeong et al., 2019).

The Internet of Things (IoT)

Integrating sensors and smart devices, collectively known as the Internet of Things (IoT), is increasingly becoming a crucial aspect of the construction industry (Benachio et al., 2020). Even minor upgrades can significantly reduce the industry's carbon footprint. Installing sensors in vehicles and machinery that can shut them off when idle is one example of how IoT can reduce fuel waste.

3D printing

The construction industry increasingly relies on 3D printing, which uses computer-aided design to produce three-dimensional objects (Lim et al., 2012). This technology is invaluable because it creates precise samples and full objects, ensuring that every detail is appropriately designed (Khoshnevis, 2004). By doing so, it significantly reduces material waste and saves time. Additionally, 3D printing makes it possible to prefabricate materials in advance, either offsite or directly at the construction site, for immediate use (Vries & Geraedts, 2015). When integrated into the pre-construction process, 3D printing can help reduce labour costs, increase energy savings, and promote overall sustainability (Belém & Sousa, 2016).

Renewable energy technologies

Solar panels can be installed on buildings to generate renewable energy and reduce reliance on fossil fuels. These technologies can generate clean energy on-site and reduce reliance on fossil fuels. Wind turbines are a great way to reduce energy costs and reduce the environmental impact of a building. Wind turbines can generate electricity, heat water, and provide hot water for buildings. They can also provide cost savings over the long term, particularly as the cost of renewable energy technologies continues to decline. Geothermal systems use the earth's constant temperature to heat and cool buildings, reducing energy consumption and greenhouse gas emissions (Dadzie et al., 2018).

Water conservation technologies

This can also be adopted for the housing units. Low-flow fixtures like toilets and faucets can significantly reduce water usage without sacrificing performance. Water recycling systems, which capture and treat wastewater for reuse in non-potable applications, can also reduce water usage and costs. Water-saving technologies, such as low-flow fixtures, rainwater harvesting systems, and greywater reuse systems, can be installed to reduce water usage and promote sustainability. Rainwater harvesting systems can collect and store rainwater for non-potable uses such as irrigation, toilet flushing, and cleaning (Hofman-Caris et al., 2019).

B. BUILDING MANAGEMENT TECHNOLOGY

Smart Building Management Systems/ Smart Homes

According to Lee et al. (2015), smart homes are key technology drivers for sustainability in construction infrastructure development and operation. Thus, smart homes are embedded with advanced technologies such as smart thermostats, lighting systems, and energy-efficient appliances that can be conveniently controlled remotely via smart devices. The integration of advanced technologies in smart homes enables the end-users to effectively control energy consumption according to their needs, preferences, and occupancy levels; as a result, waste is minimised, and energy is optimally utilised (Lee et al., 2015).

Building information modelling (BIM)

Kaming and Olawumi (2019) claimed that the adoption of Building Information Modeling (BIM) is gaining attraction as one of the innovative technologies with the potential towards revolutionising the processes and methods of building design, construction, operation and management. Eastman et al. (2011) encouraged the Built environment sectors to leverage BIM as advanced software to create digital models of structures, enabling architects, engineers, and contractors to collaborate and seamlessly partner for optimal project delivery and maintenance. Thus, BIM application can be utilised for simulating building performance and to detect potential inefficiencies and opportunities for improvement, which will ensure less environmental impact of construction development on society (Wang et al., 2013). With additional technologies such as augmented reality, robotics, and artificial intelligence, BIM can fully digitise real estate and enhance industry productivity (Giel et al., 2014).

C. RENEWABLE ENERGY

Renewable energy involves developing and deploying technologies that harness renewable energy sources (Khan & Pareek, 2017). Renewable energy technologies, such as solar, wind, geothermal, hydropower, and biomass, harness natural resources to generate electricity, heat, and fuel with lower carbon emissions and environmental impact than fossil fuels and are essential to the transition to a low-carbon, sustainable energy system, with the potential to reduce greenhouse gas emissions, enhance energy security, and support economic development." (Rao et al., 2015; IPCC, 2011).

D. RADICAL INNOVATIONS

These involve radical shifts in construction practices, such as adopting entirely new technologies or introducing disruptive business models. Using blockchain for transparent property transactions could be an example of radical innovation in the construction industry.

Smart locks:

According to a study by Bae and Kim (2015), smart locks can improve security and convenience for property owners and tenants. The study notes that smart locks can be integrated with other smart home technologies, such as thermostats and lighting, to create a more connected and efficient living environment.

Energy-efficient windows:

Research by Gou and Prakash (2013) suggests that energy-efficient windows can significantly reduce energy consumption in buildings, particularly in colder climates. The study notes that advances in window technology have made it possible to achieve high insulation levels without sacrificing natural light or visibility.

E. SUSTAINABLE DESIGN

Green building materials

Environmentally-friendly building materials, such as recycled materials, sustainably sourced wood, and non-toxic paints and finishes, can be used to reduce the environmental impact of building holistic management. These materials, like recycled steel, bamboo, and reclaimed wood, have lower embodied energy and carbon emissions than traditional building materials (Dadzie et al., 2018). Mass timber is a renewable building material that has a low carbon footprint. It is made from sustainably harvested wood and can be used for various construction applications, including structural framing, wall panels, and floor systems. Green Insulation or environmentally friendly insulation materials such as cellulose, wool, and cotton are made from recycled materials and are free of harmful chemicals. Smart glass is a dynamic glazing system that can change its tint to control the heat and light entering a building. This technology can reduce energy consumption and improve occupant comfort (Dadzie et al., 2018).

Energy-efficient buildings

One of the significant contributions of technology to sustainability in the construction industry is the emergence of energy-efficient and sustainable buildings (Asif et al., 2007). Such buildings utilise advanced insulation materials, energy-efficient and intelligent windows, and heating, ventilation, and air conditioning (HVAC) systems (Sharma &

Pareek, 2020). These systems are designed to adapt to the changing temperature and occupancy levels, effectively reducing energy waste, resource consumption, operational costs, and carbon emissions. Moreover, green buildings can benefit from green bonds and climate-linked funds (Wang et al., 2020). For instance, LED lighting systems can significantly reduce excessive energy consumption and substantially save on costs. According to Dadzie et al. (2018), intelligent lighting systems allow for occupancy to enjoy natural light levels, which further increase energy efficiency, thereby reducing the amount of energy needed to heat and cool a building.

Green roofs

Green roofs are vegetated roof systems that provide a range of environmental, social, and economic benefits, such as urban heat island mitigation, biodiversity conservation, and energy efficiency (Oberndorfer et al., 2007). Integrating green roof technology into the construction sector enhances green building sustainability (Getter & Rowe, 2006). Studies estimate that green roofs can hold up to 60 -100 per cent of the rainwater, and when adorned with vegetation, they aid in the absorption of carbon dioxide and diminish heat absorption green roofs (Oberndorfer et al., 2007; Getter & Rowe, 2006). It can be installed on buildings to reduce the amount of heat absorbed by the building, improve air quality, and provide habitat for wildlife. Green roofs are an effective way to reduce energy consumption and improve the environmental performance of a building. Green roofs can reduce the amount of heat absorbed by a building, reduce stormwater runoff, and improve air quality (Oberndorfer et al., 2007; Getter & Rowe, 2006).

Sustainable Resource Sourcing

Sustainable resource sourcing involves the responsible extraction, production, and disposal of natural resources, such as wood, minerals, and metals, to minimise environmental impact and support social and economic development." (UNEP, 2011).

Low-Energy House and Zero-Energy Building Design

Low-energy house and zero-energy building design aim to create buildings that use little or no energy from external sources through design strategies and technologies such as passive solar heating, high-performance insulation, energy-efficient lighting and appliances, and on-site renewable energy generation." (Lomas et al., 2007).

Low-Emitting Materials

Low-emitting materials emit low levels of volatile organic compounds (VOCs) and other harmful pollutants, improving air quality and occupant health." (Green Seal, 2015).

Green Innovation

Green innovations focus on environmentally sustainable practices. In the construction sector, this may involve adopting energy-efficient building materials or implementing eco-friendly construction techniques (Vigren et al., 2022).

Sustainable Resource Sourcing

Sustainable resource sourcing is a key pillar of sustainable construction technology. It ensures the use of building materials created from recycled, remanufactured, recyclable products and obtained from sustainable and environmentally friendly sources (Martin &

Perry, 2019). For example, agricultural wastes or by-products may be used to produce building materials (Danso, 2018).

Low-Energy House and Zero-Energy Building Design

This refers to mechanisms to lessen energy consumption. For instance, the construction of buildings with wood is a sustainable construction technology as it has a lower embodied energy than those built of steel or concrete. Also, the strategic placement of windows makes daylighting available, thereby minimising the need for electric lighting during the day (Hossain et al., 2020).

Low-Emitting Materials

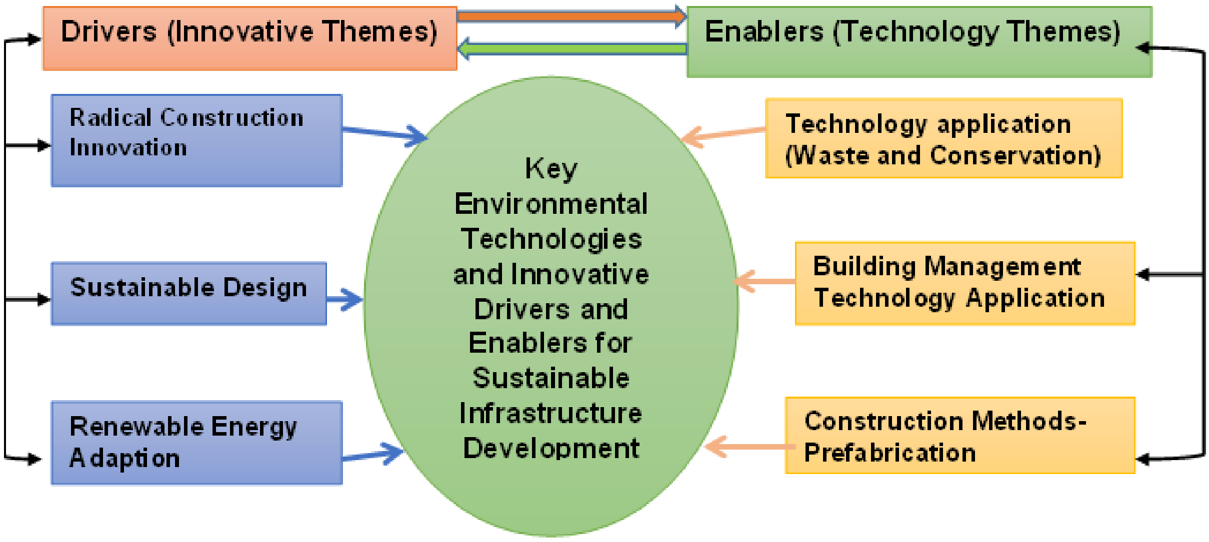
Selecting low-emitting materials and products is essential in today's design and construction world. It helps building projects achieve green building credits from agencies like LEED, IGBC, and GRIHA and improves human health. (Bisegna et al., 2016).

F. CONSTRUCTION METHODS: PREFABRICATION

This involves assembling building components in a factory and transporting them to the construction site. This process reduces waste, improves quality control, minimises construction time and can incorporate sustainable design features into prefabricated components. Modular construction enables flexible and adaptable building designs (Li et al., 2018). Prefabrication falls under the construction theme because it involves assembling building components offsite in a factory setting, using standardisation and automation to improve quality, reduce waste, and increase efficiency (Gibb & Isack, 2003).

G. CONCEPTUAL FRAMEWORK: KEY ENVIRONMENTAL TECHNOLOGIES AND INNOVATIVE DRIVERS AND ENABLERS

Figure 1 presents a conceptual framework for drivers and enablers of key environmental technologies and innovation for sustainable infrastructure development. These drivers, namely radical construction innovation, sustainable design, and renewable energy, are the factors that precipitate technology application, building management technology application and construction methods, which ultimately result in sustainable infrastructure development. This implies using new technology and innovative processes to sustain industry growth.



Source: (Researchers' Construct: 2024)

4 Conclusion and Further Research

In conclusion, the construction industry is critical in creating a safer, more innovative, and more sustainable environment. By embracing the technologies identified in this literature review, including robotics, green building materials, big data, the Internet of Things (IoT), 3D printing, energy-efficient buildings, and smart building management systems, the industry can enhance efficiency and safety and reduce environmental footprints. However, to realise these benefits, all industry stakeholders must invest in these technologies and embrace sustainability and climate considerations in the building process. By doing so, industry leaders can future-proof their buildings, yield higher returns, and become more responsible stewards of our planet. The area recommended for further research is concerning building materials. Much has yet to be discovered of materials widely accepted for replacing traditional building materials.

5 References

AlRushood, M.A. et al. (2023) "Accelerating Use of Drones and Robotics in Post-Pandemic Project Supply Chain," *Drones*, 7(5), pp. 313–313. doi:10.3390/drones7050313.

Asif, M., Muneer, T., & Kelley, R. (2007). Building-integrated photovoltaic systems: Critical success factors. *Renewable and Sustainable Energy Reviews*, 11(8), 1694-1707.

Bae, J., & Kim, Y. G. (2015). Smart locks for a smart home: A comparative analysis of ten smart locks. *International Journal of Smart Home*, 9(7), 187-194.

Belém, C., & Sousa, J. B. (2016). "Additive Manufacturing in Construction: A Review." *3D Printing and Additive Manufacturing*, 3(3), 139-148. https://constructionblog.autodesk.com/3d-printing-construction-industry/

Benachio, M., Farahani, P., & Rezaei, F. (2020). Internet of Things in construction industry: a systematic review. *International Journal of Construction Management*, 20(1), 1-16.

Bisegna, F., Mattoni, B., Gori, P., Asdrubali, F., Guattari, C., Evangelisti, L., Sambuco, S. & Bianchi, F. (2016) Influence of Insulating Materials on Green Building Rating System Results. *Energies*.

Dadzie, K. Q., Ameyaw, E. E., Mensah, S., & Biney, M. O. (2018). An empirical analysis of factors influencing energy efficiency adoption in Ghana's building sector. *Journal of Engineering, Design and Technology*, 16(5), 719-734.

Danso, H. (2018) Identification of Key Indicators for Sustainable Construction Materials. *Advances in Materials Science and Engineering*.

Eastman, C., Teicholz, P., Sacks, R. and Liston, K. (2011). Building Information Modeling (BIM) for Construction Management - Critical Review and Future Directions. *Automation in Construction*, 20(2), pp. 147-159. Available at: https://www.constructiondive.com/news/study-bim-use-rises-dramatically-among-large-construction-firms/516682/

Freeman, C., & Soete, L. (1997). The economics of industrial innovation. *Routledge*

Getter, K. L., & Rowe, D. B. (2006). The role of extensive green roofs in sustainable development. *HortScience*, 41(5), 1276-1285.

Giel, A.T., Issa, R.R.A. and Olbina, S. (2014). Implementing Building Information Modeling (BIM) for Facility Management: A Review and Case Study. *Journal of Facilities Management*, 12(4), pp. 349-365. Available at: https://www.ukgbc.org/resource/bim-and-sustainability/

Gou, P., & Prakash, S. (2013). Energy-efficient windows: A review. *Renewal and Sustainable Energy Reviews*, 20, 308-320.

Gould, J., & Nissen-Petersen, E. (2009). Rainwater harvesting in urban areas. *Earthscan.*

Green Seal (2015). Standard for low-emitting interior building materials, furnishings, and finishes. *Green Seal*.

Hofman-Caris, R. C. H. M., Zeeman, G., & Kujawa-Roeleveld, K. (2019). Rainwater harvesting as a source for irrigation and toilet flushing. In Environmental technology & innovation (Vol. 13, pp. 126-139). *Elsevier*.

Hossain, M., Ng, S., Antwi-Afari, P. & Amor, B. (2020) Circular economy and the construction industry: Existing trends, challenges and prospective framework for sustainable construction. *Renewable & Sustainable Energy Reviews*.

IPCC (2011). Special report on renewable energy sources and climate change mitigation. *Cambridge University Press*.

Jeong, M. S., Kim, B. W., & Lee, H. S. (2019). Big Data Analytics in Construction Industry: A Review. *Sustainability*, 11(9), 2660.

Kaming, P.F. & Olawumi, T.O. (2019). Building Information Modeling: A Review of its Evolution and Adoption in Construction. *Journal of Engineering, Design and Technology*, 17(5), 1021-1037.

Kassem, M., Hawileh, R., & Attia, S. (2017). Big Data in Construction: A Review of Present Status, Opportunities, and Future Directions. *Journal of Big Data*, 4(1), 1-27.

Khan, M. R., & Pareek, V. (2017). Renewable energy technologies for sustainable development of the world. *Renewable and Sustainable Energy Reviews*, 71, 735-744.

Khoshnevis, B. (2004). "Automated construction by contour crafting—related robotics and information technologies." *Automation in Construction*, 13(1), 5-19. https://www.weforum.org/agenda/2020/08/how-3d-printing-is-revolutionizing-the-construction-industry/

Khosravi, A., & Ahmed, V. (2018). The Role of Big Data in Construction Project Management. *Procedia Engineering*, 196, 828-835.

Kim, Y., & Lee, J. (2021). Internet of things (IoT) and big data analytics for sustainable construction: A review. *Sustainability*, 13(12), 6545.

Lee, J., Kim, J., & Shin, Y. (2015). Smart building automation system: a review of architecture and applications. *Energies*, 8(10), 9639-9669.

Li, X., Shen, G., Wu, P., Fan, H., Wu, H. & Teng, Y. (2018) RBL-PHP: Simulation of Lean Construction and Information Technologies for Prefabrication Housing Production. *Journal of Management in Engineering*.

Lim, S., Buswell, R. A., Le, T. T., & Austin, S. A. (2012). *"Innovative 3D concrete printing system."* Proceedings of the Construction Research Congress 2012, 1763-1772. https://www.sciencedirect.com/science/article/pii/S2214509520301979

Lomas, K. J., Eppel, H., & Huang, Y. (2007). Designing low-energy buildings in Hong Kong. *Building and Environment*, 42(3), 1344-1354.

National Renewable Energy Laboratory. (2018). Rainwater harvesting. *NREL*.

Oberndorfer, E., Lundholm, J., Bass, B., Coffman, R. R., & Doshi, H. (2007). Green roofs as urban ecosystems: ecological structures, functions, and services. *BioScience*, 57(10), 823-833.

OECD. (2005). Oslo manual: Guidelines for collecting and interpreting innovation data. *The Measurement of Scientific and Technological Activities*, 3(10), 1-300.

Patrick, O.O., Nnadi, Ezekiel.O.E. and Ajaelu, H. (2020) “Effective use of Quadcopter drones for safety and security monitoring in a building construction sites: Case study Enugu Metropolis Nigeria,” *Journal of Engineering and Technology*, 12(1), pp. 37–46. Doi:10.5897/jetr2020.0695.

Rao, P., Power, R., & Dincer, I. (2015). Renewable energy technologies: a review of the status and costs of selected technologies. *Renewable and Sustainable Energy Reviews*, 51, 1460-1465.

Sharma, A., & Pareek, V. (2020). Energy-efficient building for sustainable future: A review. *Journal of Building Engineering*, 32, 101753.

Shehhi, S. and Maflahi, M.A.A. (2021) “Eyes on Air,” in Day 3 Wed, November 17, 2021. doi:10.2118/207455-ms.

Sivunen, M. et al. (2013) “Service-dominant innovation in the built environment,” Construction Innovation: Information, Process, Management, 13(2), pp. 146–164. doi:10.1108/14714171311322138.

Ullah, F. et al. (2021) “Barriers to the digitalisation and innovation of Australian Smart Real Estate: A managerial perspective on the technology non-adoption,” 22, pp. 101527–101527. doi:10.1016/j.eti.2021.101527.

UNEP (2011). Sustainable Resource Management: Good Practices. *United Nations Environment Programme*.

United Nations Environment Programme. (2019). Global Status Report for Buildings and Construction 2019. https://www.worldgbc.org/news-media/global-status-report-buildings-and-construction-2019

Vigren, O., Kadefors, A. and Eriksson, K. (2022) "Digitalisation, innovation capabilities and absorptive capacity in the Swedish real estate ecosystem," *Facilities*, 40(15/16), pp. 89–106. doi:10.1108/f-07-2020-0083.

Vries, M. B., & Geraedts, R. P. (2015). *"3D concrete printing: Machine and mix design, manufacturing parameters and application possibilities."* Proceedings of the 2nd International Conference on 3D Construction Printing (3DcP), 91-102. https://all3dp.com/2/the-benefits-of-3d-printing-for-the-construction-industry/

Wang, J., Li, N., Wang, X., Skibniewski, M.J. and Li, Q. (2013). Building Information Modeling (BIM) and safety: Automatic safety checking of construction models and schedules. *Automation in Construction*, 34, pp. 3-10. Available at: https://www.autodesk.com/redshift/benefits-of-bim-in-construction/

World Economic Forum. (2018). Shaping the Future of Construction: A Breakthrough in Mindset and Technology. https://www.weforum.org/reports/shaping-the-future-of-construction-a-breakthrough-in-mindset-and-technology-1

Yen, Y. H., & Lu, H. P. (2018). Effects of personalised emails on email marketing campaign performance. *Journal of Business Research*, 88, 301-309.

Factors Affecting Adoption of Incremental Housing Development Strategy for Home Ownership: The Case of Staff Members of Obafemi Awolowo University, Ile-Ife

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Abstract
In the traditional African society, home ownership is very important. At the same time, the need for more access to capital needed for housing construction has forced many residents to build incrementally. This study examines factors affecting the adoption of incremental housing development (IHD) strategy among Obafemi Awolowo University staff to provide information that could enhance housing delivery. The research employed a survey design, administering a close-ended questionnaire to 144 academic and non-academic staff. The findings identify several factors hindering the adoption of IHD, including the high cost of building materials, land acquisition, and lack of finance. The results suggest that most respondents need help accessing credit facilities and traversing the complex legal system to secure formal land titling. The study concludes that addressing these challenges is crucial for promoting IHD and enhancing the overall housing conditions of low-income households in Nigeria. Therefore, The study recommends that governments focus on improving the overall financial and mortgage systems to make it easier for low/middle-income earners to access credit and finance for housing.

Keywords: Housing, housing delivery, incremental housing development, OAU, Nigeria.

1. Introduction

In many African societies, a man is regarded as complete once he builds a house. This underscores the importance of home ownership in African societies. Housing has been considered a key factor that provides the basic living elements for individual households. As a fundamental aspect of human existence, it has become a deep focus of city design and socio-economic policy (Greene & Rojas, 2008). Over the years, as population increases, housing has been a significant concern for governments, international organisations, and non-profit organisations (Aliyu *et al.*, 2017; Park *et al.,* 2018).

In recent years, there has been an increasing population growth in African countries, resulting in a corresponding housing shortage (Wibowo & Larasati, 2018). A report by UN-Habitat (2016) and UNPD (2004) shows that, by 2030, Africa's urban population is expected to surpass its rural population. The result is seen in the rapid growth of the total number of dwellers within each housing unit and the massive growth of informal housing settlements in urban areas and their periphery. This has awakened the government's concern about implementing different strategies to provide quantitative housing facilities. However, these strategies are constrained by inadequate funding, bureaucracy issues, lack of political will, corruption, and sectarian manipulation (Aliyu *et al.,* 2017; Aliyu *et al.*, 2011; Chinyere, 2019). As a result, the populace now resorted to building their houses incrementally. With this strategy, housing is not seen as a finished product but rather as a process where potential homeowners can participate in designing their houses according to their needs and financial ability (Alananga & Kusiluka, 2015) and building houses in gradual and manageable phases (Magigi & Majani, 2006).

Incremental housing development is a process that integrates different stages based on the self-help activities of the owner(s) (Amoako & Boamah, 2017; Nwuba, 2015; Park *et al.*, 2018; Zulu, 2010). This informal housing development and expansion is often the de facto housing delivery model in neighbourhoods occupied by low- and middle-income earners. Accordingly, Wakely and Riley (2011) established that 70 per cent of the urban dwellers in emerging cities develop their houses incrementally. For instance, in Nigeria, accessibility to homeownership is mainly through an incremental building process often achieved through equity financing or personal savings. It is against this background that this study examines and provides answers to the following research questions;

I. What are the different stages involved in incremental housing development strategy?
II. What are the factors affecting incremental housing development strategy in the study area?

2. The Concept of Incremental Housing Development

Incremental housing development (IHD), as a concept, has been discussed and analysed by various authors in the literature. Studies such as those conducted by Baqutayan *et al.* (2015), Park *et al.* (2018), and Roberto (2003) have argued that incremental housing development (IHD) focuses on design strategies that allow for a progressive expansion and improvements of housing units. Such houses are inhabitable even when construction is incomplete, thus addressing the immediate housing needs of the occupants. This approach helps reduce the initial cost of housing development as low- and middle-income earners struggle to meet necessities such as food, clothing and education. Authors such as Ronald and Chiu (2010) and Wibowo and Larasati (2018) have established that IHD considers the dynamics involved in land acquisition, finance, infrastructure, building materials, and labour. This implies a step-by-step approach towards housing construction. Such construction spans a reasonable period in terms of quality and size (Hasgül, 2016). However, this reflects the function of several factors, such as those embedded in individual household income and expenditure metrics.

2.1 Stages Involved in the Incremental Housing Development Process

Incremental housing development describes an open-ended housing supply mechanism where housing units grow incrementally over a range of time as the income or demographic of the household increases (Alananga & Kusiluka, 2015). This process begins with land acquisition, often done through an informal system. Then, the building is constructed incrementally at the rate determined by the household's resources, priorities and requirements (Hasgül, 2016). Low- and middle-income households are known to build their houses incrementally.

These processes are staged into different sequences and broadly categorised as the unit's base-house, extension, and aesthetic customisation (Wibowo & Larasati, 2018). The base house is the initial structure representing an unfinished housing unit. The unit at this stage provides essential functionalities such as protection from natural elements (Park *et al.*, 2018). Low/middle-income earners prioritise basic construction elements such as partition walls, bathrooms, kitchens, and roofs to meet their immediate needs. Following the establishment of the base house, the extension phases unfold. These phases enable homeowners to expand and develop their houses according to their evolving needs, utilising available resources and potluck materials to extend their houses to align with their preferences and necessities (Magigi & Majani, 2006). The final stage in incremental housing development is the aesthetic customisation of the housing unit, where homeowners focus on refining their homes' design and spatial layout (Park *et al.*, 2018; Magigi & Majani, 2006). This process averagely spans 5 to 15 years (Greene & Rojas, 2008; Hasgül, 2016).

2.2 Factors Affecting the Adoption of the Incremental Housing Strategy

Adopting incremental housing strategies in developing countries such as Nigeria is influenced by various factors. Authors like Aribigbola (2008) grouped these as driving and conditioning factors. Driving factors reflect the outcomes of complex interactions between socio-economic and demographic indices, while conditioning factors concern physical and cultural values. Again, Enisan and Ogundiran (2013) identify factors such as land inaccessibility, inadequate finances and deficiencies in the mortgage system as having a negative impact on the adoption of IHD. However, a recent study by Adeyeni et al. (2016) and Chinyere (2019) added that the high cost of building materials and the difficulty in getting building approval hinder the adoption of IHD. While many factors have been identified in the literature affecting IHD, studies have yet to examine these factors holistically from the perspective of a developing country such as Nigeria.

3. Research Method

A survey research design was adopted for this study, with data sourced via close-ended questionnaires. The questionnaire was administered to the academic and non-academic staff of Obafemi Awolowo University, Ile-Ife, Osun. The University has a staff strength of 4000, comprising 1365 academic staff and 2635 non-teaching staff (staff directory of Obafemi Awolowo University, 2024). A sample size of 183 was adopted, representing 4.58% of the entire population of 4000 staff members at Obafemi Awolowo University. This sample size was chosen due to the variation in the average number of staff in their first three years of service to the University. This category of staff was excluded from the sample. The sample size helps maintain a manageable and cost-effective data collection process while ensuring a representative sample that accurately reflects the diversity of the population. Out of this sample size, 60% of the respondents were non-academic staff, while 40% were academic staff. This was done due to the variation in the average number of staff under each category. However, only 144 questionnaires were retrieved and found useful, giving a response rate of 78.69%. The data were analysed using descriptive and inferential statistics.

4. Findings and Discussion

This section is divided into three parts: the first part assesses the socio-economic characteristics of the respondents, the second part explores the stages that are involved in incremental housing development, the third part evaluates factors that influence the adoption of incremental housing development strategy.

4.1 Table 4.1: Socio-Economic Characteristics of Respondents

Variables	Category	Frequency	Percentage (%)
Sex	Male	68	47.22
	Female	74	51.39
	Unascertained	2	1.39
	Total	***144***	***100.00***
Marital Status	Single	26	18.06
	Married	112	77.78
	Unascertained	6	4.17
	Total	***144***	***100.00***
Age	30-39years	31	21.53
	40-49 years	68	47.22
	50 years & above	44	30.56
	Unascertained	1	0.69
	Total	***144***	***100.00***
Qualification	SSCE	9	6.25
	HND	38	26.39
	B.Sc.	55	38.19
	M.Sc.	19	13.19
	PhD	16	11.11
	OND	2	1.39
	Unascertained	5	3.47
	Total	***144***	***100.00***
Year of working experience	4 – 5 YEARS	21	14.58
	6– 10 YEARS	43	29.86
	11 – 20 YEARS	35	24.31
	21- >	44	30.56
	Unascertained	1	0.69
	Total	***144***	***100.00***
Category of respondent	Academic staff	51	35.42
	Non-academic staff	93	64.58
	Total	***144***	***100.00***
Type of household	Nuclear	112	77.78
	Extended	27	18.75
	Undisclosed	5	3.47
	Total	***144***	***100.00***
Own a landed property?	Yes	102	70.83
	No	42	29.17
	Total	***144***	***100.00***

Source: ***Authors' fieldwork***

Table 4.1 reveals that 47.2% of the respondents were males, while 51.3. % females. From the above, it is shown that there were more female respondents than males, and the reason for this was that the female respondents were more approachable and willing to fill out the questionnaire. Further analysis shows that the majority of the respondents were within the age range of 40 to 49, which indicates that the majority were middle-aged, representing 36%, While 23.0% fall within age 50 and above, amongst other age categories. The data indicate that most of the respondents are of active age. For the respondents' working experience, 30% have a working experience of 21 to 35 years, and 29.8% of the respondents have a working experience between 6 to 10 years. 24.3% and 14.5% have a working experience of 11-20 years and 4-5 years, respectively. This indicates that most respondents have worked for a long time at this institution. Also, the study suggests that the non-academic staff of OAU contributed 64.58% of the respondents, while the academic staff represented 35.42% of the respondents. Findings show that 70.83% of the respondents own landed properties while 29.1% stay in rented apartments.

Table 4.2: Stages Involved in Incremental Housing Development

Table 4.2 shows how long it could take to develop a house using an incremental development strategy. Of the 144 respondents surveyed 102 own landed properties. Therefore, the presentation, analysis, and interpretation of findings for this objective are from the 102 respondents who own landed properties.

Stages	Less than one month	1-6 months	6-12 months	1-3 years	Above 3 years(state)
Site Acquisition	30(29.4%)	26(25.4%)	17(16.7%)	18(17.6%)	11(10.7%)
Planning approval	11(10.7%)	61(59.8%)	18(17.6%)	18(17.6%)	4(3.9%)
Clearing of site	60(58.8%)	28(27.4%)	9(8.8%)	3(2.9%)	2(1.9%)
Laying of foundation	45(44.1%)	37(36.2%)	16(15.6%)	3(2.9%)	1(0.98%)
Blockwork	13(12.7%)	39(38.2%)	34(33.3%)	11(10.7%)	7(6.8%)
Roof construction	42(41.1%)	29(35.2%)	18(17.64%)	7(6.8%)	6(5.8%)
Electrical installation	31(30.3%)	36(35.2%)	20(19.6%)	11(10.7%)	4(3.9%)
Plumbing installation	38(37.2%)	27(26.4%)	21(20.58%)	10(9.8%)	6(5.8%)
Plastering/ Rendering of walls	41(40.1%)	26(25.4%)	17(16.7%)	11(10.7%)	7(6.8%)
Painting of Walls	40(39.2%)	27(26.4%)	6(5.8%)	9(8.8%)	10(9.8%)
Finishes, eg, doors, flooring	35(34.3%)	27(26.4%)	15(14.7%)	16(15.6%)	9(8.8%)

Source: Authors' filed work

Table 4.2 presents the stages of incremental housing development, categorised by time periods. The table shows that most respondents (30%) acquired the site in less than a month, while 25.4% took 1-6 months. The planning approval stage took the longest, with 59.8% taking 1-6 months. The delay in securing planning approval could be linked to the tedious and complex processes required as part of formalisation procedures. The clearing of the site, laying of foundations, blockwork, roof construction, electrical installation, plumbing installation, plastering/rendering of walls, painting of walls, and finishes took varying amounts of time, with the majority taking 1-3 years. The table highlights the gradual nature of incremental housing development, with each stage taking significant time to complete.

Table 4.3: Factors Affecting the Adoption of Incremental Housing Development Strategy

Factors affecting the adoption of IHD	SA	A	N	D	SD	M	R
High cost of building materials	54(36.0%)	51(34.0%)	19(12.7%)	9(6.0%)	3(2.0%)	3.15	1st
High cost of acquiring land	36(24.0%)	62(41.3%)	16(10.7%)	9(6.0%)	3(2.0%)	2.88	2nd
High cost of construction	44(29.0%)	54(36.0%)	13(8.7%)	15(10.0%)	5(3.3%)	2.79	3rd
Lack of credit facilities	42(28.0%)	47(31.3%)	27(18.0%)	13(8.7%)	6(4.0%)	2.76	4th
Lack of finance from personal income	35(23.3%)	59(39.0%)	23(15.3%)	21(14.0%)	0(0.0%)	2.70	5th
Land Title registration	33(22.0%)	59(39.3%)	15(10.0%)	22(14.7%)	7(4.7%)	2.67	6th
Non-housing expenditures, e.g. school fees, bills.	25(16.7%)	64(42.7%)	22(14.7%)	15(10.0%)	7(4.7%)	2.66	7th
Stunted financial and mortgage system	45(30.0%)	51(34.0%)	26(17.3%)	12(8.0%)	3(2.0%)	2.64	8th
Poverty level	29(19.3%)	49(32.7%)	16(10.7%)	30(20.0%)	2(1.3%)	2.58	9th
Lack of available land with basic infrastructure	21(14.0%)	67(44.7%)	20(13.3%)	25(16.7%)	6(4.0%)	2.57	10th
Planning approval	36(24.0%)	58(38.7%)	25(16.7%)	15(10.0%)	4(2.7%)	2.57	11th
Land acquisition process	25(16.7%)	56(37.3%)	16(10.7%)	18(12.0%)	6(4.0%)	2.54	12th
Limited skilled manpower	15(10.0%)	51(34.0%)	23(15.3%)	34(22.7%)	10(6.7%)	2.54	13th
Lack of effective implementation strategies	21(14.0%)	55(36.7%)	34(22.7%)	13(8.7%)	11(7.3%)	2.54	14th
Problems from the Community Development Association	21(14.0%)	50(33.3%)	33(22.0%)	24(16.0%)	4(2.7%)	2.53	15th
Land inaccessibility	25(16.7%)	58(38.7%)	19(12.7%)	28(18.7%)	10(6.7%)	2.50	16th
Land use control and regulations	18(12.0%)	53(35.0%)	25(16.7%)	24(16.0%)	6(4.0%)	2.48	17th
Inadequate physical planning	18(12.0%)	53(35.0%)	25(16.7%)	25(16.7%)	9(6.0%)	2.42	18th
Property Tax	17(11.3)	53(35.3%)	32(21.3%)	22(14.7%)	10(6.7%)	2.39	19th
Youth harassment of developers	31(20.7%)	36(24.0%)	34(22.7%)	21(14.0%)	16(10.7%)	2.36	20th
Developmental control	14(9.3%)	51(34.0%)	36(24.0%)	17(11.3%)	12(8.0%)	2.34	21th
Statutory regulation and Bye-laws	14(9.3%)	52(34.7%)	27(18.0%)	26(17.3%)	8(5.3%)	2.21	22th
Lack of infrastructural facilities	25(16.7%)	47(31.3%)	36(24.0%)	11(7.3%)	8(5.3%)	2.21	23rd
Health challenge	19(12.7%)	40(26.7%)	32(21.3%)	18(12.0%)	20(13.3%)	2.10	24th

SA = Strongly Agree, A = Agree, N = Neutral, Disagree, SD = Strongly Disagree, M = Mean, R = Rank.

Table 3 outlines the factors affecting the adoption of incremental housing development. These factors are discussed below in three categories based on their mean scores:

Category 1: Most Significant Factors (Mean 3.15-2.66)

These factors are the most significant hindrances to adopting incremental housing development. The high cost of building materials (3.15) is the most significant factor, followed closely by the high cost of acquiring land (2.88) and the high cost of construction (2.79). The lack of credit facilities (2.76) and lack of finance from personal income (2.7) also significantly affect the adoption of incremental housing development. Significant factors include non-housing expenditures such as school fees, utility bills, rental payments (2.66), and land title registration (2.67).

Category 2: Moderate Significant Factors (Mean 2.64-2.48)

This category includes factors that are also significant but to a lesser extent than those in the first category. Stunted financial and mortgage systems (2.64) and poverty level (2.58) are significant factors. Lack of available land with basic infrastructure (2.57), planning approval (2.57), and land acquisition process (2.54) moderately affects the adoption of IHD. Limited skilled manpower (2.54) and lack of effective implementation strategies (2.54) are additional factors in this category. Moreso, problems from the community development association (2.53) and land inaccessibility (2.5) are considered under the last part of this category.

Category 3: Less Significant Factors (Mean 2.42-2.1)

This category includes less significant factors that still affect the adoption of incremental housing development. Inadequate physical planning (2.42), property tax (2.39), youth harassment of developers (2.36), and developmental control (2.34) are factors in this category. Statutory regulation, bye-laws (2.21), and lack of infrastructural facilities (2.21) are less significant factors. Health challenges (2.1) are the least significant factor affecting the adoption of incremental housing development.

5. Conclusion

The study identified several factors hindering the adoption of incremental housing development among the staff of Obafemi Awolowo University. The high cost of building materials was the most significant factor, primarily due to the considerable gap between supply and demand and the reliance on imported materials. The long and complex process of obtaining planning approval was another significant challenge. These findings are consistent with the broader literature on the challenges of incremental housing development (Adeyeni et al., 2016; Chinyere, 2019; Festus & Amos, 2015; Enisan & Ogundiran, 2013)

Compared with other housing development strategies, IHD is distinct from other housing development strategies in several ways. For instance, public social housing programmes often involve large-scale, centralised housing projects that often exclude low/middle-income earners at the point of allocation, even though such programmes are targeted to meet their housing needs (Chinyere, 2019; Festus & Amos, 2015). Similarly, sites and services projects involve the provision of serviced plots of land to households, which may not necessarily address the housing needs of low-income households due to their inability to afford such plots of land. Incremental housing development, by contrast, allows households to build and improve their housing incrementally based on their own needs and resources.

In line with its findings, this study recommends that government at all levels provide financial support to low/middle-income households through initiatives like the National Housing Fund. Moreover, simplifying the land titling process and offering affordable credit facilities are vibrant steps that will promote incremental housing. Investing in housing infrastructure, addressing regulatory barriers, and enhancing legal frameworks are essential to overcoming these challenges.

References

Adeyeni, G.O., Olayiwola, L. M. & Oladehinde, G. J. (2016). Challenges to Incremental Housing Development in Ibadan Municipality, Nigeria. *Asian Research Journal of Arts & Social Sciences, 1(*4), 1-10.

Alananga, L. & Kusiluka, A. (2015). Incremental housing development in Tanzania: Challenges and opportunities. *Journal of Housing and the Built Environment, 30*(2), 257-273.

Aliyu, A., Okugya, M., Jibri, S. & Abdu, A. (2017). An evaluation of affordable housing provision for the urban poor in Lafia metropolis, Nigeria. *International Journal of Research & Review, 4*(8), 1-17

Aliyu, A., Kasim, R. & Martin, D. (2011). Factors Affecting Housing Development in Makama Jahum Area of Bauchi Metropolis, Nigeria. *International Journal of Trade, Economics and Finance, 2*(4), 263-268.

Amoako, J. & Boamah, F. (2017). Incremental housing development in Ghana: A case study of Accra. *Journal of Housing and the Built Environment*, *32*(2), 257-273.

Aribigbola, A. (2008). Housing policy formulation in developing countries: Evidence of program implementation from Akure, Ondo State, Nigeria. *Journal of Human Ecology*, *23*(2), 125-134.

Baqutayan, S., Ariffin, A. & Raji, F. (2015). Describing the need for affordable, liveable, sustainable housing based on Maslow's theory of need. *Mediterranean Journal of Social Sciences*, *6*(3), 353–269.

Bangura, J. S. & Lee, S. M. (2021). Affordable housing strategies for the urban poor in Nigeria. *Journal of Housing and the Built Environment, 36*(2), 147-162.

Chinyere, N. (2019). Nigerian housing policy and implication for achieving sustainable development goal 3. *African Journal of Politics and Administration Studies, 12*(2), 85–92.

Enisan, O. & Ogundiran, A., (2013). Challenges of Housing Delivery in Metropolitan Lagos. *Research on Humanities and Social Sciences, 3*(20). 294-321

Festus, I. & Amos, I. (2015). Housing policy in Nigeria: An overview. *Journal of Contemporary Research, 5*(2), 53–59.

Greene, L. & Rojas, E. (2008). Incremental housing development in Latin America: A review of the literature. *Habitat International, 32*(2), 143-153.

Hasgül, E. (2016). Incremental housing: A participation process solution for informal housing. *ITU A/Z*, *13*(1), 15-27.

Magigi, P., and Majani, J. (2006). Incremental housing development in Tanzania: A case study of Dar es Salaam. *Journal of Housing and the Built Environment, 21*(2), 147-162.

Martins, A. & Farias, J. (2019). Inclusive sustainability within favela upgrading and incremental housing: The case of Rocinha in Rio de Janeiro. *Sustainable Development*, 1–9. https://doi.org/10.1002/sd.1879

Nwuba, C. (2015). *Development of a model for measurement of urban incremental housing affordability in Kaduna State* (Unpublished doctoral dissertation). Department of Estate Management, University of Nigeria, Nsukka, Nigeria.

Park, J., Lim, Y., Kim, K. & Wang, H. (2018). Revisit incremental housing focusing on the role of a comprehensive community centre: the case of Jinja, Uganda. *International Journal of Urban Sciences, 23*(6), 1-20. https://doi.org/10.1080/12265934.2018.1488605

Roberto, C. (2003). *Incremental housing: The past and future dwelling solution for the poor*. MIT Press, Massachusetts.

Ronald, R. & Chiu, R. L. (2010). Changing housing policy landscapes in Asia Pacific. *International Journal of Housing Policy, 10*(3), 223 - 231.

UN-Habitat, (2016). Incremental Housing as a Method to the Sustainable Habitat. United Nations, Lisbon, Portugal.

UNPD (United Nations Department of Economic and Social Affairs, Population Division) (2004). World Urbanization Prospects: The 2003 Revision. New York: United Nations.

Wakely, P. & Riley, E. (2010). *The case for incremental housing. CIVIS Special Issue.* Paper presented at the World Urban Forum 5, 1 -7

Wibowo, A. & Larasati, D. (2018). *Incremental Housing Development; An Approach In Meeting the Needs Of Low Cost Housing In Indonesia.* HABITechno 3 International Conference, IOP Conf. Series: Earth and Environmental Science, 152 (2018) 012006 https://doi.org/10.1088/1755-1315/152/1/012006

Zulu, E. (2010). *Understanding the self-help incremental housing processes in informal settlements as a strategy for providing low-income housing: A case of Ipusukilo, Kitwe-Zambia*. PhD Thesis, European University Institute

Turning The Tide: Achieving Sustainability Through Building Information Modelling Utilisation For Housing Refurbishment

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Abstract
Concerned about the worsening climate change situation, poor adaption strategies in developing economies, and the increasing housing shortages for urban dwellers in Nigeria, this paper examines the role of building information modelling utilisation for housing refurbishment in increasing affordable housing supply and fostering the attainment of sustainability. The data for the study was elicited through a qualitative survey involving interviews of real estate developers who are members of the Lagos State branch of the Real Estate Developers' Association of Nigeria (REDAN) participating in housing development. Ten developers were contacted for the survey, with six volunteering to participate in the data collection process. The collected data were manually transcribed and interpreted using thematic content analysis. The findings revealed that BIM can improve the sustainable design of housing refurbishment. More so, all the respondents agreed that using BIM for housing renovation could eliminate material wastages associated with error-prone designs, thereby reducing cost and making housing affordable. Further findings showed that BIM usage for housing refurbishment could model activities throughout the building life cycle and reduce operational costs associated with building maintenance. The high cost of purchasing BIM software, inadequate knowledge, and lack of government support for BIM usage were identified as the key challenges inhibiting BIM usage for housing renovation by real estate developers. These findings have implications for combating the housing deficit and enhancing the provision of affordable and sustainable housing in the study area, scalable to the whole country.

Keywords: BIM, Housing, Housing Affordability, Refurbishment, Nigeria, Real Estate Developers

1 Introduction

Globally, there has been a growing concern about the impact of human activities on the environment. The built environment, which involves construction and housing development, contributes significantly to natural resource depletion, polluted atmosphere, and degraded ecosystems (Hammond, Nawari & Walters, 2014). As affirmed by the United States Energy Information Administration, buildings are among the highest energy consumers, as 47.6% of total energy generated in the United States is consumed by buildings and accounts for 74.9% of electricity use. In the United Kingdom, about 45% of the entire CO_2 emission emanates from buildings, with residential dwellings accounting for 27% of carbon emissions (Park & Kim, 2014). As a result, the housing sector has been identified as the most significant contributor to climate change as it has been found to emit 44.6% of estimated greenhouse gas emissions (McGraw-Hill, 2014). As such, the housing sector is key to attaining sustainability by reducing carbon emissions and minimising the generation of greenhouse gases inducing climate change. In combating the worsening climate change situation in most countries of the world, governments, international aid agencies and civil societies have become particularly concerned about the inadequacies and inability of adaptation strategies. While developed countries have made appreciable progress in reducing their carbon footprint by adopting a wide range of adaptation strategies, such as housing refurbishment, most developing third-world countries continue to grapple with combating the climate change menace. Several studies such as Park and Kim (2014), Zulkefli, Mohd-Rahim and Zainon (2020), Senior (2020), and Liao, Ren and Li (2023), among others, have documented that building information modelling (BIM) enabled housing refurbishment leading to the renovation of existing buildings is an effective way of reducing energy consumption and carbon emission. Zulkelfi *et al*. (2020) contended that housing refurbishment upgrades existing buildings through green technologies and eco-friendly materials, thereby enhancing environmental sustainability.

The slow uptake of innovative technologies, including BIM, in developing third-world countries implies that traditional practices and processes have continually hampered the quest for sustainability and the attainment of sustainable development goals. These practices manifest in how goods are manufactured, bridges and roads constructed and houses built. For example, studies beginning with the pioneering work of Eastman, Teicholz, Sacks and Liston (2011) have reported the ability of BIM to effect vital changes to the traditional ways of producing housing. The study contended that the application and adoption of innovative technology of BIM for construction could fundamentally alter traditional practices, ultimately fostering a sustainable drive. As such, using BIM technology in housing refurbishment could assist in resolving the issues of communication and information sharing, which is problematic among the construction team and leads to the integration of efforts, improved coordination, and minimised errors and waste, which fundamentally optimises resource requirements, resulting in reduced housing development costs. More so, Park and Kim (2014) noted the role of BIM in improving sustainable housing development by enhancing the fragmented and complex nature of housing production, integrating stakeholders' requirements and technical resources, as well as lowering high development costs, thereby facilitating the attainment of sustainability. BIM, therefore, provides an innovative means of achieving affordable housing delivery.

Despite the increasing potential of BIM in enabling housing refurbishment, its adoption remains very low. Homeowners and real estate developers have not embraced this innovation in improving housing stock. More so, available evidence on BIM usage for housing refurbishment and renovation centred on developed countries, notably the United Kingdom and the United States of America. This suggests that the phenomenon is yet to gain traction in developing countries, including Nigeria. The country grapples with acute housing shortages arising from the inability of supply to meet existing demand. Besides, the resource constraints and national budget limitations experienced by Nigeria have constricted the availability of funds for the production of new houses. Hence, the provision of publicly-funded large-scale housing is limited, while the existing old housing stock provides the basis for meeting the accommodation needs of the citizens. The national housing policy recognises private sector participation as a strategy for ensuring housing development in Nigeria. As such, most of the new housing developments have been by individual homeowners or through private developers.

As a gateway to civilisation in Nigeria, Lagos has a lot of old housing stock, which is unsuitable for habitation. The renovation of these houses could close the housing gap and foster sustainability. However, there is limited information on the role of BIM in housing renovation as most studies on BIM in Nigeria have focused mainly on its adoption, readiness, risk factors and implementation barriers in the architecture, engineering and construction (AEC) industry. The study, therefore, aims to assess the role of BIM in housing refurbishment in Lagos, Nigeria, with a view to providing information for improving ageing housing and enhancing sustainability. The rest of the paper is structured as follows: following this introduction is the literature review. The third section focuses on the methodology, while the results and discussions are in the fourth part. The paper concludes in the fifth section.

2 Literature Review

The literature review for this study is divided into two parts: the first introduces BIM and its application for housing refurbishment, while the second discusses the current state of BIM deployment in Nigeria.

2.1 BIM Implementation for Housing Renovation

BIM has been a subject of interest in the literature, with varying definitions and descriptions from writers, authors, researchers, and government agencies. These diverse definitions notwithstanding, scholars and researchers agree that BIM facilitates collaboration and information exchange among construction professionals for successful project delivery. It also integrates efforts while incorporating stakeholder needs into projects, minimising delays and wastage and enhancing productivity. In this way, BIM can be described as multi-dimensional computer modelling applied to design structures and stimulating the construction and operational phases of building projects (Khoshfetrat, Sarvari, Chan & Rakhshanifar, 2022). With dimensions varying from 3D to 7D, BIM is useful for stakeholders from the beginning of a project to its operation and maintenance phase for increasing efficiency.

Although the uptake of BIM for housing refurbishment is low, the potential of BIM in greening existing buildings, reducing energy consumption and reducing carbon footprints of old housing stock, which ultimately galvanises the attainment of environmental sustainability, has been noted by studies (see for example Park & Kim, 2014; Hammond *et al*., 2014; Kim & Park, 2018; Senior 2020; Liao *et al*., 2023). For instance, Kim and Park (2013) investigated the possibility of utilising BIM as an information management system for housing refurbishment in the United Kingdom. The finding affirmed BIM’s potential in facilitating housing refurbishment based on the availability of sufficient information sets. The study only documented the possibility of BIM usage for housing refurbishment and was limited to construction professionals. To overcome this shortcoming, Park and Kim (2014) examined homeowners' preferences and decision-making factors in developing essential input data for housing refurbishment in the United Kingdom. Based on a survey of 112 and 39 homeowners and construction professionals involved in housing renovation, the capability of BIM usage in facilitating housing refurbishment by incorporating clients' preferences and material choices early in the design stage was affirmed, a crucial indicator of enabling sustainable housing development. The study focused mainly on individual homeowners rather than corporate organisations involved in large scale development. Furthermore, Hammond *et al*. (2014) investigated the feasibility of BIM in facilitating the sustainability of existing buildings through renovation and retrofitting activities in the United States. The outcome showed the potential of BIM integration for housing renovation to facilitate sustainable design and renovation practices that could promote the greening of old buildings.

In another study conducted in the United Kingdom, Alwan (2016) examined the role of BIM in housing refurbishment by developing a proposal for a BIM performance framework for the maintenance and refurbishment of housing stock. Based on the simulation of BIM, the study established the possibility of BIM adaptation for effective housing maintenance towards the attainment of sustainability. This agrees with the research of Kim and Park (2016), which recognised the capability of BIM to facilitate sustainable housing refurbishment in the United Kingdom. Again, Kim and Park (2018) examined the feasibility of BIM as an information management platform to ascertain the financial and environmental profitability of housing refurbishment based on life cycle cost analysis. Employing data based on a BIM simulated case study, the findings highlighted the suitability of BIM as an information management platform to enhance the life cycle cost analysis of existing housing and enhance sustainable housing renovation decisions. The potential was, however, limited by the interoperability difficulties crippling seamless information among BIM tools and materials. Likewise, Okakpu *et al*. (2018) identified the potential of leveraging BIM for housing refurbishment in the United Kingdom subject to the incorporation of essential factors such as refurbishment attributes, environmental influence, stakeholders' interaction and structure optimisation which influences the maximisation of BIM tools for successful housing refurbishment. These studies only documented the possible utilisation of BIM to enhance housing renovation. The specific contributions of BIM in improving the refurbishment of existing housing, thereby enhancing housing affordability, were not identified.

More so, Senior investigated the role of BIM in fostering the sustainable renovation of residential buildings in Norway (Senior, 2020). Using qualitative and quantitative data obtained from homeowners, the study recognised the role of BIM in enabling citizens' engagement for successful housing refurbishment, which could entrench housing sustainability. This assertion was strengthened by the work of Zulkefli *et al*. (2020), which affirmed the ability of BIM to ensure the integration and management of activities throughout the phases of the life-cycle of buildings, including greening existing buildings through refurbishment to attain sustainability. Sertyesilisik, Sertyesilisik, Cetin, and Ocakoglu (2021) investigated the potential of BIM dimensions and their application for enhancing the sustainability of affordable housing. The study established the usability of BIM for energy and facility management, and it found the potential of the integrated application of BIM to add value to housing through reduced energy usage and greening activities throughout the entire life cycle. More so, Liao *et al*. (2023) recognised the increasing potential of BIM among all the building renovation technologies to seamlessly facilitate sustainable housing renovation by incorporating users' preferences and information sharing at the early stage of the decision-making process, which could optimise resource requirements and material usage. While fulfilling their aims and objectives, these studies focused on professionals' opinions on housing construction. The opinions of real estate developers engaging the professionals in housing development projects were not investigated. Since BIM usage is often implemented at the firm level, real estate developers' opinions are critical to entrenching BIM deployment for housing refurbishment.

The corollary of the preceding review indicates that despite the growing recognition of the significance of BIM in enhancing the sustainability of existing buildings as documented by the reviewed studies, its usage is still limited to the United Kingdom, Australia, France and the United States of America. Its uptake has yet to gain traction in many countries due to the inadequacy of existing studies documenting the practice. As such, there is low research evidence on the suitability of BIM for housing refurbishment as an innovative means of achieving housing affordability and realising the sustainability agenda. This is even more critical in developing countries, particularly in sub-Saharan Africa, including Nigeria, where housing affordability is problematic, and issues of carbon emission, energy shortages, and housing deficits are endemic and alarming.

2.2 BIM Adoption in Nigeria

Nigeria is a BIM infant country as the state of BIM deployment has been generally slow, relative to what obtains in other emerging economies. However, despite the slow uptake of BIM, there is evidence of BIM usage in the AEC industry. For instance, studies such as Olapade and Ekemode (2018), Ibrahim (2019), Olawumi and Chan (2020), and Ekemode (2024) have documented the evidence of BIM usage in the construction, infrastructure development and facility management sectors. BIM adoption revolves around the intermediate level, with the current usage level restricted to 3D and 4D levels. This shows that the country is still at Level 1 on the BIM maturity matrix. Studies such as Olawumi and Chan (2020) and Ekemode (2024) have attributed this unpalatable situation to a plethora of BIM application obstacles endemic in Nigeria. Factors such as lack of government support to facilitate adoption, financial incapacitation constricting software acquisition and deployment, absence of government policy framework mandating BIM usage, poor technical know-how and expertise, high cost of deployment and lack of client demand were identified as inhibiting effective BIM utilisation in Nigeria (Olawumi & Chan, 2020; Ekemode, 2024). Besides, there is a lack of empirical evidence on BIM's usage for refurbishing existing housing stock in Nigeria despite recognising its innovative role in enhancing affordable housing production. This study fills this knowledge gap by examining the role of BIM technology in housing refurbishment in Lagos, Nigeria.

3 Methodology

A qualitative research approach is adopted for the study. As such, data utilised for this study were sourced from interviews held with private real estate developers involved in residential property development in Nigeria. The collapse of public housing provision in the country necessitates the choice of private developers. More so, a large proportion of the existing housing stock in Nigeria is held by private individuals and corporations. Besides, the national housing policy recognises private sector participation as a strategy for ensuring housing development in Nigeria. As such, most of the new housing developments have been by individual homeowners or through private developers. The choice of Lagos is justified as its status as the economic centre-point and the gateway to civilisation in the country. As a former British Colony, Lagos has sizeable holdings of old housing stock with the potential to increase the Nigerian housing situation if refurbished. In this wise, ten property developers who are members of the Lagos State branch of the real estate developers' association of Nigeria (REDAN) were initially contacted to participate in the research. After several persuasions, only six developers agreed to be interviewed, and this accordingly forms the basis for the study. The low number of respondents reflects the difficulty of obtaining qualitative and evidence-based data in a country like Nigeria, where research apathy is very rife. Moreover, since real estate developers in Lagos are homogenous, there is a likelihood of some level of convergence in their perception. This suggests that reliance on the opinions of the six respondents could offer insights into the perception of other real estate developers concerning the investigated phenomenon.

Data was collected using a semi-structured interview guide using open-ended questions. The interviews were manually transcribed using thematic content analysis, which arranged them into themes for meaningful interpretation. The profiles and codes of the respondents are summarised in Table 1.

Table 1: Profiles and Codes of the Respondents

Code	Sex	Position	Years of Experience	Educational Qualification	Professional Qualification	Type of Housing Developed
RED 1	M	Managing Director/CEO	15 years	B.Sc.	SURCON, MNIS	Terrace, block of flats
RED 2	F	Project Manager	12 years	B.Sc., MArch	Registered Architect	Detached houses, Terrace
RED 3	M	Manager	10 years	B.Sc.	ACA	Luxury apartments
RED 4	M	Builder	9 years	HND, PGD, M.Sc	MNIOB, Registered Builder	Block of flats, Terrace
RED 5	M	Project Manager	18 years	B. Sc., MBA	MNIOB, Registered Builder	Detached houses, Flats
RED 6	M	Structural Engineer	12 years	B. Eng.	MNSE, Registered Engineer	Terrace, Maisonette

The respondents' profiles in Table 1 showed that they have been involved in housing development for more than nine years. More so, they possess requisite academic and professional qualifications germane to housing development, as a vast majority belonged to the built environment professions of architects, builders, and engineers. As such, their opinions could be highly accurate and reliable.

4 Results and Discussions

The analysis of the data collected from the respondents revealed four themes about the state and role of BIM utilisation for housing refurbishment in the study area. Based on these themes, this section discusses these findings.

4.1 Enhancing Sustainable Design

One of the benefits of BIM, as identified by researchers, is its ability to improve the design of building and construction projects. The study also found this to be one of the key attributes of BIM in the housing sector. As revealed by the findings, BIM is essential in facilitating the sustainable design of housing refurbishment projects. One of the interviewees affirmed that "…. through the usage of BIM, energy requirements and consumption pattern of the building under renovation is predicted by the 3D models… (RED 4)". This finding revealed that infusing 3D BIM models with energy usage information could guide property developers on the sustainability of the buildings regarding energy efficiency. As such, BIM has the potential to ensure the incorporation of green features into existing housing to attain sustainability. This agrees with the findings of Hammond *et al*. (2014) and Sertyesilisik *et al.* (2021), which recognise the role of BIM in greening existing buildings and reducing carbon footprints.

Furthermore, using BIM could also ensure the selection of appropriate designs among a range of possible alternatives based on the prediction of costs associated with the operational phase of the renovated housing throughout the whole life cycle. In this regard, respondent RED 2 averred that "…BIM enabled design for renovation has the potential of guiding developers on the cost and other resources associated with the development option, and this transcends construction cost but includes operational cost…(RED 2)". The selection of appropriate design among a range of alternatives enabled by BIM usage could infuse sustainability into housing renovation. Through this, real estate developers are able to evaluate the resource requirements of alternative designs throughout the entire life cycle. This would guide rational and well-informed decisions in selecting the design that optimises resource use and conserves depleting natural resources. This agrees with the submission of studies such as Kim and Park (2016), Kim and Park (2018), and Zulkefli *et al*. (2020), affirming the ability of BIM to make sustainability decisions at the design phase - the earliest stage of any housing refurbishment activity.

4.2 Material Usage and Quantification

The study also established BIM's critical role in using construction materials required for implementing housing renovation. Respondent (RED 5) noted that "… BIM optimises the use of building construction materials … (RED %)". This is one of the key potentials of BIM usage in housing refurbishment and is critical to attaining the sustainability agenda. For instance, the utilisation of BIM is helpful in the feasibility and viability phase of housing development as it enhances the optimisation of resource use, ultimately reducing development costs. Apart from ensuring sustainability, it also guarantees profitability, which is a key driver of developers' investment decisions in the housing market. In this regard, respondent (RED 1) retorted that "… lower housing renovation costs reduce project cost, thereby increasing developers margin … (RED 1). This translates to reduced rent and sale prices, implying that BIM usage can reduce development costs, profit margins of real estate developers and rent/sale prices of housing refurbishment projects.
Similarly, using BIM leads to strict adherence to design and project timelines. As such, it could help minimise design errors, which often result in material wastage. This strengthens the findings reported by Liao *et al*. (2023) on the capability of BIM to ensure resource optimisation when deployed for building renovation. The visualisation capability of BIM is also relevant in renovation. Respondent (RED 6) opined that "…one key advantage of BIM usage for housing renovation is the visualisation of the end product – what the building would look like upon completion of renovation…". By visualising the outcome of the proposed housing renovation project, BIM effectively improves project design implementation during the construction phase, reducing design errors requiring corrections, which results in the wastage of materials. This could assist in eliminating challenges associated with project delivery, such as cost and time overruns, project delays and client dissatisfaction. In addition, visualisation enables risk prediction and identification of hazards and incorporates strategies for their elimination (Khoshfetrat *et al*., 2022).

4.3 Collaboration and Information Exchange

A key attribute of BIM is its ability to facilitate interoperability and ensure collaboration and information exchange in the construction industry (Eastman *et al*., 2011). This is critical to resolving fragmentation, which is a problem among the development team. The study identified the attribute as one of the critical roles of BIM usage in refurbishing existing housing. The respondents were unanimous in recognising the ability of BIM to promote teamwork and understanding among the members of the development team and all professionals participating in the housing renovation project. This eliminates conflicts and promotes stakeholder engagement, reducing conflicts, frictions and disagreements among the development team that could impinge on the pace of work. This validates the assertion of Okakpu *et al*. (2018), affirming BIM's capability to seamlessly integrate project stakeholders' aspirations, leading to improved outcomes of housing refurbishment projects.

4.4 Functionality and Satisfaction

BIM can enhance the functionality and satisfaction of housing refurbishment projects. This is done by enhancing the decisions concerning the proper location and siting of facilities such as lifts, elevators, and other common services, including walkways, open spaces, parking lots, electricity mains, and sewer lines, without which most housing developments, vast estates, would be deemed functionally obsolete. The digital representation attribute of BIM could depict how these could be appropriately and adequately replicated in housing refurbishment projects to enhance building functionality and users' satisfaction.

However, all the respondents agreed that these enormous potential and utilisation benefits notwithstanding, BIM utilisation for housing refurbishment is still at its lowest ebb. All the respondents reported the usage of 3D BIM for some of their housing projects in the last two years. This shows that BIM usage in housing development is gaining traction relative to the results of earlier studies like Ekemode and Olapade (2021). More so, the little use of BIM in refurbishing houses by real estate developers was ascribed to contributory factors like the high cost of purchasing BIM software, inadequate knowledge and lack of government support towards BIM. This validates the findings of Ekemode (2024), which ascribes the slow usage of BIM in the housing sector of emerging economies like Nigeria to inhibiting factors, notably cost of acquisition and deployment and operating environment constraints.

Based on these findings, BIM, when used for housing refurbishment, could lower the costs associated with housing development, particularly throughout the life-cycle phases. This ultimately reduces the rising overall cost of housing production, which is incredibly high in an inflationary economy like Nigeria. Thus, the innovative digital technology of BIM usage is an innovative means of galvanising sustainable affordable housing delivery. Therefore, effective and appropriate deployment of BIM in the renovation of existing housing stock in Nigeria could increase housing availability by reducing the acute housing deficit prevalent in the country, especially for the urban poor.

5 Conclusion and Further Research

This paper examines the role of BIM in housing refurbishment as a means of greening existing buildings and enhancing the realisation of the sustainability agenda. This is done from the lens of real estate developers involved in housing production in Lagos, Nigeria. The results showed that BIM is useful in enriching the sustainable design of housing refurbishment projects by facilitating the selection of appropriate designs among a range of possible alternatives based on the prediction of energy requirements and carbon reduction. Furthermore, BIM uptake could eliminate design errors, reduce materials' wastage, and optimise resource use. Also, the potential of BIM to promote cooperation among members of the development team involved in housing development, which is critical to project success, was established. The study also found that acquisition and deployment cost issues and the absence of government support hamper the realisation of these utilisation benefits.

These findings indicate that BIM technology helps facilitate sustainable housing refurbishment, which could promote sustainability by incorporating green features into existing buildings, thereby promoting energy efficiency, reducing carbon emissions on the one hand and increasing housing supply and affordability on the other hand. Emanating from these findings, the study concludes by recognising the role of BIM in enhancing the success of housing refurbishment. Apart from greening old housing stock and promoting a sustainable built environment, it increases housing stock, which could assist in affordable housing delivery by lowering the country's housing deficit. To facilitate BIM usage, it is pertinent for developers involved in housing refurbishment to pay adequate attention to BIM inhibiting factors. For instance, to overcome the challenge associated with the high cost of deployment, organisations are encouraged to collaborate to aggregate the required finance to acquire BIM. The government should fulfil its responsibility as an enabler by taking centre stage in BIM acquisition and employment. It is also necessary for the Nigerian and Lagos State governments to formulate and initiate a policy incorporating BIM into the National Housing Policy to guide sustainable housing development and renovation similar to what is obtained in the United Kingdom. BIM could be mandated for residential property development and refurbishment, fostering BIM uptake in the sector.

The potential of BIM for housing refurbishment from the perspectives of property developers was examined in this study. Since the housing market is populated by several players, such as housing corporations and mortgage institutions, further studies could explore the opinions of these participants. More so, further studies could explore the development of an integrated framework/model for BIM usage in housing renovation. This study only focused on Lagos, one of the three first-tier cities in Nigeria. Further research could be undertaken to document this phenomenon in the other first-tier cities of the country.

6 References

Alwan, Z. (2016). 'BIM Performance Framework for the Maintenance and Refurbishment of Housing Stock, *Structural Survey*, Vol. 34 (3), pp. 242–255.

Eastman, C., Teicholz, P., Sacks, R. & Liston, P. (2011). '*BIM Handbook; A Guide to Building Information Modelling for Owners, Managers, Designers, Engineers and Contractors*', Wiley & Sons: Hoboken, New Jersey

Ekemode, B. G. (2024). 'Factors Influencing Building Information Modelling Adoption for Residential Property Development', *International Journal of Construction Management*, Vol. 24 (9), 986–996.

Ekemode & Olapade (2021). 'Building Information Modeling Adaptability for Sustainable Residential Real Estate Development in Lagos, Nigeria', In Abdulai, R. T. & Awuah, K. G. (eds), *Sustainable Real Estate in the Developing World*, Emerald Publishing, pp. 169-190.

Hammond, R., Nawari, N. O. & Walters, B. (2014). 'BIM in Sustainable Design: Strategies for Retrofitting/Renovation', In Issa, R. R. (Eds), *Computing in Civil and Building Engineering International Conference,* American Society of Civil Engineers, pp. 1969-1977.

Khoshfetrat, R., Sarvari, H., Chan, D. W. M. & Rakhshanifar, M. (2022). 'Critical Risk Factors for Implementing Building Information Modelling (BIM); A Delphi-Based Survey', *International Journal of Construction Management*, Vol. 22 (12), 2375-2384.

Ibrahim, A. D. (2019). 'Collaborative Initiatives for Sustainable Development in the Built Environment of Developing Economy. Keynote Paper Presented at the *1st International Conference for Sustainable Development in the Built Environment*, 29-30 April, Faculty of Environmental Sciences, University of Ilorin, Nigeria, pp. 1-39.

Kim, K. P. & Park, K. S. (2013). 'BIM Feasibility Study for Housing Refurbishment Projects in the UK', *Organization, Technology and Management in Construction: An International Journal*, Vol. 5 (3), pp. 756-774.

Kim, K. P. & Park, K. S. (2016). 'Exploring Capabilities of BIM Tools for Housing Refurbishment in the UK', *Journal of KIBIM*, Vol. 6 (4), 9-17.

Kim, K. P. & Park, K. S. (2018). 'Delivering Value for Money with BIM-embedded Housing Refurbishment', *Facilities*, Vol. 36 (13/14), pp. 657-675.

Liao, H., Ren, R. & Li, L. (2023). 'Existing Building Renovation: A Review of Barriers to Economic and Environmental Benefits', Vol. 20, *International Journal of Environmental Research and Public Health*, pp. 1-23.

McGraw-Hill, (2014). '*The Business Value of BIM for Construction in Major Global Markets*', Bedford: McGraw Hill Construction, Research and Analytics.

Okakpu, A., Ghaffarian-Hoseini, G., Tookey, J., Haar, J., Ghaffarian-Hoseini, A., & Rehman, A. (2018). 'A Proposed Framework to Investigate Effective BIM Adoption for Refurbishment of Building Projects', *Architectural Science Review*, Vol. 61 (6), 467-479.

Olapade, D. T. & Ekemode, B. G. (2018). 'Awareness and Utilisation of Building Information Modelling (BIM) for Facility Management (FM) in a Developing Economy: Experience from Lagos, Nigeria', *Journal of Facilities Management*, Vol. 16 (4), 387-395.

Olawumi, T. O. & Chan, D. W. M. (2020). 'Key Drivers for Smart and Sustainable Practices in the Built Environment, *Engineering, Construction and Architectural Management*, Vol. 27 (6), 1257-1281.

Park, K. S. & Kim, K. P. (2014). 'Essential BIM Input Data Study for Housing Refurbishment: Homeowners' Preference in the UK', *Buildings*, Vol. 4 (3), pp. 467-487.

Senior, C. (2020), 'Open BIM for Citizens Engagement in Sustainable Renovation Projects', In Djukic, A., Krstic-Furundzic, A., Lazarevic, E. V. & Vukmirovic, M. (Eds), *7th International Academic Conference on Places and Technologies: Keeping up with Technology to act Responsively with the Urban Environment*, Faculty of Architecture, University of Belgrade, Belgrade, pp. 255-262.

Sertyesilisik, B., Sertyesilisik, E., Cetin, H. T. & Ocakoglu, E. (2021), 'BIM Dimensions and Application Areas for Enhancing Sustainability and Affordability of Affordable Housing: As A Key for Effective Housing Policies', *Periodica Polytechnica Architecture*, Vol. 52(1), pp. 85-93.

Zulkefli, N. S., Mohd-Rahim, F. & Zainon, N. (2020), 'Integrating Building Information Modelling (BIM) and Sustainability to Greening Existing Building: Potentials in Malaysian Construction Industry', *International Journal of Sustainable Construction Engineering and Technology*, Vol.11 (3), 76-83

"Beyond the Mirage": A Review of Nigerian Sustainable Methods, Materials and Policy Propositions for Low-Cost and Affordable Housing

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Abstract
The challenges of affordable housing could be so elusive that some consider its attainment and adequate provision for low-income earners to be a mirage. As in many parts of the world, the Nigerian situation is not an exception in the challenges that bedevil government and private sector efforts in providing Low-Cost and Affordable Housing (LCAH). This study presents a systematic content analysis of extant studies considering current propositions toward efficient public-private initiatives to meet the demands of LCAH in Nigeria, which border on construction techniques, materials, and government policies. Six categorical challenges to LCAH in Nigeria were found and reported in the study, the two significant challenges being the unsustainable cost of conventional building materials and the inattentiveness to local and sustainable materials. The currently proffered solutions to the challenges of LCAH in Nigeria were also categorised along the building techniques, government policies, building materials, and a multi-dimensional approach. The overarching implication of the findings of this study is that the cost of financing the traditional delivery models of affordable housing in Nigeria is prohibitive; efforts should be geared towards cost-efficient alternative construction technologies/techniques as well as the use of local/sustainable building materials.
Keywords: Affordable Housing, Alternative Building Technologies, Innovative Housing Solutions, Public-Private Partnerships, Sustainable Building Materials

1. Introduction
Many countries worldwide are experiencing a significant gap between housing demand and supply (Kusisto & Grant, 2019). By 2030, approximately 40% of the world's population, which equals about 3 billion people, is projected to need housing (UN-Habitat, 2014). In Africa, several nations have been struggling with housing shortages. For instance, Kenya, Madagascar, and Mozambique each faced a 2 million housing unit backlog, while South Africa had a deficit of 2.3 million housing units, Tanzania had a backlog of 3 million units, and Egypt had a deficit of 3.5 million units (El-hadj *et al.*, 2018). Nigeria is included as the country had a deficit of about 17 million housing units in 2012 and needed to construct an average of 800,000 houses to make up the shortfall (Centre for Affordable Housing Finance in Africa - CAHF, 2016). On the contrary, the actual increase in stock was only around 100,000 units per year (CAHF, 2019). Available data indicates that the deficits in housing later grew to an estimated 22 million units in Nigeria (CAHF, 2019). Consequently, housing affordability challenges in Nigeria have become an intractable problem for low-income earners (Anthony *et al.*, 2016). The provision of affordable housing is viewed as a human right and should be within the reach of every citizen of a country, irrespective of their income level (Adeleke & Olaleye, 2020). Due to their inability to afford housing, most low-income earners in the country are forced to live in poor-quality, substandard housing (Makinde, 2014; Adeleke, 2021).

Despite the government's efforts to provide low-cost housing, the demand for affordable housing units significantly outweighs the supply, leading to a growing housing deficit (Moore, 2019).

Although low-cost and affordable housing may be synonymous in principle, the two concepts can also be circumstantially and contextually different. Low-cost housing refers to housing built considering lower construction costs without compromising functionality and durability (Olanrewaju *et al.*, 2021). Affordable housing refers to housing that is inexpensive to low-income earners and those earning moderate incomes (Puri *et al.*, 2015). Thus, while low-cost housing may be affordable, affordable housing may not necessarily be low-cost, and vice versa. The intended urban poor and low-income earners' inability to access low-cost housing due to socio-political barriers, bureaucratic costs, and other similar factors has given rise to the concept of unaffordable low-cost housing (Iwuagwu *et al.*, 2016). Low-cost housing is affordable when it is within reach for people who make less than the typical household income in an area (Srivastava & Kumar, 2018).

While low-cost housing may not always be the same as affordable housing, it can still play a vital role in addressing the affordable housing crisis in Nigeria. Therefore, prioritising the construction of low-cost housing units is crucial to bridging the identified gap between the demand for affordable housing and its supply in the country. This is because the adverse effects of inadequate supply of low-cost and affordable housing include homelessness, overcrowding, the growth of slums, and urban degradation (Ojo *et al.*, 2022). It is no gainsay that making housing affordable for low-income earners should be a primary concern for policymakers in Nigeria by providing inexpensive residential accommodations.
Considering the preceding characterisation of the need for Low-Cost and Affordable Housing (LCAH), this study adopted the systematic content analysis of extant literature in presenting current propositions that border on housing construction materials, methods, and policies to address the challenges of LCAH in Nigeria. The specific objectives are to examine the topical LCAH considerations in Nigeria, scrutinise the challenges that hinder the provision of LCAH in Nigeria, and analyse the currently suggested courses of action to make LCAH a consistent reality in Nigeria.

2. Methodology

The study adopted systematic content analysis to review extant studies that have examined the challenges to low-cost and affordable housing in Nigeria. Systematic content analysis combines systematic review and content analysis to offer a more scientific procedure for selecting and reviewing literature (Khirfan *et al.*, 2020; Ogunbiyi *et al.*, 2022; Ogunbiyi *et al.*, 2024). Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) (Moher *et al.*, 2009; Ogunbiyi, 2024) was the systematic review model adopted in this study, combined with content and thematic analyses.
Extant studies were sourced for the current study using Google Scholar. Using Boolean operators, an initial search prompt was designed that captured the critical terms of the study, including "cost-effective housing", "cost-saving housing", "low-cost housing", "affordable housing", “Nigeria”, "building technologies", "building techniques", "building materials", “policies”, “methodology”, “empirical”, and "primary data". The search string yielded 534 articles. Then, the search string was delimited to a five-year period (2022-2024), which resulted in 264 articles. To further reduce the articles to manageable but relevant ones, the search string was further delimited to a two-year period (2023-2024),

which resulted in 93 articles. The 93 articles were subjected to individual reviews to ensure strict relevance to the current study. The effectiveness of the final search string is reflected in the fact that it captured all the key terms of the study; it ensured the recency of articles reviewed (2023-2024), and it attempted to capture only empirical research and 'primary data' collected for the previous studies.

The titles of the 93 selected articles were screened; irrelevant articles and studies found not to have been primarily conducted in or focused on Nigeria were excluded (n=61). Additionally, screening abstracts of the remaining 32 articles revealed the presence of unrelated studies, which were also excluded (n=10). Full-text screening of the remaining 22 articles showed that the studies in two other articles were unconnected to the current study and were excluded from further analysis. Hence, content and thematic analyses were undertaken on 20 extant studies to achieve the aim of this study.

3. Findings and Discussion

3.1 Topical issues on low-cost and affordable housing in Nigeria

Results of content and thematic analyses of the topical items of consideration in the selected extant studies on LCAH in Nigeria are presented in Table 1.

1. Eco-friendly/sustainable building materials: This suggested that, in line with global trends, studies on LCAH in Nigeria have significantly shifted focus to seeking how sustainability can be maintained while tackling the challenges of LCAH. The studies examined the availability (Micah, 2023; Musa, 2023), benefits (Lekjep *et al.*, 2024; Nwaki *et al.*, 2023), and barriers (Eze *et al.*, 2023; Nwaki *et al.*, 2023) to the use of sustainable materials for LCAH and other building constructions in Nigeria.

2. Alternative building technologies/techniques (ABTs): The studies aimed at investigating alternative building techniques and technologies to determine their applicability in LCAH provision in Nigeria. The studies examined modular construction (Nwoko, 2023); Thermal Storage Material (TSM) (Farouq, 2023); shipping container housing (Okeoma, 2023); use of polystyrene material (Jan 2023); sandbag building technology (Sunday *et al.*, 2023), and various ABTS (Ebekozien *et al.*, 2024).

3. Affordable housing challenges: The studies examined the challenges of affordable housing in the semi-arid climate (Modu *et al.*, 2024) and other various challenges of affordable housing provision in Nigeria (Adedeji *et al.*, 2023; Enwin & Ikiriko, 2023).

Table 1. Thematic and content analyses of topical issues on LCAH in Nigeria

Theme	Sub-themes	Freq.	%	Sources
Topical low-cost and affordable housing considerations in Nigeria	1. Eco-friendly/Sustainable building materials	7	35%	Ekhaese & Ndimako (2023); Musa (2023); Lekjep *et al.* (2024); Nwaki *et al.* (2023); Micah (2023); Eze et al (2023); Elisha *et al.* (2023)
	2. Alternative Building technologies/techniques	6	30%	Ebekozien *et al.* (2024); Nwoko (2023); Farouq (2023); Okeoma (2023); Jan (2023); Sunday *et al.* (2023)
	3. Affordable housing challenges	3	15%	Modu et al (2024); Adedeji *et al.* (2023); Enwin & Ikiriko (2023)
	4. Housing design	2	10%	Emusa & Idakwoji (2023); Aliyu & Ismail (2023)
	5. Conventional building materials	1	5%	Akano (2023)
	6. Housing project finance	1	5%	Eze (2023)
	Total	**20**	**100%**	

(Source: Authors’ Review, 2024)

4. Housing design: The studies examined the imperatives of traditional housing pattern (Emusa & Idakwoji, 2023) and Afrocentric architecture (Aliyu & Ismail, 2023) and their applicability in LCAH in Nigeria.

5. Conventional building materials: Akano (2023) evaluated the effects of the cost of conventional building materials on quality and affordable housing supply.

6. Housing project finance: Eze (2023) examined how time-bound funding percentages affect the timeliness of housing and other construction project delivery and quality in Nigeria.

The observed research gaps in the selected studies concerned other innovative housing solutions that are being explored in other countries, including incremental housing, self-help models, cooperative housing, microfinance housing, viability appraisal of green building projects and materials, and multidisciplinary studies of issues affecting affordable housing delivery.

3.2 Challenges to methods, materials, and policies on LCAH in Nigeria

Concerning the challenges to methods, materials, and policies on LCAH in Nigeria as examined in the extant studies, the results of thematic and content analyses are presented in Table 2.

1. Inattentiveness to local and sustainable materials: This was considered the current leading challenge to LCAH in Nigeria from the authors' perspectives of the selected studies. Micah (2023) and Nwaki *et al.* (2023) opined that sustainable building materials are available in Nigeria, but their cost-effective use is not being adequately explored. Eze *et al.* (2023) suggested that resistance to change, insufficient awareness, unhelpful preexisting regulations, lack of research funds, current cost of procurement, and other market barriers comprise the significant challenges to the adoption of sustainable materials in LCAH and other construction projects in Nigeria. Other identified challenges to LCAH in Nigeria were the high cost of cement (Musa, 2023), the cost of energy due to the tropical climate of Nigeria (Farouq, 2023), and inattentiveness to other indigenous environmental and socio-cultural considerations (Emusa & Idakwoji, 2023).

Table 2. Thematic and content analyses of the challenges to methods, materials, and policies on LCAH in Nigeria

Theme	Sub-themes	Freq.	%	Sources
Challenges to low-cost and affordable housing in Nigeria	1. Inattentiveness to local and sustainable materials	8	35%	Micah (2023); Eze et al (2023); Elisha *et al.* (2023); Musa (2023); Farouq (2023); Lekjep *et al.* (2024); Nwaki *et al.* (2023); Emusa & Idakwoji (2023)
	2. Unsustainable cost of conventional materials	4	10%	Ekhaese & Ndimako (2023); Jan (2023); Okeoma (2023); Nwoko (2023)
	3. Rapid urbanisation/population growth	3	15%	Aliyu & Ismail (2023); Sunday *et al.* (2023); Eze (2023)
	4. Cross-classified challenges	3	15%	Ebekozien *et al.* (2024); Adedeji *et al.* (2023); Enwin & Ikiriko (2023)
	5. Poor maintenance activities	1	5%	Modu *et al.* (2024)
	6. Housing developers' challenges	1	5%	Akano (2023)
	Total	**20**	**100%**	

(Source: Authors' Review, 2024)

2. Unsustainable cost of conventional materials: This has led to the high cost of housing development and maintenance (Okeoma, 2023), as well as costly construction wastes and other environmental challenges (Nwoko, 2023; Jan 2023).

3. Rapid urbanisation/population growth: This has led to insufficient affordable housing options (Aliyu & Ismail, 2023) and a general increase in housing deficit (Sunday *et al.*, 2023; Eze, 2023).

4. Cross-classified challenges: The studies also reported the mix-match of challenges that affect LCAH in Nigeria. The challenges included inadequate long-term repayment funds, bureaucratic costs of housing development approvals, and expensive building materials (Adedeji *et al.*, 2023). Ebekozien *et al.* (2024) also reported the peculiar constraints of government, private sector developers, users, and materials manufacturers that may affect LCAH construction. Enwin & Ikiriko (2023) suggested the challenges as comprising shortcomings in urban planning, inaccessible finance, cost-prohibitive construction materials and labour, infrastructural inadequacies, bureaucratic bottlenecks, and corrupt practices.

5. Poor maintenance activities: Poor maintenance of building components may lead to faster deterioration of buildings, thereby limiting the effectiveness of existing LCAH stock in meeting housing demands (Modu *et al.*, 2024).

6. Housing developers' challenges: Private developers face several daunting challenges that hinder their contributory participation in the provision of LCAH in Nigeria. These challenges include the high cost of building materials, unforeseen disruptions to the materials supply chain, overwhelming demand, unstable regulatory regimes, and labour costs (Akano, 2023).

These findings on the challenges of LCAH in Nigeria reflect the complexity of the current built environment. They represent diversified circumstances and a significant departure from the traditionally reported challenges to LCAH, which were majorly focused on governments as the major providers of LCAH in Nigeria (Ebekozien *et al.*, 2021).

3.3 Proposed solutions to the challenges affecting LCAH in Nigeria

In addressing the challenges affecting LCAH provision in Nigeria, the extant studies proposed solutions that affect the housing processes, methods, building materials, and government policies. The results of the thematic and content analyses are presented in Table 3. This study classified the existing propositions under materials, methods, policies, and multi-dimensional solutions.

Table 3. Thematic and content analyses of the solutions to methods, materials, and policies on LCAH in Nigeria

Theme	Sub-themes	Freq.	%	Sources
Proposed solutions to low-cost and affordable housing challenges in Nigeria	1. Methods/Techniques: modular construction, stabilised earth mud bricks, polystyrene building technologies.	16	41%	Aliyu & Ismail (2023); Ebekozien *et al.* (2024); Eze *et al.* (2023); Modu *et al.* (2024); Elisha *et al.* (2023); Akano (2023); Musa (2023); Nwoko (2023); Farouq (2023); Okeoma (2023); Lekjep *et al.* (2024); Jan (2023); Sunday *et al.* (2023); Ekhaese & Ndimako (2023); Eze (2023); Emusa & Idakwoji (2023)
	2. Government Policies: PPPs with collaborative regulations bordering on financial incentives and support for developers.	13	33%	Eze *et al.* (2023); Elisha *et al.* (2023); Aliyu & Ismail (2023); Ebekozien *et al.* (2024); Akano (2023); Musa (2023); Nwoko (2023); Okeoma (2023); Lekjep *et al.* (2024); Nwaki *et al.* (2023); Sunday *et al.* (2023); Eze (2023); Enwin & Ikiriko (2023)
	3. Materials: - Composite materials - Recycled materials - Local materials - Innovative materials	9	23%	Akano (2023); Ekhaese & Ndimako (2023); Musa (2023); Farouq (2023); Lekjep *et al.* (2024); Sunday *et al.* (2023); Ekhaese & Ndimako (2023); Okeoma (2023); Jan (2023);
	4. Multi-dimensional solution: - Economic, environmental, etc. approaches.	1	3%	Adedeji *et al.* (2023)
	Total	**39**	**100%**	

(Source: Authors' Review, 2024)

1. Methods: The selected studies proposed using innovative and sustainable building technologies/techniques (Ebekozien *et al.*, 2024; Aliyu & Ismail, 2023) in providing LCAH to meet the existing demand for affordable housing in Nigeria. Such innovative building practices may include the use of stabilised earth mud bricks (Musa, 2023); modular construction techniques with associated housing designs (Nwoko, 2023); local building materials with passive cooling techniques (Farouq, 2023); polystyrene building technologies (Jan 2023), and the use of earthbag in buildings (Sunday *et al.*, 2023) among others. Accordingly, practitioners need more awareness and hands-on training on the applications of innovative building materials and techniques (Eze *et al.*, 2023; Elisha *et al.*, 2023). Besides, social, cultural, and other Indigenous considerations may afford local sustainable and affordable building practices to aid LCAH in Nigeria (Emusa & Idakwoji, 2023). Moreover, competently executed planned, predictive, and preventive maintenance would also forestall the failure of the existing housing stock in reasonably catering to the current level of demand for LCAH (Modu *et al.*, 2024).

2. Policies - While acknowledging that the best way forward remains efficient public-private partnerships (PPPs), the selected studies suggested the relevant regulations and policies that could aid the actualisation of LCAH for the target Nigerian populace. The policies were suggested to support the use and affordability of sustainable construction materials and practices (Eze *et al.*, 2023; Musa, 2023). This would also involve government regulations and initiatives geared towards awareness creation and encourage the willingness of stakeholders to adopt innovative and eco-friendly construction techniques (Nwoko, 2023; Sunday *et al.*, 2023). The studies also recommended that government policies foster financial incentives for developers and support research and development, training, retraining, and interdisciplinary collaboration among practitioners (Aliyu & Ismail, 2023; Eze, 2023). Such policies must also make provisions for subsidy support on the procurement of building materials and tax exemptions to encourage the adoption of local and sustainable building materials for LCAH developments (Akano, 2023).

3. Materials: Extant studies on LCAH in Nigeria are increasingly advising the adoption of a range of building materials that are considered less expensive when compared to conventional building materials. The studies suggest the adoption of:
Composite materials are combined through mixing and heat treatment, e.g., hemp-based composites (hempcrete) (Akano, 2023).

- Recycled materials - reclaimed wood, recycled concrete aggregates (Akano, 2023), and recycled steel (Ekhaese & Ndimako, 2023).

- Local materials – bamboo (Akano, 2023); earth mud bricks with palm tree derivatives (Musa, 2023); local earthen materials (Farouq, 2023); wood, bamboo, straw bales, earth, clay brick, stone, timber, and laterite (Lekjep *et al.*, 2024;); earth-based materials such as adobe (laterite) blocks, rammed earth, compressed earth bricks, natural clay and mud bricks and tiles (Nwaki *et al.*, 2023); clay soil for plastering, granites for footing/wall base (Sunday *et al.*, 2023).

- Innovative materials - the innovative application of existing materials such as Phase-change material (PCM) and other thermal energy storage (TES) materials (Farouq, 2023); shipping containers (Okeoma, 2023); advanced plastic materials like the expanded polystyrene (Jan 2023); solid-weave polypropylene bags, flat-weave tubes, HDPE mesh tubes/bags (Sunday *et al.*, 2023); insulated concrete, green concrete, geo-polymer brick, stabilised earth brick, flyash concrete (ashcrete) (Ekhaese & Ndimako, 2023).

4. Multi-dimensional solution: Adedeji *et al.* (2023) proposed that the challenges to LCAH in Nigeria would require a multi-dimensional solution. The author suggested aggregating economic, environmental, social, technological, and institutional considerations in addressing the challenges.
The findings of this study underscored the need for a multi-pronged approach to address the challenges of LCAH provision in Nigeria. This requires very effective public-private partnerships that adequately utilise cost-effective and sustainable building materials, building techniques/technologies, and cutting-edge government policies efficiently implemented to aid the actualisation of LCAH. An evident gap in the available studies is the lack of sufficient detailed and practical demonstrations of successful applications of sustainable materials for LCAH constructions.

5. Areas for Further Studies

Arising from the review of the literature, the following gaps and areas for further studies were identified:

1. Studies need to be more articulate and practical on how government regulations may guide sustainable, affordable housing in Nigeria.
2. More research is needed on other innovative affordable housing solutions, such as incremental housing, self-help models, shipping container housing, sandbag construction, cooperative housing, and microfinance housing.
3. Viability appraisal of the applicability of local and sustainable (green) building materials for LCAH delivery in Nigeria.
4. More laboratory research and dissemination of knowledge about the structural strength and durability of local and sustainable building materials in Nigeria.

6. Conclusion

This study shows that building affordable housing in Nigeria using traditional methods is too expensive over time. Instead, efforts should be focused on alternative, inexpensive construction techniques and materials that are readily available and environmentally friendly. The study also emphasises the central position of government regulations and policies in effectively implementing and realising LCAH for the urban poor and low-income earners.

7. References

Adedeji, I., Deveci, G. & Salman, H. (2023). 'The challenges in providing affordable housing in Nigeria and the adequate sustainable approaches for addressing them', *Open Journal of Applied Sciences*, 13(3), pp. 431-448.

Adeleke, F.G. & Olaleye, A. (2020). 'Housing affordability among low-income civil servants in Lagos State, Nigeria', *African Journal for the Psychological Study of Social Issues (AJPSSI)*, 23(1), pp. 1-13.

Aliyu, A.A. & Ismail, A.S. (2023). 'Afrocentric architecture for lowcost housing design in Kano, Nigeria: exploring opportunities', *Malaysian Journal of Sustainable Environment*, 10(2), pp.155-178.

Akano, C.M. (2023). 'Evaluating the effects of building material cost on quality housing delivery in Nigeria', *Irish International Journal of Engineering and Scientific Studies*, 6(6), pp. 1–18.

Anthony A.I., Dabara D.I., Joseph O., Odewande, A.G. & Agidi, O.M. (2016). *'Low income residential housing delivery in Osogbo, Osun State, Nigeria'*, Conference of the International Journal of Arts & Sciences, 9(1), pp. 15-28.

Centre for Affordable Housing Finance in Africa (2016), *Housing Finance in Nigeria*. CAHF. http://housingfinanceafrica.org/countries/nigeria/

Centre for Affordable Housing Finance in Africa (2019), *Housing finance in Africa: A review of Africa's housing finance*. Tenth anniversary edition. CAHF.

Ebekozien, A., Abdul-Aziz, A.R. & Jaafar, M. (2021). 'Low-cost housing policies and squatters struggles in Nigeria: the Nigerian perspective on possible solutions', *International Journal of Construction Management*, 21(11), pp.1088-1098.

Ebekozien, A., Aigbavboa, C.O. & Samsurijan, M.S. (2024). 'Appraising alternative building technologies adoption in low-cost housing provision to achieving Sustainable Development Goal 11', *Engineering, Construction and Architectural Management*, 31(13), pp. 41-58.

Ekhaese, E.N. & Ndimako, O.O. (2023). 'Eco-friendly construction materials and health benefits in the design of an all-inclusive health resort, Nigeria', *Frontiers in Built Environment*, 9.

El-hadj, M.B., Issa, F. & Zekebweliwai, F.G. (2018). *Housing market dynamics in Africa.* Palgrave, Macmillan.

Elisha, Y.V., Habibu, S. & Kabir, K.M. (2023). 'Effect of Indigenous materials in resettlement housing construction in insurgency-affected areas of Adamawa State', *Int Journal of Earth Design and Innovation Research*, 2(1), pp.17-30

Emusa, H. & Idakwoji, W.A. (2023). 'Sustainability of traditional building practices in Nigeria: The case of Igala traditional architecture', *International Journal of Science and Research Archive,* 10(2), pp. 041-055.

Enwin, A.D. & Ikiriko, T.D. (2023). 'Understanding the challenges of affordable housing provision in Nigeria: analysis of key factors and implications', *European Journal of Theoretical and Applied Sciences,* 1(4), pp. 420-436.

Eze, U.M. (2023). *Sponsors milestone payment effect on sustainable construction.* (Masters dissertation, Metropolia University of Applied Sciences).

Eze, E.C., Sofolahan, O. & Omoboye, O.G. (2023). 'Assessment of barriers to the adoption of sustainable building materials (SBM) in the construction industry of a developing country', *Frontiers in Engr. & Built Envrt*, 3(3), pp.153-166.

Farouq, M.M. (2023). *Development and evaluation of phase change material-enhanced earthbag buildings for thermally comfortable and sustainable temporary housing in Nigeria: Numerical and experimental approach.* (Doctoral dissertation, University of Nottingham).

Iwuagwu, B.U., Onyegiri, I. & Iwuagwu, B.C. (2016). 'Unaffordable low-cost housing as an agent of urban slum formation in Nigeria: How the architect can help', *International Journal of Sustainable Development,* 11(2), pp. 05-16.

Jan, Y.Y. (2023). *Level of awareness and attitude towards the use of polystyrene as a damp proof material in building construction in Minna, metropolis of Niger.* (Bachelor dissertation, Federal University of Technology, Minna, Nigeria).

Khirfan, L., Peck, M. & Mohtat, N. (2020). 'Systematic content analysis: A combined method to analyse the literature on the daylighting (de-culverting) of urban streams', *MethodsX*, 7, 100984.

Kusisto, L. & Grant, P. (2019, April 2). 'Affordable housing crisis spreads throughout the world'. *The Wall Street Journal*. https://www.wsj.com/articles/affordable housing crisisspreads-throughout-world-11554210003

Lekjep, R.S., Kagai, K.J., Chong, J.D. & Baji, J.A. (2024). 'Improving thermal and energy performance of residential buildings in Nigeria by developing and using eco-friendly and sustainable local materials', *Bima Journal of Science and Technology*, 8(1B), pp.157-169.

Makinde, O.O. (2014). 'Housing delivery system, need and demand', *Environment Development and Sustainability,* 16(1), pp. 49-69.

Micah, Z.Z. (2023). *Assessment of the need for environmentally friendly building materials in Kaduna State.* (Bachelor dissertation, Federal University of Technology, Minna, Nigeria).

Modu, M.A., Sapri, M. & Ab Muin, Z. (2024). 'A quantitative approach to investigate Factors contributing to social housing occupants' challenges in the semi-arid climate Of Nigeria', *Facilities,* 42(5/6), pp. 537-552.

Moher, D., Liberati, A., Tetzlaff, J., Altman, D.G. & The PRISMA Group (2009), 'Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement', *PLoS Medicine*, 6(7), pp. 1-6.

Moore, E.A. (2019). 'Addressing housing deficit in Nigeria: Issues, challenges and prospects', *CBN Economic and Financial Review,* 57(4), 201–222.

Musa, S.A. (2023). *Effect of earth mud bricks stabilised with palm tree derivatives on compressive strength and water absorption rate.* (Masters dissertation, Federal University of Technology, Minna, Nigeria).

Nwaki, W., Sofolahan, O. & Eze, E. (2023). 'Inhibitors to earth-based materials adoption In urban housing construction: the view of design experts', *Civil and Sustainable Urban Engineering,* 3(2), pp. 123-137.

Nwoko, C. & Abdulrahman, M. (2023). 'Enhancing construction quality and efficiency in Abuja, Nigeria: Modular construction for hotels', *International Journal of African Research and Sustainability Studies,* 2(2), pp. 53-61.

Ogunbiyi, J.O., Oladokun, T.T. & Emmanuel, O.F. (2022). 'Isomorphism of client satisfaction and client sophistication in client influence on valuations: a systematic content analysis', In *21st African Real Estate Society Conference,* 6-9 September 2022,Accra, Ghana, pp. 458-491.

Ogunbiyi, J.O., Adeleke, F.G. & Oladimeji, D.E. (2024). 'Ethical delimitation of client satisfaction, client sophistication, and client influence in property valuation practice in Nigeria', *Journal of Nigerian Institution of Estate Surveyors and Valuers,* 45(1), pp. 100-114.

Ojo, O., Adeleke, F.G. & Jogunola, A. (2022). 'Housing delivery, finance and mortgage system in Nigeria', *Ife Research Publications in Geography*, 21(1), 52-61.

Olanrewaju, S.B., Okedare, D.K. & Fagbohun, J.O. (2021). 'Prospect of low-cost housing delivery for middle income earners in Nigeria', International *Journal of Engineering and Science*, 10(7), pp. 48-54.

Okeoma, I. (2023). *Exploring the viability of shipping container housing as a solution to student accommodation deficit in Nigeria*. (Masters dissertation, Metropolia University of Applied Sciences).

Puri, V., Chakrabortty, P. & Majumdar, S., (2015). 'A review of low-cost housing technologies in India', *Advances in Structural Engineering: Materials,* 3, pp.1943-1955.

Srivastava, M. & Kumar, V. (2018). 'The methods of using low-cost housing techniques in India', *Journal of Building Engineering*, *15,* pp.102-108.

Sunday, Y.U., Charles, A.F., Ekule, A.A., Baiyegunhi, M. & Albert, A.B. (2023). 'Performance-based building regulations: an imperative to earthbag construction innovation in Nigeria'. *Fuoye Planning Journal*, 1(1), pp. 190-210.

United Nations Habitat (2014). *Housing and slum upgrading*. http://unhabitat.org/urban-themes/housing-slum-upgrading.

Limitations, Challenges, and Solutions to Housing Construction in Informal Settlements

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Abstract
Our study aims to understand the problems of informal settlement builders to improve housing construction through sustainable construction practices and build more sustainable communities. The research combined several qualitative approaches, including desk research, focus group discussions, key informant interviews and site observations at Ocean View and Khayelitsha informal settlements. The study found that the significant challenges of informal settlement builders, amongst others, include lack of access to quality materials, lack of formal training and unwillingness of customers to change. The study recommends a thorough consideration of the material procurement strategies and supply chain adaptability for alternative building materials, short vocational and apprentice training programmes or courses for informal settlement builders, mentorship, and a general overhauling of communal mindsets of informal settlement dwellers through networking for reflection, awareness, and growth. The study is qualitative, and a survey approach can be used to rank the challenges for prioritizing solutions.

Keywords: Building construction, Challenges, Informal settlements, Sustainable Communities, Sustainable construction.

1. Introduction

As of 2020, about 1.1 billion people live in informal conditions in urban areas, and an additional 2 billion are expected to join over the next 30 years (UN System Factsheet, 2023). Eighty-five per cent of slum dwellers are concentrated in Central and Southern Asia (359 million), Eastern and South-Eastern Asia (306 million) and sub-Saharan Africa (230 million). The informal settlement is one of the biggest challenges facing developing countries in recent times; the phenomenon is increasing daily, downgrading the quality of life and eradicating urban fabric (El Menshawy & Shafik, 2016). Empirical studies have shown that rapid urbanization over the past two decades has produced considerable challenges of an ever-increasing urban housing deficit, social exclusion and the emergence and growth of informal settlements across the cities of South Africa (Ziblim, Sumeghy and Cartwright, 2013).

The latest statistics of informal settlement dwellers in South Africa stand at 16.6% in 2022 (Stat SA, 2023), and one in five people in South African cities now live in informality (DAG, 2023). The UN SDG Goal 11 focuses on making cities and human settlements inclusive, safe, resilient, and sustainable (UN, 2020). As such, there is a need to garner efforts to achieve this goal. As the DFID (2000) has noted, "*Informal Settlements can only be sustainable when they cope with and recover from stresses and shocks and the concept can be achieved by maintaining or enhancing their capabilities and assets...*"

Globally, different efforts have been channelled towards the challenges in informal settlements and building more affordable and sustainable informal settlement communities. Specifically, examples in South Africa include providing RDP and GAP housing and different support from the Government and Non-Governmental organizations *(*El Menshawy & Shafik, 2016; Huchzermeyer & Karam, 2006*)*. However, a significant solution gap is in understanding the limitations and challenges of the informal builders, self-builders, and those involved with participatory design and construction in informal settlements. As Lizarralde and Root (2008) have noted, there is a need to recognize that the informal sector already plays a fundamental role in the building industry, and further inclusion of the informal sector in the construction industry is essential.

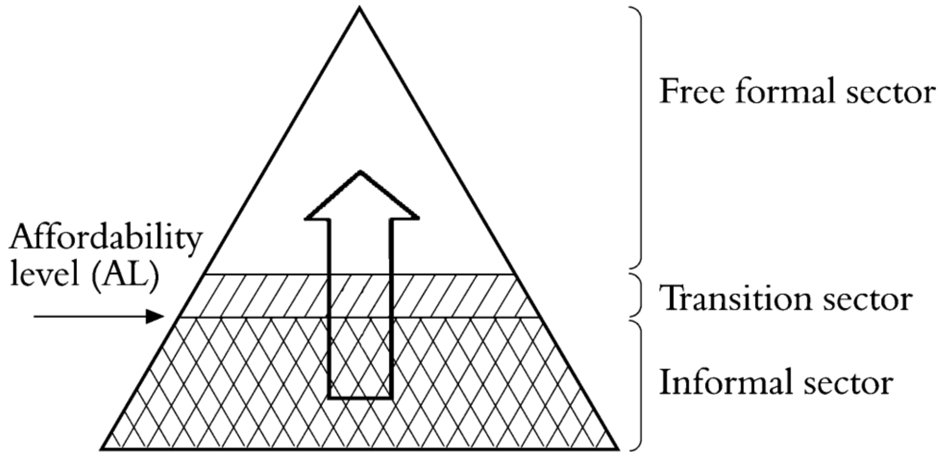
This study understands the limitations and challenges of housing construction in informal settlements to provide recommendations for more sustainable construction and communities. It is essential because such understanding will provide valuable insights for the builders, policymakers, practitioners, and stakeholders involved in informal settlement housing, urban planning, and development. It will also inform the design and implementation of policies, programs, and interventions to address housing deficits, improve building standards, and promote inclusive and sustainable urban development. The following section gives an overview of the informal settlement market and the nature of construction.

2. Literature Review

2.1 The Informal Settlement Housing Market

Informal settlements are urban neighbourhoods or districts that develop and operate without the formal control of the state, co-existing but not synonymous with 'squatter' settlements and 'slums' (Dovey & King, 2011). The DHS (2016) noted that informal settlements are places of multiple deprivations, and the national averages on key development indicators revealed poor levels of health and nutrition, high unemployment, and under-employment levels, as well as high levels of risk and vulnerability. The significant characteristics of informal settlements include lack of basic services and inadequate infrastructure, lack of security and vulnerability to disasters. Lizarralde and Root (2008), in their housing pyramid shown in Fig 1.0 below, suggested that the urban housing market in developing countries reflects the contrasting participation of two delivery systems: the informal and the formal sectors.

Figure 1 The urban housing market of developing countries (Source, Lizarralde and Root, 2008).



There is also the possibility of climbing the housing ladder from informal to formal sectors, which usually depends on the availability of products across a wide range of prices. As Merrill *et al.* (2021) have shown, informal households' choices of building their home are significantly impacted by the cost and availability of materials and construction services they can access. This contrasts with what it obtains in the formal and transition sectors, where there is direct delivery of houses by the Government or developers, which is then purchased when already completed.

2.2 Informal Housing construction techniques

The extant literature reveals different kinds of Housing construction techniques in informal settlements, mainly characterized by flexibility, adaptability, and resilience as residents navigate resource constraints, land tenure insecurity, and other challenges (Venter, Marais and Morgan, 2019). This alludes to Ferlito et al. (2019) that using affordable, locally sourced building materials for sustainable, affordable housing is a good development strategy. Cost-effectiveness and affordability are primary concerns for builders in informal settlements, while sustainability, energy efficiency and disaster resilience are not a significant consideration.

The standard construction techniques for informal settlement housing found in the literature include improvised and self-help construction, incremental construction, use of local and recycled materials and participatory design and construction (Ndlangamandla & Combrinck, 2020; Moreno et al.,2019; Dakhli & Lafhaj, 2018; Lombard, 2014). Informal settlers mostly rely on their self-help construction methods, which they use to build with the help of family members, friends, and neighbours to reduce labour costs. In addition, they frequently use locally available and recycled materials such as wood, bamboo, corrugated metal sheets, salvaged building materials, and plastic bottles filled with sand for construction to minimize costs. Some informal settlements engage in participatory design and construction, where residents collaborate to provide housing solutions to meet their needs. These settlements are sometimes constructed in room-by-room accretions (Dovey et al., 2020).

2.3 Challenges of Informal Settlement Builders

The literature shows that informal settlement builders face several limitations that hinder their ability to construct safely, durably, sustainably and economically. The following is the summary of the challenges of informal settlement builders found in the literature: Mathiba (2019), Venter, Marais and Morgan (2019) and Ehebrecht (2014):

1. Limited access to resources: Informal settlement builders often need more financial resources, materials, tools, and construction equipment. This limited resource access can restrict their ability to build structurally sound and resilient housing.
2. Lack of technical expertise: Many informal builders need more formal training and technical expertise in construction techniques, building codes, and safety standards. This lack of expertise leads to the construction of substandard and unsafe housing, posing risks to occupants' health and well-being.
3. Access to formal markets: Informal builders may need help accessing formal construction markets, contracts, professional development and advancement opportunities. Discrimination, lack of recognition, and exclusion from formal construction sectors can limit their ability to access higher-paying jobs and expand their businesses.
4. Limited capacity for innovation: Due to a lack of awareness, training, and access to information, informal builders may need more capacity for innovation and adoption of modern construction technologies and practices. This can constrain their ability to improve building techniques, enhance efficiency, and adapt to changing market demands.
5. Informal land tenure: Informal builders often operate in areas with insecure land tenure, where they may face eviction, displacement, or legal challenges to their right to occupy and build on the land. Informal settlements built on insecure land tenure may need more access to essential services and infrastructure, making building and maintaining safe and livable housing difficult.

3. Methodology

The research combined several qualitative approaches, including desk research, focus group discussion, key informant interviews and site observations at Ocean View and Khayelitsha informal settlements. The research began with reviewing publicly available data about informal settlement housing and construction. The focus group discussion was carried out on the 8th of May 2024, and the site visit on the 13th of May 2024. Two heads of communities who self-built their home in the Ocean View informal settlement were also interviewed during the site visit. Participants signed an informed consent form, and the process was facilitated by a community member who mediated for clarity at different intervals to ensure smooth running. A combination of structured questions was asked relating to the construction process and the challenges faced before and during the process. Further, the opportunity was given to participants to ask questions for clarity, and participants sought permission to voice-record the focus group and photographs of structures built.

4. Findings and Discussion

4.1 Types of Informal Housing

The participants highlighted different types of informal houses they built, often noted as "Shacks", "Wendy houses", "Bungalows", or "Hockey homes" by the builders. "Temporary" or "permanent" are the two main types of informal housing, according to the informal builders. Exists depending on clients' requirements and resources. While the temporary structures are prefabricated and movable, often used in backyards or informal settlements, and are without permanent foundations, the permanent structure is built on site with a foundation. The photographs taken at the Kyelitsha and Ocean View informal communities are shown in Fig.2 and 3 below.

Fig. 2 Temporary Shack structure

Fig. 3 Permanent Shack structure

Table 1 below presents the different sizes and associated costs of the shacks erected in Khayelitsha, irrespective of whether they were permanent or temporary. The interview did not provide information about the cost of the 10m shacks. According to the conversations with the participants, the cost of the shacks is not significantly affected by the profile of the sheets but rather by the thickness. Nevertheless, the price of the shacks may fluctuate based on the thickness and configuration of the metal sheets used for both the walls and roofs.

Table 1: Type and costs of shacks

SIZE	COST	NOTES
3 x 3m	R 4500	The cost of the shacks depends on the thickness and profile of the metal sheets used. Thickness of the sheets start from 0.3mm thick
4 x 4m	R 5000 – R 5500	
10m	R 10000	
TOOLS		
Saw	Hammers	Scissors

4.2 The Construction Process

Participants explained that the construction process is simple and involves laying a foundation, assembling a wooden or metal frame, and installing the walls and roof. This was also observed during the case study visit to construct a shack at Khayelitsha. The construction of a 3mx3m shack was completed from scratch in less than 3 hours. The process commences by evaluating the client's requirements and the site's prevailing conditions. The materials utilized consist of timber and metallic sheets. Structures can be prefabricated and assembled on-site or built entirely on-site. The duration of construction can vary between one and three days, contingent upon the dimensions and intricacy of the structure. For example, constructing a standard dwelling for a household of five can be accomplished in three days, irrespective of the material being wood or metal. The team typically comprises four individuals, with the chief builder being one of them.

The assembly process is expeditious, typically taking only one day on-site, depending upon the dimensions and materials employed. According to the builders, the shacks are seldom built on site but are instead installed at the site. The 10m shacks are not prevalent in Khayelitsha, and the local builders said they must familiarize themselves with constructing such structures. The Key informants at Ocean View settlement revealed that their construction was self-built, on an incremental basis, i.e. depending on the availability of materials, which they often must source for in their environment. They explained that the residence was originally a one-bedroom hock, and they have successfully expanded their home by adding two additional extensions to the property, as shown in Fig.3 below. Figure 3 illustrates the progression of upgrades to the living space, starting from one-bedroom hocks on the far left, then adding second hocks in the middle, and finally extending the two hocks with concrete blocks and a rubble room on the far right.

Fig. 3 Hocks extension showing incremental progression

4.3 Common challenges and limitations of informal settlement builders.

The informal settlement builders in this study shared several limitations with the researchers who consent to the extant literature. Some of these challenges were also witnessed during the site visit. These challenges are itemized below:

4.3.1 Access to construction site

Challenges arise when transporting materials to the site, especially in crowded settlements. Conveying materials, particularly in densely populated areas with restricted access, frequently obstructs movement, and there is a need to transport materials across adjacent houses. Disputes often arise with neighbours regarding access, which affects completing the work on time. Mathiba (2019) and Ehebrecht (2015) advocated for Government services in informal settlements, concluding that such provision is necessary to fast-track development.

4.3.2 Access to construction materials

This study found that local builders use what is readily available, affordable, and within their reach. This agrees with the literature (Ndlangamandla & Combrinck, 2020; Moreno et al.,2019; Dakhli & Lafhaj, 2018). However, when probed about alternative building technologies for upgraded housing options, such as Sandbags and MIBT, they need to be more knowledgeable about where they can be obtained.

4.3.3 Labour Coordination and Training

As already noted by Mathiba (2019) and Ehebrecht (2014), the participants in this study cared less about safety practices. However, in contrast to the literature, their limited formal training and technical expertise in construction techniques and building codes did not affect their precision. The local informal builders also noted that they only managed to get by in profit-making, suggesting their lack of business skills.

5. Conclusion and Recommendations

This study has shown the different approaches to informal settlement housing from a qualitative viewpoint. The approach to the study was engaging and enriching, helping the researchers experience the construction methods and challenges of the local builders firsthand. Based on the findings of this study, the following recommendations are made to address the challenges and limitations of informal settlement builders:

i. Prioritize providing essential services such as good road networks for easy access to the informal settlement communities, local suppliers and builders.
ii. Expand the Alternative Building Technologies (ABTs) market around informal settlements. There appears to be little or no information available to the local builders on where to get what on ABTs
iii. Comprehensive and integrated training programs that address a range of skills and knowledge areas, especially in safety practices, business management, and entrepreneurship, are needed.
iv. Avail informal settlement builders with information and opportunities to refine their skills for more structurally durable and aesthetically pleasing structures.

6. Research limitations and future directions:

This study, like any other, has limitations. The few samples of the study limit the findings of this study. As such, a wider population is needed for the study. Future studies should use survey methods to cover more samples. For instance, ranking the challenges of the informal settlement builders can be conducted to prioritize the solutions provided. In addition, this study is limited to only two cases: Ocean View and Khayelitsha informal settlements; analyzing more case studies and best practices from different contexts would provide practical insights into successful housing construction initiatives in informal settlements. This would help to identify further lessons learned and transferable strategies for addressing housing challenges.

7. References

Azhar, A., Buttrey, H., & Ward, P. M. (2021). "Slumification" of Consolidated Informal Settlements: A Largely Unseen Challenge.

Beardsley, J., & Werthmann, C. (2008). Improving informal settlements. *Harvard Design Magazine Spring*, pp. 31–34.

Caballero Moreno, W. G., Alegre, I., Armengou-Orús, J., & Aguado, A. (2019). Self construction in informal settlements: a multiple-criteria decision-making method for assessing the sustainability of floor slabs in Bucaramanga, Colombia. *Journal of Housing and the Built Environment*, *34*, 195-217.

Dakhli, Z., & Lafhaj, Z. (2018). Considering materials management in construction: An exploratory study. *Logistics*, *2*(1), 7.

DFID (2017), Sustainable Live hoods, Department for International Development, IDS, Institute of Development Studies.

DHS (2016). A Baseline assessment for future impact evaluation of informal settlements targeted for upgrading.

Dovey, K., & King, R. (2011). Forms of informality: Morphology and visibility of informal settlements. *Built environment*, *37*(1), 11–29.

Dovey, K., Van Oostrum, M., Chatterjee, I., & Shafique, T. (2020). Towards a morphogenesis of informal settlements. *Habitat International*, *104*, 102240.

Ehebrecht, D. (2015). *The challenge of informal settlement upgrading: Breaking new ground in Hangberg, Cape Town?* (Vol. 7). Universitätsverlag Potsdam.

El Menshawy, A., & Shafik, S. (2016). Affordable housing as a method for informal settlements sustainable upgrading. *Procedia-Social and Behavioral Sciences*, *223*, 126-133.

Ferlito, T. L., Musonda, I., Tjebane, M. M., & Onososen, A. (2022, May). Systematic literature review on sustainable construction strategies for the development of affordable housing. In *Proceedings of the Twelfth International Conference on Construction in the 21st Century (CITC-12 Amman, Jordan)* (pp. 195-203).

Huchzermeyer, M., & Karam, A. (Eds.). (2006). *Informal settlements: A perpetual challenge?* Juta and Company Ltd.

Lizarralde, G., & Root, D. (2008). The informal construction sector and the inefficiency of low-cost housing markets. *Construction Management and Economics*, *26*(2), 103-113.

Lombard, M. (2014). Constructing ordinary places: Place-making in urban informal settlements in Mexico. *Progress in Planning*, *pp. 94*, 1–53.

Mathiba, L. (2019). *The challenges of upgrading informal settlements: a case study of*

Denver informal settlement, Johannesburg. University of Johannesburg (South Africa).
Merrill, S., Markel, E., Scarampi, A., Bolden, M., & Yoder, S. (2021). Beyond building: how social norms and networks shape mason construction practices in incremental homebuilding. *Enterprise Development & Microfinance*, (3), pp. 161–178.
Nassar, D. M., & Elsayed, H. G. (2018). From informal settlements to sustainable communities. *Alexandria Engineering Journal*, *57*(4), 2367–2376.
Ndlangamandla, M. G., & Combrinck, C. (2020). Environmental sustainability of construction practices in informal settlements. *Smart and Sustainable Built Environment*, *9*(4), 523-538.
Shortt, Niamh K., and Daniel Hammett. "Housing and health in an informal settlement upgrade in Cape Town, South Africa." *Journal of housing and the built environment* 28 (2013): 615-627.
UN System (2023). Facts and Figures, High level political forum. *SDG Implementation Database.*
Venter, A., Marais, L., & Morgan, H. (2019). Informal settlement upgrading in South Africa: A preliminary regenerative perspective. *Sustainability*, *11*(9), 2685.

Sustainable Building Development in Nigeria: A Climate Change Response Review

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Abstract:
Building development is a significant source of problems posed by climate change, and buildings are vulnerable to climate change. Hence, climate change and buildings are mutually influenced by each other. The paper examines the changing landscape of sustainable building development in Nigeria as a strategic response to the problems of climate change. The study investigates the various perspectives of building experts regarding sustainable building development in Nigeria. To do so, the researchers distributed 265 questionnaires to professionals from various fields, such as architects, engineers, surveyors, contractors, developers, facilities managers, estate surveyors and valuers, and sustainability consultants. The researchers received 250 completed questionnaires, which were used for the study. The researchers used inferential statistics of t-test statistics to evaluate the effectiveness of current policies and frameworks promoting sustainable building practices in Nigeria. The p-value obtained (0.0000) was lower than the critical value (5%) for most factors. However, the barriers negatively affect sustainability, with a 1% increase in obstacles resulting in a 0.93% decline in sustainable building development. Also, the PPASB's p-value of 0.3560 was insignificant, indicating a need for a deeper understanding of sustainable construction development. The effectiveness of sustainable building policies and technologies has enhanced development in Nigeria despite climate change challenges. Public perception of sustainable buildings has not significantly affected development. Nigeria can become a leader in sustainable construction by leveraging traditional knowledge systems and new technologies. Adherence to professional standards, proper implementation of building policies, and solid regulations can lead to sustainable building development in Nigeria.

Keywords: Built environment, Climate Change, Nigeria, Policy impact, Professionals, Sustainable Building Development,

1 Introduction

Climate change refers to long-term shifts in weather patterns resulting from natural or human causes. Climate change has emerged as a worldwide issue, with its consequences persistently jeopardising human existence and significantly impacting people's livelihoods worldwide. Nigeria and numerous other countries confront the formidable obstacles presented by climate change (Odjubo, 2010). The housing sector is crucial in climate change research due to buildings' significant impact on the activities that contribute to climate change. Moreover, it is worth mentioning that buildings are recognised as the primary sources of greenhouse gas (GHG) carbon emissions because of their significant energy usage. Specifically, residential structures contribute the most to the overall energy consumption (Jens Laustsen et al., 2011). Therefore, building development is a significant source of problems posed by climate change. Buildings are crucial for the progress of every nation and are integral to human daily life (Cam, 2012). However, they result from human construction efforts utilising natural resources (Surenran & Sekar, 2010). Surenran and Sekar (2010) note that these natural resources are decreasing. Therefore, it is imperative for experts in the built environment to actively participate in alternative processes and utilise renewable natural resources in order to reduce the effect of climate change on the environment.

Buildings make a substantial contribution to the emission of greenhouse gases and the depletion of resources. Hence, Sustainable building development is becoming increasingly important to reduce these adverse effects while promoting resilience and adaptation. Sustainable buildings, as described by researchers and academics, are green buildings that surpass conventional ones in their potential to decrease GHG emissions and meet the Net-Zero Carbon Buildings Commitment (Wang et al., 2016). Sustainable buildings require efficient adaptation to climate changes and committed parties to maintain long-term viability. Effective design should consider current climatic indices to successfully mitigate and adapt to changes (Guan, 2009; Radhi, 2009; Bond, 2011). Dedicated individuals or groups involved in this process are critical to making a significant impact.

Denton et al. (2002) report that the West African region is very susceptible to the impacts of climate change due to its high likelihood of experiencing drought and desertification, heavy reliance on subsistence agriculture, and susceptibility to inadequate rainfall. Nigeria is a prominent African country and the most populous nation on the continent. According to the National Population Commission (2012) and World Gazetteer (2014), it is also the 7th most populated country globally.

According to Odjubo (2010), there is evidence of the effects of climate change in Nigeria. Nigeria is also facing a housing deficit, which adds to the existing climate change problems. The housing gap in Nigeria is estimated to be around 16-17 million Mbazor (2018). This indicates the possibility of significant future emissions if sustainable initiatives are disregarded. Hence, achieving success in Nigeria will undeniably have a good impact on the entire continent.

Despite growing interest and efforts, more research is needed to understand the socio-cultural dimensions of sustainability initiatives in Nigeria to address these problems. This research, therefore, evaluates the effectiveness of current policies and frameworks promoting sustainable building practices in Nigeria. It involves multiple stakeholders, as sustainable building development in Nigeria requires collaboration. The study offers insights into the socio-cultural, economic, and governance aspects of sustainable building development. The findings enable the development of relevant strategies to tackle climate change in the built environment.

2. Literature Review

2.1 Climate change and sustainable development

Climate change and sustainable development are two distinct ways to address global environmental change. Climate change is a significant manifestation of unsustainability. The public's awareness of Climate Change and Global Warming has significantly increased, as these phenomena offer insights into the current state of the climate. Although the two phrases have similar meanings, they are used in slightly distinct semantic situations, as Lineman et al. (2015) observed. Global warming is recognised as a significant issue. It is currently considered the most crucial challenge that humanity will face in several years. (Buttel et al., 1990).

Research has demonstrated that underdeveloped countries would experience the most severe consequences of climate change, as their populations are highly susceptible and have limited capacity to adapt. The fluctuations in temperature, availability, and purity of water will significantly affect agricultural output, human habitation and well-being, biodiversity, and the migration patterns of animals (IPCC, 2001a,b). According to Dorling (2021), the world's population will increase from 7.7 billion to 9.7 billion by 2050 and is expected to exceed 10.9 billion by the end of the century. This will increase demand for water, energy, and natural resources, putting pressure on biological systems and degrading the environment. It will also significantly impact the built environment. Butt et al. (2010) suggest that the built environment sector should incorporate sustainability into its activities. Akadiri et al. (2012) believe that the sector can collaborate and lead in the global sustainable agenda, which requires all developmental activities to include sustainability. Nevertheless, the sustainable development research community has typically overlooked the potential consequences of climate change on the progress towards creating more sustainable societies (Sev, 2009; UN-Habitat, 2009; Janda, 2011).

The topic of sustainable buildings has become a significant concern for numerous developing and developed nations in the twenty-first century. The building sector is one of the most energy-intensive sectors. It contributes to around 33% of the overall greenhouse gas (GHG) emissions, making it a crucial contributor to global warming and climate change. This activity also produces waste and potentially hazardous atmospheric emissions (Shad et al., 2017; Wang et al., 2016; Danish et al., 2019). Buildings are not only responsible for contributing to climate change but are also vulnerable to the impacts of climate change. Lam et al. (2005) claimed that buildings and climate are intricately interconnected since they mutually influence each other, directly impacting the environment and leading to changes in architectural methodologies and design decisions worldwide. UN-Habitat (2009) report revealed that buildings are highly susceptible to climate change, including floods, hurricanes, bushfires, and other unfavourable conditions that can significantly affect their proper functioning. The significance of this relationship is that buildings serve as a connection point between the external environment, which is affected by climate change, and the internal environment, as well as the occupants' comfort needs (Zubairu, 2012).

The impact of construction on climate change can be noticed at every level of the building development process, starting from the design phase, continuing through the construction phase, and extending to the management stage. Jagger et al. (2013) argue that the construction industry, specifically the building sector, is crucial in reducing carbon emissions by implementing sustainable practices in all aspects of building production, including material selection and usage, site management, and maintenance.

3. Methodology

The research used a survey design to gather data by distributing 265 questionnaires to randomly selected participants. Out of the 265 questionnaires provided, only 250 were returned and used for the study. The data collected from the respondents was analysed using descriptive statistics such as simple percentages, mean, and standard deviations. Additionally, inferential statistics, specifically t-test statistics, were used to assess the effectiveness of policies and frameworks promoting sustainable building practices in Nigeria. The t-test statistics were employed because of the sufficiently large sample size. More so, it was the t-critical ratio that was used, not just the ordinary t-test, that only considered the sample size of less than 30. This approach was chosen to determine the significance of each test item. It was assumed that the population mean for each test item was normal or zero.

4. Findings and Discussion

4.1 Respondents Demographic Characteristics

The respondents' demographic characteristics are presented below:

Table 1: Frequency Distribution of Respondents Demographic Characteristics

Demographic Variable	Frequency	% Percentage
Discipline		
Architecture	44	17.60
Estate management	60	24.00
Contractors/developers	100	40.00
Engineers	30	12.00
Others	20	8.00
Gender		
Male	190	76.00
Female	60	24.00
Ethnicity		
Yoruba	120	48.00
Igbo	80	32.00
Hausa	50	20.00
Level of Education Qualification		
No formal education	8	3.20
Primary Education	10	4.00
Secondary education	20	8.00
Tertiary Education	212	84.80

Source: Researchers' Field work, 2024

Table 1 displays the frequency distribution of the demographic parameters of the respondents. The table shows that the frequency distribution of respondents by discipline indicated that 17.60% were architects. By comparison, the survey revealed that 24% of the participants were estate managers, 40% were contractors/developers, 12% were engineers, and 8% fell into the "others" category, which included government servants, homeowners, and line managers involved in building projects. This suggests that a significant proportion of the participants worked as contractors or developers. Therefore, any viewpoint from this group of participants could improve the research results.

The data shows that 76% of the respondents were male, while 24% were female. This indicates a satisfactory proportion of male participants. Additionally, the analysis of respondents' ethnicity found that 48% identified as Yoruba, 32% as Igbo, and 20% as Hausa. This suggests that a sufficient proportion of the participants were from the Yoruba ethnic group. These variables could potentially enhance the accessibility of insights for the researcher's discoveries.

It was found that 3.20% of the respondents had no formal education, while 4% had completed primary education. Moreover, 8% and 84.80% of the participants had secondary and tertiary educational qualifications, respectively. This suggests that a significant number of the participants had higher education credentials. Including this specific group of participants could significantly contribute to the study's outcomes.

4.2 Perception of Respondents on Sustainable Building Development in Nigeria: A Climate Change Consideration

Nigeria needs to adopt sustainable building development to address the challenges arising from climate change. Sustainable buildings can withstand the test of time and respond positively to climate change. Table 2 shows the frequency distribution of respondents on sustainable building development and climate change.

Table 2 Mean and Standard Deviation computed for the variable of sustainable Building Development

S/N	Variables	N	Mean	STD	Rank	Remark
1	**Effectiveness of current sustainable Building Policies (ECSBP)**	250	4.06	0.99	7th	Fairly Adopted
2	**Awareness and Adoption of sustainable Building Practices (AASBP)**	250	4.19	0.76	5th	Adopted
3	**Integration of Climate Change Considerations in Building Design and Construction (ICCBDC)**	250	3.73	1.04	8.5th	Fairly Adopted
4	**Perceived impact of sustainable Buildings on Climate Resilience (PISBCR)**	250	4.10	0.89	6th	Fairly adopted
5	**Barriers to Sustainable Building Development (BSBD)**	250	3.73	1.04	8.5th	Fairly adopted
6	**Perceived Effectiveness of Sustainable Building Technologies (PESBT)**	250	4.46	0.65	1st	Seriously Adopted
7	**Capacity Building Needs for Sustainable Building Professionals**	250	4.43	0.66	2.5th	Seriously Adopted
8	**Public Perception and Acceptance of Sustainable Buildings**	250	4.29	0.74	4th	Seriously Adopted
9	**Long-Term Viability and Performance of Sustainable Building**	250	4.43	0.66	2.5th	Seriously Adopted

Source: Author's Fieldwork, 2024

** Acceptable mean =3.00 on a 5-point Likert scale.

A test item was fairly adopted, adopted and seriously adopted if the mean was calculated greater than or equal to 3.00 or otherwise **STD= Standard Deviation ** Ranked was done on the basis of STD.

Table 2 shows that most participants perceive the current sustainable building policies as effective. The average value of 4.06 is significantly higher than the acceptable average of 3.00, indicating that the policies have successfully met building requirements. Respondents also believe that awareness and adoption of sustainable building practices have been enhanced through public relations and information dissemination—the results in Table 2 show that climate change is integrated into building design and construction. The perceived impact of climate change on sustainable buildings has been effectively addressed, and barriers to sustainable building development have been incorporated into different components of building sustainability strategies. These assertions were based on the fact that the average value for test items was higher than 3.00, with minor deviations from the average indicated by standard deviations.

Moreover, the results in Table 2 inspire optimism. They show that sustainable building technologies are effective, that capacity-building is needed for sustainable building professionals, and that there is a positive public perception and acceptance of sustainable buildings. This indicates that buildings can be sustainable and viable in the long term with sustainable building policies that encourage modern technologies.

Table 3 T-test Calculated for the variable of Sustainable Building Development

Variable	Coefficient	Standard Error	T-calculated	P-value	Remark
Effectiveness of current sustainable Building Policies (ECSBP)	0.45	0.11	4.09	0.0000	Significant
Awareness and Adoption of sustainable Building Practices (AASBP)	0.26	0.032	8.13	0.0000	Significant
Integration of Climate Change Considerations in Building Design and Construction (ICCBDC)	0.016	0.0021	7.62	0.0000	Significant
Perceived impact of sustainable Buildings on Climate Resilience (PISBCR)	0.087	0.0034	25.59	0.0000	Significant
Barriers to Sustainable Building Development (BSBD)	-0.93	0.063	-14.76	0.0000	Significant
Perceived Effectiveness of Sustainable Building Technologies (PESBT)	0.65	0.21	3.10	0.0007	Significant
Capacity Building Needs for Sustainable Building Professionals	1.05	0.11	9.55	0.0000	Significant
Public Perception and Acceptance of Sustainable Buildings	0.38	0.26	1.46	0.3560	Significant
Long-Term Viability and Performance of Sustainable Building	0.054	0.013	9.55	0.0000	Significant

Source: Researcher's Computation (E-view 12) ** The Test was carried out at a 5% critical level of significance.

Table 3 shows the t-test results on sustainable building development policies in Nigeria. The findings indicate that the policies are effective in addressing climate change goals. The p-value of the t-statistics was 0.0000, lower than the critical value of 5%, indicating the variable's significance, and the regression coefficient was positive at 0.45. Having solid policies is crucial for building sustainability in Nigeria. Awareness and adaptation of sustainable building practices are significant for sustainable building development. The test item was statistically significant with a t-statistic value of 8.13 and p-value of 0.0000, and it positively contributes to sustainable building development. The regression coefficient of 0.26 indicates that higher awareness and adaptation of sustainable building practices lead to better compliance with standards, procedures, and practices for achieving better sustainability in building projects.

Considering climate change in building design and construction is crucial for sustainable development. The test item significantly impacted sustainable building development, with a p-value below 5% and a t-statistics value of 7.62. Even a slight increase of 1% in ICCBDC can lead to a 0.016% improvement in building sustainability. To achieve building sustainability, professionals must anticipate potential climate effects and take corrective measures during development. Table 3 further shows that sustainable buildings significantly impact climate change resilience in building development. The obtained t-statistics p-value of 0.0000 is lower than the critical value of 5%. A 1% increase in PISBCR results will account for a 0.087% increase in sustainable building development. Considering this impact from the beginning of any building project is essential.

Table 3 further shows that significant barriers in Nigeria hinder sustainable building practices and development. The test item was statistically significant with a t-statistic value of -14.76 and a p-value of 0.0000, indicating that it negatively contributes to sustainable building development. Primary obstacles included unskilled workers, dishonest developers, inadequate funding, high poverty rates, lack of cooperation from building owners, and government failure to penalise fraudulent builders. These obstacles make it challenging to design and construct buildings that can withstand the effects of climate change.

The result further shows that sustainable building technology is significant in building development. A 1% increase in PESBT could lead to a 0.65% increase in building development sustainability in Nigeria. Latest technologies can enhance building sustainability, which is why collaboration among stakeholders is necessary to deploy proper building technology. Furthermore, Sustainable building professionals in Nigeria require capacity building. The t-value of the computed t-statistics for the test variable was 0.0000, smaller than the critical value of 5%, while the t-statistics value of 9.55 was statistically significant. Adequate training for developers, contractors, estate surveyors, valuers, and other stakeholders is crucial for achieving sustainable building development, and modern trends should be exposed.

Public perception and acceptance did not significantly affect building sustainability in Nigeria, with a p-value of 0.3560 and a t-statistics value of 1.46. Due to low perception and acceptance in Nigeria, increasing awareness and education on sustainable construction development is important. The test variable positively impacted sustainable building development but was not statistically significant, with a regression coefficient of 0.38.

Finally, the variable of the long-term viability and performance of sustainable buildings was found to be significant in building development in Nigeria. A t-statistics value of 9.55 was considered significant, indicating that the p-value of the test item was below 5%.

Therefore, building professionals must ensure sustainable buildings meet current climate change standards and specifications.

5. Conclusions and Recommendations

5.1 Conclusions

Sustainable building development in Nigeria is possible by adhering to professional standards and regulations. The effectiveness of current sustainable building policies, awareness and adaptation of sustainable buildings, integration of climate change consideration, and perceived impact of sustainable buildings on climate resilience enhanced sustainable building development in Nigeria in the face of unpredictable climate change. Furthermore, the perceived effectiveness of sustainable building technologies, capacity building needs for sustainable building development, long-term viability, and performance of sustainable buildings have contributed positively to sustainable building development in Nigeria despite the worsening climate change situation.

However, public perception and acceptance of sustainable buildings did not significantly affect building development in Nigeria. Additionally, barriers to sustainable building development negatively affected it.

5.2 Recommendations

Recommendations to improve sustainable building practices in Nigeria:

1. Ensure all stakeholders' adherence to sustainable building standards.
2. Sanction erring developers to reduce quackery's effect on building development.
3. Emphasise capacity building for building professionals to keep them updated with the latest trends in sustainable building.

6. References

Akadiri, P. O., Chinyio, E. A., & Olomolaiye, P. O. (2012). Design of a sustainable building: A conceptual framework for implementing sustainability in the building sector. *Buildings, 2*(2), 126-152.

Bond, S. (2011). Barriers and Drivers to Green Buildings in Australia and New Zealand. *Journal of Property Investment and Finance,* 29 (4/5), 494 – 509.

Butt, T. E., Umeadi, B. B. N. and Jones, K. G. (2010) Sustainable development and climate change induced obsolescence in the built environment. ww.kadinst.hku.hk/sdconf10/Papers/p160.pdf (Accessed 11/10/2023)

Buttel, F. H., Hawkins, A. P., & Power, A. G. (1990). From limits to growth to global change: constraints and contradictions in the evolution of environmental science and ideology. *Global Environmental Change*, 1(1), 57–66.

Cam, W. C. (2012). Technologies for Climate Change Mitigation (Building Sector) http://www.uneprisoe.org/ (Accessed 20/11/2023)

Danish, M. S. S., Senjyu, T., Ibrahimi, A. M., Ahmadi, M., & Howlader, A. M. (2019). A managed framework for energy-efficient building. *Journal of Building Engineering*, *21*, 120-128.

Denton, F., Sokona, Y., Thomas, J.P., 2002. Climate change and sustainable development strategies in the making: What should West African countries expect? OECD, Environnement et Développement du Tiers Monde (ENDA-TM), Dakar, Sénégal. http://www.oecd.org/env/cc.

Dorling, D. (2021). World population prospects at the UN: Our numbers are not our problem? In *The Struggle for Social Sustainability* (pp. 129–154). Policy Press.
Guan, L. (2009). Sensitivity of Building Zones to Potential Global Warming, *Architectural Science Review*, 52(4), 279–294.
IPCC, (2001a). Climate Change 2001: Impacts, adaptation, and vulnerability. In: McCarthy, J.J., Canziani, O.F., Leary, N.A., Dokken, D.J., White K.S. (Eds.), A Report of the Working Group II of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge.
IPCC, (2001b). IPCC Third Assessment Report, Synthesis Report. Cambridge University Press, Cambridge.
Jagger N, Foxon, T & Gouldson, A. (2013). Skills Constraints and the Low Carbon Transition, *Climate Policy*, 13(1), 43–57.
Janda, K. B. (2011). Buildings Don't Use Energy: People Do. *Architectural Science Review*, 54(1), 15–22.
Jens Laustsen, J., Ruyssevelt, P., Staniaszek, D., & Strong, D. (2011). Europe’s buildings under the microscope: a country-by-country review of the energy performance of buildings.
Lam, J. C., Tsang, C. L., Yang, L., & Li, D. H. (2005). Weather data analysis and design implications for different climatic zones in China. *Building and Environment*, *40*(2), 277-296.
Lineman, M., Do, Y., Kim, J. Y., & Joo, G. J. (2015). Talking about climate change and global warming. *PloS one*, *10*(9), e0138996.
Mbazor, D. N. (2018). Assessment of housing quality and environmental conditions in selected areas of Akure, *Nigeria. International Journal of Development and Sustainability*, 7(3), 1049-1061.
National Population Commission (2012). Nigeria’s over 167 million Populations: Implications and Challenges. www.population.gov.ng. (Accessed 10/12/2023)
Odjugo, P. A. O. (2010). Regional Evidence of Climate Change in Nigeria. *Journal of Geography and Regional Planning*, 3(6), 142-150.
Radhi, H. (2009). Evaluating the Potential Impact of Global Warming on the Use Residential Buildings - A Contribution to Reduce the Co2 Emissions. *Building and Environment*, 44(12), 2451–2462.
Sev, A. (2009). How can the construction industry contribute to sustainable development? A conceptual framework. *Sustainable Development*, *17*(3), 161–173.
Shad, R., Khorrami, M., & Ghaemi, M. (2017). Developing an Iranian green building assessment tool using decision making methods and geographical information system: Case study in Mashhad city. *Renewable and Sustainable Energy Reviews*, *67*, 324-340.
Surendan, A. and Sekar, C. (2010). An Economic Analysis of Willingness to Pay (WTP) for Conserving the Biodiversity. *International Journal of Social Economics*, 37(8), 637-648.
UN-Habitat (2009) Sustainable urbanisation: Revisiting the role of urban planning, Global report on human settlements, Nairobi: UN-Habitat.
Wang, Q., Zhao, D., & He, L. (2016). Contracting emission reduction for supply chains considering market low-carbon preference. *Journal of Cleaner Production*, *120*, 72–84.
World Gazetteer (2014). The World Population http://www.geoba.se/population.php?pc=world&type=28(Accessed 22/12/2023)

Zubairu, S. (2012). The importance of evaluation and sustainability in the built environment. In *Proceedings: 4th West Africa Built Environment Research (WABER) Conference* (pp. 9–13).

Sustainability Challenges of Providing Essential Services to Informal Settlements in South Africa

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Abstract:
Informal settlements are prevalent globally, regardless of socio-economic and political contexts. The study investigates the sustainability of local governments providing water and sanitation services to informal settlements in South Africa, motivated by Maslow's Hierarchy of Needs Theory. The South African Constitution mandates all government bodies to provide proper housing and essential services, including potable water and adequate sanitation, to all citizens, irrespective of their living conditions. This study examines the sustainability of local authorities providing water and sanitation services to informal settlements as a temporary solution until the settlement is formalised. The research hypothesised that such provisions are sustainable with specific central government interventions. The study used a quantitative methodology to collect data through a structured questionnaire administered to municipal employees. Limitations included the small sample size, potential restrictions under the Promotion of Access to Information Act, and the focus on a single municipality. Findings indicate that while municipalities recognise their legal obligations and integrate these services into their strategic planning, significant challenges such as budget constraints, inadequate human resources, and rapid urbanisation persist and necessitate more significant support from provincial and central government. The study recommends a broader investigation involving a larger sample across multiple municipalities nationwide and suggests national government intervention to amend information access laws for more effective research.

Keywords:
Informal Settlements, Municipal Challenges, Service Delivery, South Africa, Sustainability Challenges

1 Introduction

Informal settlements are a global phenomenon characterised by unplanned housing with minimal infrastructure and poor service delivery systems. In South Africa, these settlements are particularly prevalent due to historical and socio-economic factors. The apartheid-era policies of racial segregation and job reservation laid the groundwork for their establishment (UN-Habitat, 2015). Even after apartheid ended in 1994, factors such as poverty, high housing costs, and inadequate education and training have perpetuated their existence (Turok, 2012; Govender, Barnes, & Pieper, 2011). Rapid urbanisation and migration, driven by economic growth and regional conflicts, have further exacerbated the issue (Turok, 2013).

Utility services like water and sanitation meet basic human needs. Maslow's 1943 theory of human needs recognises them as physiological needs. Food, shelter, and water are human needs. As shown in (Figure 1.), specific lower-level needs must be met before higher needs. The basic needs are air, water, food, shelter, sleep, clothing, and reproduction. Next comes basic safety and security. Following that are the psychological needs of love/belonging and esteem, which seek prestige and accomplishment.

The final stage is self-actualisation, which involves reaching one's full potential and being creative.

Figure 1.1: Maslow's Hierarchy of Needs (Maslow, 1943)

The South African Constitution mandates the provision of adequate housing and essential services, including potable water and sanitation, to all citizens if it is done financially and environmentally sustainable (Republic of South Africa, 1996). Despite this, local authorities responsible for service delivery face significant challenges such as budget constraints, technical limitations, and corruption (Govender, Barnes, & Pieper, 2011; Turok, 2012). These challenges raise concerns about the sustainability of providing essential services to informal settlements.

This study investigates the long-term sustainability of local authorities providing potable water and adequate sanitation to informal settlements. The research hypothesises that these services are sustainable with special provisions from the central government (UN-Habitat, 2015; Turok, 2012). This investigation addresses a critical knowledge gap in the feasibility of service delivery to informal settlements and aims to inform policy and planning strategies (Govender et al., 2011).

The primary aim of the research was to determine whether local authorities can sustainably provide potable water and sanitation to informal settlements in the long term. Specific objectives included assessing the present-day mandate and capacity of local government for service provision (Republic of South Africa, 1996), evaluating the sustainability of current service delivery efforts (Turok, 2012), analysing the strategic planning and policies guiding local government (Turok, 2013), and identifying the financial and labour resources available for these services (Govender et al., 2011).

The research employed a quantitative methodology involving an exploratory survey of municipal employees. Due to accessibility constraints, a non-probability sampling approach was used, recognising that not all members of the research population would be available to provide the requisite data due to work pressures and geographic location (Govender et al., 2011). Data was collected through structured questionnaires and analysed using statistical methods. Limitations include a small sample size and the focus on a single municipality, which may affect the generalizability of the findings (Turok, 2012).

The study revealed significant insights into the sustainability challenges of service delivery in informal settlements. Preliminary findings suggest that informal settlements will persist, and upgrading them comprehensively is a long-term goal (Turok, 2013). These settlements often occupy unsuitable land for housing and infrastructure, complicating service delivery (UN-Habitat, 2015). The findings highlighted the constraints faced by local authorities and the necessity for central government support (Govender et al., 2011). This study contributes to a broader understanding of the dynamics of service delivery and hopes to inform future policy and strategic planning.

2 Literature Review

This influx of people into the cities and towns, which is internationally referred to as urbanisation, resulted in the segregated residential areas set aside for non-whites becoming overcrowded and the limited service infrastructure becoming wholly inadequate. Reed (2013) found that Black South Africans migrated more before the repeal of The Pass Laws Act of 1952 and the end of apartheid. The socio-economic and socio-political environment of informal settlements includes intricate social and survival systems and the practical and communal challenges of housing and infrastructure development (Companie, 2020).
Understanding 'spatial injustice''s origins and development is crucial. This construct shows its political and practical effects on South African society, contextualised against the many challenges facing all levels of government (Turok, 2012; Windapo & Goulding, 2013). According to Soja (2009), space justice is fair land distribution and free association. Spatial justice is measured by the distribution of land, wealth, opportunities, and social privileges (Turok, 2012).

Spatial injustice became a significant issue in South African society after the Native Land Act, No. 27 of 1913, took effect on June 19. This legislation, later renamed The Bantu Land Act of 1913 and The Black Land Act, regulated land ownership. The unintended consequence was lawful racial segregation and discrimination in South Africa, limiting Black land ownership to 7% of the total surface area (Cameron & Spies, 1986; Turok, 2012). In informal settlements on the periphery of towns, non-whites like Black, Coloured, and Indian people lived in temporary housing with limited infrastructure and services like potable water and waterborne sanitation.

Bantu homelands, or Bantustans, were created under the 1959 Bantu Self-Government Act to promote separate development. To displace Black South Africans from urban to rural dumping grounds, this act caused overcrowding and poverty in the homelands (Khunou, 2009; Evans, 2017; Sithole & Mathonsi, 2015). Economic assets, natural resources, and infrastructure needed to be improved in these homelands (Phuhlisani NPC, 2017).

Many Black South Africans lived in poorly serviced townships or informal settlements like Soweto, Tembisa, and Soshanguve due to spatial injustice. These cities' outskirts had terrible living conditions (Cameron & Spies, 1986; Turok, 2012). In the 1960s and 1970s, people moved to cities for better jobs, worsening this situation (Cameron & Spies, 1986; Turok, 2012). Reed (2013) notes that Black internal migration in South Africa was suppressed and censored. South Africa's economy has long relied on cheap labour from neighbouring countries, according to the Economic and Political Weekly (2003).

The African National Congress replaced the four-province structure with a nine-province structure after the first democratic elections in 1994 to better serve an inclusive society (The Constitution of South Africa, 1996). This restructuring made balancing socio-economic rights, interest group aspirations, and societal development complex (Arndt et al., 2019). The Department of Human Settlements (2009) notes that developing countries with rapid urbanisation and inadequate infrastructure have informal settlements. According to the National Sanitation Policy, one to two million South African households live in informal settlements (Department of Water and Sanitation, 2016). Shacks house 10% of South African households, according to the Housing Development Agency (2014). The Socio-Economic Rights Institute of South Africa (2018) and the Prevention of Illegal Eviction and Unlawful Occupation of Land Act, No. 19 of 1998, emphasise the government's duty to help displaced South Africans find housing. The Housing Act specifies national, provincial, and local government housing development and service provision for people experiencing poverty (Republic of South Africa, 1997). 'Breaking New Ground,' the Comprehensive Plan for Sustainable Human Settlements, and the 1994 White Paper on the New Housing Policy and Strategy for South Africa aim to integrate communities and upgrade informal settlements (Department of Human Settlements, 2010). Misunderstandings about informal settlements and local government. Water and sanitation are essential, but residents rarely mention formal housing (Community Organisation Resource Centre, 2016). According to the South African Human Rights Commission (2014), improvements to informal settlements and basic services should be integrated.

2.1 Mandates for informal settlement water and sanitation

South African law mandates water and sanitation for equality. All communities within the jurisdiction of local government must receive appropriate and sustainable services under Section 152(1)(b) of Chapter 3 of The Constitution of South Africa (Republic of South Africa, 1996). According to the Republic of South Africa, the Local Government Municipal Systems Act, No. 32 of 2000, local communities are prioritised, encouraged to grow, and provided with essential municipal services in a financially and environmentally sustainable manner.

All South Africans, including those in informal settlements, are entitled to essential water and sanitation under the Water Services Act, No. 108 of 1997, with some restrictions. Local governments must also create a Water Services Development Plan to provide water and sanitation to all residential areas through their Integrated Development Plan (Republic of South Africa, 1997).

2.2 Guidelines for informal settlement water and sanitation

According to the Water Services Act, the Minister of Human Settlements, Water, and Sanitation must create and publish water service standards. National Norms and Standards for Domestic Water and Sanitation Services (Department of Water and Sanitation, 2017) address equitable water supply, financial issues, and service backlogs. With provisions for informal settlements, these standards classify water supply as bulk, full, middle, and minimum.

A minimum level of service requires potable water from communal standpipes and adequate sanitation from shared facilities. The Department of Water and Sanitation (2017) states that everyone must have free basic water up to a specific limit before it is tariffed.

2.3 Water and sanitation strategy for informal settlements

Legislation and national and local regulations affect water and sanitation strategy. The Local Government Municipal Systems Act mandates a 5-year Integrated Development Plan for development and governance (Republic of South Africa, 2000). The community helps identify priority needs and adapt to changing circumstances each year.

Spatial Development Framework, Integrated Zoning Scheme, Integrated Human Settlement Plan, and Water Services Development Plan are essential to the Integrated Development Plan. For sustainable service delivery, sector plans guide land use, housing development, and infrastructure planning (Stellenbosch Municipality, 2019).

Informal settlements are included in the Spatial Development Framework's planning to provide services and discourage unsuitable development. Stellenbosch Municipality (2019) states that the Integrated Zoning Scheme regulates land use to meet municipal land development goals. Urban development strategies and the Integrated Human Settlement Plan promote sustainable settlements. Considering population growth and infrastructure needs, the Water Services Development Plan addresses water supply and demand (Department of Water and Sanitation, 2020).

2.4 Water and sanitation resources for informal settlements

Budgeting and funding for water and sanitation services are needed to provide equipment, materials, and people. The South African Constitution and Municipal Finance Management Act require municipal budgets to prioritise community needs and justify funding requests: property rates, service charges, government grants, and other sources fund municipalities. Conditions grants are given for housing, infrastructure, and basic services (Van der Westhuizen et al., 2017). Strategic planning, a budget steering committee, and the Integrated Development Plan are needed for resource management (Stellenbosch Municipality, 2019).

Water services and human settlement plans guide resource allocation and service delivery as part of the municipality's Integrated Development Plan. The plan emphasises community involvement, regular reviews, and adjustments to meet changing needs and ensure sustainable development (Stellenbosch Municipality, 2019).

Informal settlements are prevalent in developing countries like South Africa, experiencing rapid urbanisation. Low infrastructure and poor service delivery characterise these unplanned settlements. The Housing Act and other laws for people experiencing poverty require basic services like water and sanitation. Municipal strategic plans, including Integrated Development Plans, must guide service delivery and resource allocation. Resources, budgeting, and alignment with national standards and community needs are needed to deliver effective services.

3 Research Methodology

This study employed a quantitative research methodology, utilising a structured questionnaire to collect data from officials in a case study municipality. The research design followed a systematic process, including identifying the research topic and problem, conducting an in-depth literature review, and planning a suitable methodology (Terre'Blanche et al., 2006; De Vos et al., 2005). The choice of a quantitative approach was driven by the need to gather numerical data that could be analysed statistically to determine the sustainability of providing water and sanitation services to informal settlements (Creswell, 2014).

The research population comprised officials from the municipality's operational units involved in water and sanitation service delivery. Due to the specific nature of the research problem, a purposive sampling method was initially chosen (Watkins, 2016). However, judgment sampling was ultimately used to include all relevant officials, resulting in a sample size of seventeen, with ten completed responses (Neuman, 2006).

The questionnaire, constructed using Likert's technique, included closed-ended questions to ensure ease of analysis and reliability of responses (Likert, 1967). The data collection process was conducted electronically, ensuring anonymity and ethical considerations. An ethical clearance letter accompanied the questionnaire, assuring participants of confidentiality and voluntary participation (Leedy & Ormrod, 2010). The raw data was then analysed using descriptive and inferential statistical methods, primarily with the Statistical Package for the Social Sciences (SPSS-25), to extract meaningful insights and establish the significance of associations between variables (Neuman, 2006).

This methodology was selected for its robustness in handling quantitative data and suitability for addressing the research problem, providing reliable and valid results supporting the study's objectives (Watkins, 2016; Collis & Hussey, 2009). The research methodology should discuss the approach and the research design, data collection, and data analysis adapted or adapted. One of the most critical issues to be discussed here is the appropriateness of the selected methodology, which is the most appropriate choice compared to other alternatives. This is the opportunity for the authors to demonstrate their awareness and understanding (appropriate for the level of study) of the research tools commonly used in their field and how this knowledge is used to inform them in constructing a robust methodology to tackle the research problems/questions.

4 Findings and Discussion

The quantitative data for this investigation was collected through a survey conducted in a pre-selected municipality using a questionnaire. The questionnaire included six biographical questions, seven empirical questions with dichotomous responses, and eight six-point Likert-type bi-polar scale statements. Standardised statistical analysis methodologies were employed to extract meaning from the raw data, achieve the research objectives, answer the investigative research questions, and accept or reject the research hypothesis. Of the seventeen questionnaires distributed, ten were correctly completed and deemed usable, resulting in a valid response rate of 58.8% (see Table 4.1). The seven questionnaires that were not returned were likely due to work pressure or respondents being out of the office.

Table 4.1 Case processing summary for the empirical questions in the questionnaire

Cases	No.	%
Valid	10	58.8
Excluded	7	41.2
Total	17	100

Correlation coefficients were calculated between the various questions to determine content and construct validity using Spearman's Correlation Coefficient methodology. The findings, shown in Tables 4.2 and 4.3, indicate that all empirical questions achieved or exceeded the generally accepted threshold of 0.80 for an acceptable level of validity, with coefficients ranging from 0.80 to 0.83.

Table 4.2 Correlation coefficient matrix for questions 7 to 13

No	7	8	9	10	11	12	13
7	1.00	0.80	0.83	0.82	0.80	0.82	0.83
8	0.83	1.00	0.82	0.80	0.83	0.82	0.82
9	0.83	0.83	1.00	0.82	0.80	0.83	0.80
10	0.80	0.80	0.83	1.00	0.82	0.82	0.83
11a	0.83	0.83	0.80	0.82	1.00	0.80	0.83
12	0.80	0.80	0.83	0.80	0.80	1.00	0.82
13	0.83	0.83	0.82	0.83	0.82	0.83	1.00

Table 4.3 Correlation coefficient matrix for questions 14 to 21

	14	15	16	17	18	19	20	21
14	1.00	0.81	0.80	0.83	0.80	0.80	0.80	0.81
15	0.81	1.00	0.80	0.80	0.83	0.80	0.83	0.80
16	0.80	0.81	1.00	0.80	0.83	0.80	0.80	0.80
17	0.83	0.81	0.83	1.00	0.80	0.83	0.80	0.83
18	0.80	0.80	0.80	0.81	1.00	0.80	0.81	0.80
19	0.81	0.83	0.80	0.80	0.80	1.00	0.80	0.83
20	0.80	0.80	0.81	0.83	0.81	0.80	1.00	0.80
21	0.83	0.81	0.80	0.80	0.80	0.83	0.81	1.00

The reliability of the questionnaire and the data collected was determined using Cronbach's Alpha measure, which was found to be 0.89, indicating high reliability (see Table 4.4).

Table 4.4 Cronbach's Alpha reliability measure for the whole questionnaire

Cronbach's Alpha statistic	N
0.89	10

The validity and reliability of the data were further corroborated using the Kaizer-Meyer-Olkin (KMO) measure of sampling adequacy and Bartlett's test of sphericity. The KMO measure was 0.702, exceeding the threshold of 0.70, and Bartlett's test showed a chi-square value of 8.112, indicating a significant relationship between variables (see Table 4.5).

Table 4.5 KMO and Bartlett's test for sphericity for all questions in the questionnaire.

Kaizer-Meyer-Olkin measure of sampling adequacy	0.702
Bartlett's test of sphericity: Approximate Chi-square	8.112
df	4
Significance level	0.05

The data from Figures 4.6 to 4.8 collectively underscores the comprehensive and informed nature of the survey responses. With all respondents having visited informal settlements within the past year and most visits being work-related, the findings are based on well-informed perspectives. This enhances the credibility of the survey results and provides a solid foundation for the subsequent analysis and conclusions regarding water and sanitation services in informal settlements. The detailed breakdown of visits by settlement and purpose also highlights the thoroughness of the investigation, ensuring that the data reflects a wide range of conditions and issues across the municipality.

Table 4.6 The Mann Whitney U test and Wilcoxon W tests of the association between the biographical variable and the knowledge and experience variable entrenched in part B of the questionnaire

Total N	10
Mann Whitney U test	21.3140
Wilcoxon W	101.500
Test statistic	21.3140
Standard error	11.124
Standardised test statistic	- 0.391
Assumptotic significance (2-test summary)	0.137

Table 4.7 The Mann Whitney U test and Wilcoxon W tests of the association between the biographical variable and the sustainability variable entrenched in part C of the questionnaire

Total N	10
Mann Whitney U test	19.413
Wilcoxon W	107.450
Test statistic	19.413
Standard error	10.024
Standardised test statistic	-0.297
Assumptotic significance (2-test summary)	0.193

Table 4.8 Hypothesis test summary for the empirical findings obtained from the questions in Part B and C of the questionnaire

Null hypothesis	Independent samples Mann Whitney U test	Sig.	Decision
Are municipalities mandated (obligated) (Q7) to provide water/sanitation, and how many have been upgraded (Q20) or eradicated (Q21)	Independent samples Mann Whitney U test	0.491	Retain the null hypothesis
Is the provision of water/sanitation part of the municipality's strategic planning (Q8), and how many have access to water/sanitation (Q14+15)	Independent samples Mann Whitney U test	0.182	Reject the null hypothesis
Is there budgetary provision for providing water/sanitation to informal settlements (Q11a+b), and are they growing too fast for the municipality to cope (Q18)?	Independent samples Mann Whitney U test	0.412	Retain the null hypothesis
Does the provision of water/sanitation equate to the rate of growth of informal settlements (Q13), and are some settlements too isolated or not on municipal land (Q16+17)	Independent samples Mann Whitney U test	0.634	Retain the null hypothesis
Does the municipality have a formal policy (Q9) and procedure (Q10), and are some settlements in environmentally and ecologically sensitive areas (Q19)	Independent samples Mann Whitney U test	0.725	Retain the null hypothesis
Does the municipality have adequate human resources (Q12), and do all settlements have access to water (Q14) and sanitation (Q15)	Independent samples Mann Whitney U test	0.862	Retain the null hypothesis

The findings indicate that municipalities are mandated by law and public policy to provide water and sanitation services to informal settlements. However, rapid urbanisation, resource constraints, and geographical isolation of settlements challenge the sustainability of this mandate. The investigation suggests that while strategic planning includes these services, the provision often needs to be improved due to budgetary and human resource limitations. These constraints underscore the need for greater involvement and support from provincial and central governments to address the challenges effectively. The statistical methods confirmed the data's reliability and validity, ensuring the findings and conclusions were scientifically defensible.

5 Conclusion and Further Research

This study, grounded in Maslow's Hierarchy of Needs Theory, aimed to assess the sustainability of local governments in providing water and sanitation services to informal settlements. The research highlighted the critical role of municipalities in ensuring these essential services as fundamental human rights. Despite understanding their legal obligations and incorporating these services into strategic planning, municipalities face significant challenges, including insufficient budgetary provisions, inadequate human resources, and the rapid growth of informal settlements, which hinder effective service delivery.

The findings indicate that municipalities need help meeting the increasing service demand due to resource constraints and rapid urbanisation. Despite robust strategic planning, resource inadequacy exacerbates these challenges, emphasising the need for enhanced resource allocation and improved strategic planning. The involvement of higher levels of government is crucial to addressing these systemic issues.

Future research should expand this investigation across multiple municipalities to enhance reliability and generalizability and explore legislative and policy interventions at national and provincial levels. This approach will provide a broader understanding of how higher-level policies can support local governments in fulfilling their service delivery mandates and explore innovative and sustainable models for delivering water and sanitation services to informal settlements.

6 Acknowledgement

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7. References

Cameron, R. (2001). The Upliftment of South African Local Government? Cape Town: University of Cape Town.

Community Organisation Resource Centre. (2016). Close-out report: Rapid appraisal of informal settlements in the Western Cape. *Pretoria: Government Publisher*.

Companie, F. (2020). *Evaluation of the challenges to project delivery confronting project leaders in the dynamic human settlement environment*. Cape Town: University of Cape Town, Faculty of Engineering and the Built Environment.

Department of Human Settlements. (2010). The National Housing Code: Part 1. Simplified Guide to the National Housing Code. *Pretoria: Government Printer*.

Department of Water and Sanitation. (2016). National Sanitation Policy. *Pretoria: Government Printer*.

Department of Water and Sanitation. (2017). National Norms and Standards for Domestic Water and Sanitation Services. *Pretoria: Government Printer*.

Govender, T., Barnes, J. M., & Pieper, C. H. (2011). Living in low-cost housing settlements in Cape Town, South Africa—the epidemiological characteristics associated with increased health vulnerability. *Journal of Urban Health*, 88(6), 1092-1102.

Maslow, A.H. (1948). Higher and Lower Needs. Journal of Psychology: Interdisciplinary and Applied. 25(2):433–436.

Manyaka, R. K., & Nkuna, N. W. (2014). The Phenomenon of Corruption in the South African Public Sector: Challenges and Opportunities. *Mediterranean Journal of Social Sciences*, 5, 1572-1580. 10.5901/mjss.2014.v5n27p1572.

Republic of South Africa. (1996). The Constitution of the Republic of South Africa. *Pretoria: Government Printer*.

Sithole, M., & Mathonsi, N. (2015). Local Governance Service Delivery Issues during Apartheid South Africa. *Potchefstroom Electronic Law Journal*, p. 12, 10.4314/pelj.v12i4.50050.

Statistics South Africa. (2019). Inequality Trends in South Africa: A multidimensional diagnostic of inequality. *Pretoria: Government Publisher*.

Stellenbosch Municipality. (2019). Fourth Generation Integrated Development Plan for 2017-2022 (IDP 2017-2022). *Stellenbosch: Government Publisher*.

Terre'Blanche, M., Durrheim, K., & Painter, D. (2006). Research in Practice (2nd ed.). *Cape Town: UTC Press*.

Turok, I. (2012). Urbanisation and Development in South Africa: Economic Imperatives, Spatial Distortions and Strategic Responses. *IIED Urbanisation and Emerging Population Issues Working Paper 8*. London: IIED.

Turok, I. (2013). Transforming South Africa's Divided Cities: Can Devolution Help? *International Planning Studies*, 18(2), 168–187.

UN-Habitat. (2015). Informal settlements. *Habitat III Issue Paper 22*. Nairobi: UN-Habitat.

ACADEMIC PAPERS: SESSION II

Innovative Construction and Material Technologies applicable to Housing

Exploring the Feasibility of Mass Timber Use in East Africa: The Effect of Nairobi's Climate on Mass Engineered Timber Structures

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Abstract:
The construction industry is responsible for approximately 37% of greenhouse gas emissions, with materials production contributing 9% of this. To reduce these emissions significantly, the industry must look into alternative materials that are sustainable. One of them is Mass Engineered Timber (MET), known for its carbon-storage characteristic and can be used to decarbonize the building sector. MET involves glued or nailed graded timber panels to enhance structural integrity, offering economic, social, and environmental benefits. While the material has been used successfully in temperate regions, its use and information in tropical urban south cities is limited. This study investigates the climate of Nairobi and analyses any potential impact on the performance of MET and overall, assesses the city's suitability to support MET structures. The objectives of the study included analyzing Nairobi's climatic conditions: rainfall, temperature, humidity and solar radiation, assessing the potential impact of these conditions on MET and determining the necessary required protective measures. Using a mixed-method approach, secondary data collection methods and causal-comparative analysis methods, the study found that Nairobi's high average ultraviolet radiation of 13.75 UVI poses a risk to the compressive strength of MET structures made from timber with a high lignin content. To prevent damage, treatment options are applied before lamination for maximum impact. However, further research on the protective measures for the material use in the climate should be done.

Keywords:
Mass Engineered Timber, Nairobi Climate, Decarbonization, Construction Materials

1. Introduction

The construction industry contributes approximately 37% of GHG emissions and consumes 40% of global energy (Sizirici *et al*., 2021). Of this, construction materials account for 9% of carbon dioxide emissions due to energy (UNEP, 2022) with steel and concrete emitting 2.3 and 2.6 billion tonnes annually. To reduce these emissions significantly, the sector must embrace alternative materials at large volumes. Mass Engineered Timber (MET) is considered an alternative material to steel and concrete due to its environmentally-friendly nature. If reinforced concrete is substituted with mass timber alternatives, almost 43% of GHG emissions are prevented from entering the atmosphere (Hemmati *et al*., 2024). Additionally, if 20% of Africa's housing is done in MET by 2050, 100+ million tonnes of CO^2 emissions are prevented annually (Gatsby Africa, 2023). Makeka and Sharma (2022) indicate that Africa currently has a deficit of 56 million housing units, with low-income affordable housing comprising 80% of the figure. Building a significant fraction of this housing in MET will greatly contribute to both a decarbonized construction industry and an increased supply of (affordable) housing. Mass Engineered Timber (MET) refers to timber or wood that has undergone manufacturing by gluing or nailing graded, sawn timber panels of a certain size together to create timber components whose structural integrity has been improved (Shang, *et al*., 2023). Various Life Cycle Assessments (LCA) done in different locations has revealed the numerous economical, social and environmental benefits of MET.

However, timber is prone to damage by various environmental factors including water and organisms. Many studies have been done on the use of this material in temperate regions, but there is scarce research covering the use of MET in other climates, for example, tropical regions like Nairobi. There is limited information about both the timber and components that go into the manufacturing of mass timber for use in certain climates. The longevity and long-term suitability of its use in the tropical climate is still unknown. Therefore, the uptake of its use in emerging markets has been minimal.

The aim of this study is to investigate the climate of Nairobi to explore its suitability to supporting mass timber structures. The study's objectives are:

i. To conduct an analysis of the rainfall, temperature, humidity, and solar radiation of Nairobi over the past 10-20 years.

ii. To investigate the impact of Nairobi's climatic conditions on the durability of mass timber structures.

iii. To analyse the performance of the material under Nairobi's climatic conditions

The study has used a mixed-use method to conduct the research using causal-comparative design to derive any relationships between the climate of Nairobi and the performance of mass timber structures. Additionally, the study used a non-probability sampling method to select its sample of tree species used in mass timber construction. Due to time and costs constraints, the study used only secondary methods, mostly observation, to collect data and analysed the data through the correlational analysis method. An outstanding limitation of the study was lack of sources to collect a chronological set of climatic data.

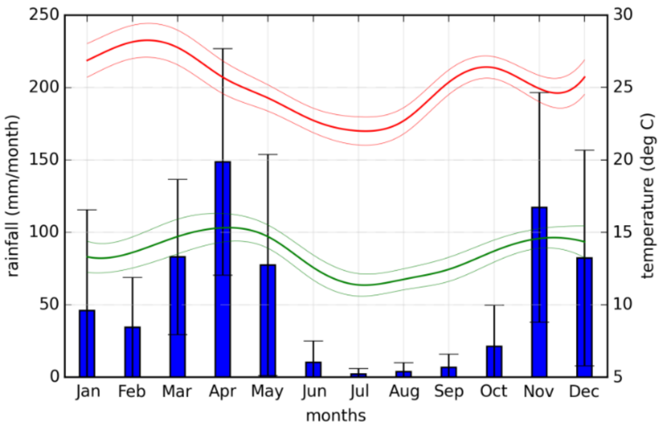
The research findings point out that Nairobi experiences high rainfall of approximately 728mm, an average mean temperature of 20.9 °C and moderate humidity of 69.4%. While these have little impact on mass timber structures, Nairobi's high ultraviolet radiation of 13.75 UVI is a point of risk to the moisture content of the identified wood species. Tree species such as *Juniperus procera* with a higher lignin quantity will more likely be affected by the UV radiation. Since the solutions to protect the material from environmental damage are outside the scope of this study, further research must be done to explore solutions to adopt mass timber as a material for the climate of Nairobi.

2. Literature Review

2.1 The Climate of Nairobi

The climate of Nairobi is influenced by its location: to the east of the Rift Valley, at an altitude of 1800m above sea level. Its climate is categorised as modified equatorial climate (Makhoka and Shisanya, 2010) because of its temperature and rainfall characteristics. Through two rainfall seasons, the city receives slightly more than 610mm of rainfall (310mm during the long rain season from March to May and the remaining 200mm from November to December during the short rain season). It however experiences a dry period between June and October (Aardenne, 2017). Ng'ang'a (1992) illustrates that the rainfall received in Nairobi is influenced by the Inter Tropical Convergence Zone (ITCZ). Nairobi experiences an average of 19°C throughout the year (Makhoka and Shisanya, 2010) with the maximum temperature varying by approximately 6°C and the minimum at 5°C. The temperature is highest from January to March at a maximum of 27.5°C and lowest in June to August at 22.5°C. The minimum daily average temperature coincides with the rainfall pattern whereby March to May (long rains) and November to December (short rains) experience the highest night-time temperature at 15°C and 14.5°C respectively (Aardenne, 2017).

Figure 2: Graph indicating the average rainfall and temperature of Nairobi from 1981 to 2010

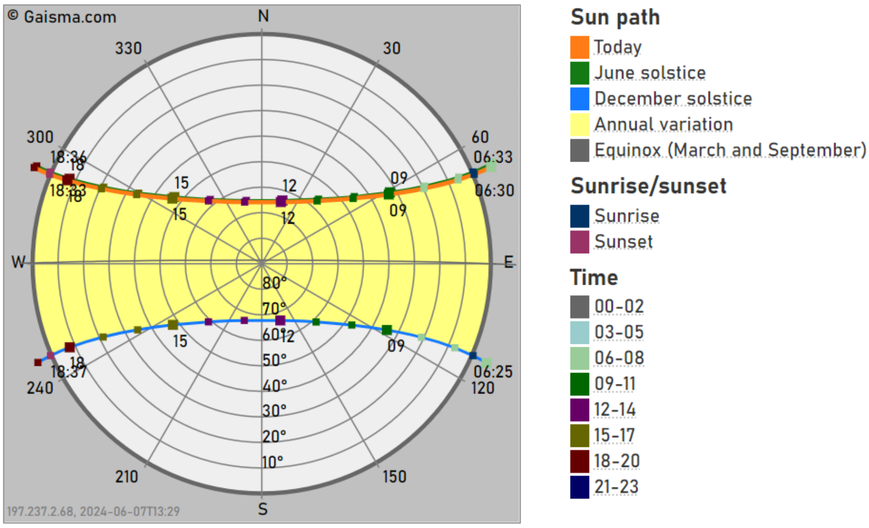


(Aardenne, 2017)

Nairobi's relative humidity is at a high of 80% in the morning and a lower value of 40% during the day, mostly in the afternoons (Makhoka and Shisanya, 2010).

The sunshine duration of Nairobi varies between four and nine hours per day (Makhoka and Shisanya, 2010) with a mean radiation of 8 hours. The annual solar insolation of Nairobi is estimated to be 2100 kWh/m2 which increases from zero just before sunrise and gets to the maximum level during the afternoon hours and back to zero after sunset. There is little variability in the daily solar insolation in the city ranging from 3kWh/m^2/day to 7kWh/m^2/day (Wasike *et al*., 2014).

Figure 3: Nairobi's sun path diagram



(Tukiainen, 2024)

Within these climatic conditions, certain tree species are grown, that can be used for MET production. The Kenya Forestry Research Institute (KEFRI) has outlined the main tree species being grown commercially as: *Pinus patula*, *Cupressus lusitanica*, Eucalyptus, *Grevillea robusta* Casuarina, and *Melia volkensii* (KEFRI, 2021). Like Kenya, Tanzania commercially grows both *Pinus patula* and *Grevillea robusta* among others (Tanzania Ministry of Natural Resources and Tourism, 2017). In Uganda, pine and eucalyptus are also the most widely grown simply because in commercial plantations, they grow well (Uganda Ministry of Water and Environment, 2007).

2.2 Mass Engineered Timber and its Characteristics

Mass timber borrows its characteristics from raw timber, which is known to be affected by natural climatic conditions. Cellulose and hemicellulose are the components responsible for the hygroscopic nature of wood. This is because they have a high hydroxyl (-OH) content (Ayanleye *et al*., 2021). The hygroscopic nature of wood and its ability to wet faster than it dries (Wang et al., 2018) creates a point of concern for timber. As a building material, care must be exercised specially to avoid reducing moisture content below the required average. The bending and compression strengths of wood increases up to a certain amount of reduction of moisture content (Kherais, *et al.,* 2020). Kherais *et al*., (2020) highlight that the conditions that affect the growth of mold are moisture present in the atmosphere and the temperature. Exposure to water from precipitation can cause increased moisture content resulting in unmet building regulations due to the growth of mold (Olsson, 2020). Proper management of moisture for structures built using timber ensures longer life spans and ensures easier maintenance. While moisture management is well understood for light timber structures, the same is yet to be determined for mass timber. Shirmohammadi (2021) points out that the wetting and drying durations for mass timber structures is yet to be fully determined.

Mass timber is timber that has undergone manufacturing through treatments application and gluing, for a high-strength construction material. Polyurethane (PUR) is the most common adhesive and has been used in both CLT and Glulam (Ayanleye *et al*., 2023).

Adhesives used in MET must have a high heat resistant character. Preservatives are used in wood as a technique to increase the durability of timber while maintaining an optimum level of performance by preventing attacks by microorganisms. The two newer copper-based preservatives currently in the market widely used in moisture control are preferred for their affordability and high protection levels. These are micronized copper azole (MCA) and Copper-azole type C (CA-C) (Ayanleye, *et al.*, 2021). However, wood preservation and modification can alter the bonding of the adhesive at different levels in the wood. This can change the wettability of the wood, alter the spread of the adhesive, and reduce penetration. Eventually, the cure rate of the adhesives is compromised leading to increased rates of delamination (Ayanleye *et al.*, 2023).

Figure 4: Image of cross laminated timber panel that has undergone gluing and treatment.

3. Research Methodology

The study employed the positivism research philosophy since the researcher was independent of the study and had no influence on the data collected on the climate of Nairobi and the chosen wood species. While this study does not exclusively analyse and use numerical data; it has systematically collected data to establish any patterns and derive relationships between and among variables. Thus, it has adopted the quantitative research approach. However, in some instances, there is some qualitative data gathered, resulting in an overall mixed method. The causal-comparative design chosen highlights the relationship between climate as the independent variable and mass timber as the dependent variable. It seeks to find out if any of the two variables are dependent on the other.

The non-probability – judgement sampling – method was used to identify samples relevant to the study. The research population comprised all the tree species that are currently used in the manufacturing of mass timber: gymnosperms (softwoods) and angiosperms (hardwoods). To select the sample, the species that are used for MET and are grown within the region were identified. The region in reference is East Africa: Kenya, Uganda and Tanzania.

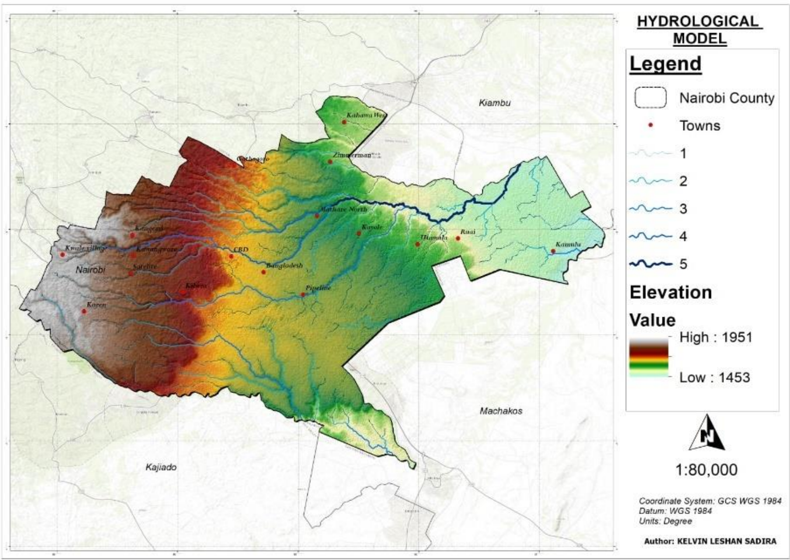
Due to time and research constraints, this study used only secondary data gathering processes. The data was gathered largely from various online sources and libraries that are reliable and contain verifiable information such as ScienceDirect, ProQuest, and website for institutions. Physical libraries and repositories in Nairobi were also used. Correlation analysis was used to evaluate any relationship between climate and MET and the potential effects. The climate data gathered was not in chronological order, but the researcher attempted to align the climatic conditions to similar years.

4. Findings and Discussion

4.1 The Location and Climate of Nairobi

The geographic location of Nairobi has an influence on its climate. Located to the eastern side of the Rift Valley, Nairobi is at a high altitude of approximately between 1450 and 1900 metres above sea level (Otiso, 2012). It is the capital city of Kenya, located approximately 140 km south of the equator and 483 km west of the Indian Ocean. Its coordinates are: 1.2921° South and 36.8219° East covering an approximate area of 696.1 km^2. It is strategically placed at the southeastern edge of Kenya's agricultural land. While it falls within the tropical climatic conditions, its more precise description is modified

Figure 5: Hydrological map of Nairobi



equatorial climate. The western side of the city is cooler and better drained while the eastern side is hotter due to its lower altitude characterised by poor drainage (Otiso, 2012). The hydrological map below is a visual representation of the altitude of Nairobi.

The amount of rainfall experienced in Nairobi is influenced by the movement of the Intertropical Convergence Zone (ITCZ) whereby when it moves to the south, the city receives its long rains between March and April and when in the north, it receives its short rains in November and December. The temperature is influenced by the amount of rainfall received while both the precipitation and temperature influence the humidity and ultraviolet radiation experienced in the city. The below table illustrates the mean monthly and annual climatic conditions of Nairobi.

Table 1: Table indicating the mean annual rainfall, temperature, humidity and ultraviolet radiation of Nairobi.

MONTH	RAINFALL (mm)	TEMP (°C)	HUMIDITY (%)	UV (UVI)
January	40.0	21.48	65.0	15
February	45.0	22.42	57.5	16
March	70.0	22.66	63.5	16
April	157.5	21.31	75.5	16
May	110.0	19.99	76.5	13
June	27.5	19.36	74.0	11
July	11.0	19.26	72.0	11
August	12.0	19.92	68.0	13
September	22.5	21.08	63.0	14
October	42.5	21.82	65.0	14
November	115.0	20.48	78.0	14
December	75.0	20.63	74.5	13
AVG	**60.6**	**20.9**	**69.4**	**13.75**

4.2 Characteristics of Tree Species used for Mass Engineered Timber

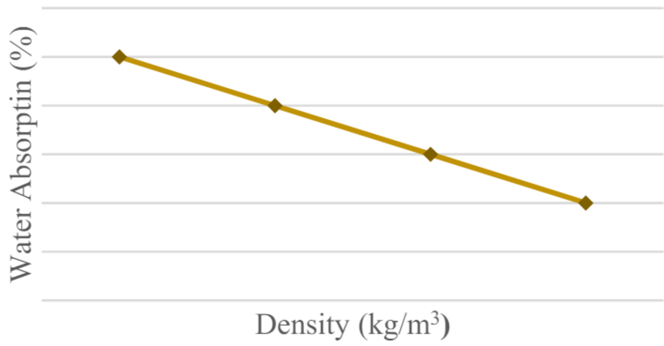
This study focused on and analysed the characteristics of specific (see Table below) gymnosperm tree species except for eucalyptus (an angiopserms found in the myrtaceae family). These species were selected for two reasons: they are the most widely grown and used tree species from in Kenya (Omondi *et al.*, 2020) and they can be used for MET production.

Table 2: Table illustrating the moisture content, density and lignin content in the chosen tree species common in Kenya and can be used for MET production.

Genus	Species	Equilibrium Moisture Content (%)	Density (kg/m3)	Amount of lignin (%)
Pinus	*Pinus patula*	12	490	26-29
Cedrus	*Juniperus procera*	12	480	47.92
Cupressus	*Cupressus lusitanica* Miller	12	446	30-31
Eucalyptus	*Eucalyptus saligna*	12	730	27.0

Since wood in its various forms is hygroscopic in nature, it is expected that in conditions such as availability of stagnant and / or moving water in any amount the timber will absorb the water. Water absorption by timber is inversely related to its density – the lower the density of the timber species, the higher the water absorption. The reverse is true. This can be illustrated in a simple line graph as shown below.

Figure 6: Graph indicating the relationship between wood density and water absorption



To obtain high quality MET, raw timber undergoes a manufacturing process that ensures a high structural strength and protection from damage by environmental factors. For maximum impact, the timber planks are first treated using preservatives such as Copper chrome arsenate (CCA) and boron-based disodiumoctaborate tetrahydrate (DOT) and are thereafter glued using adhesives such as polyurethane (PUR) and phenol-resorcinol formaldehyde (PRF). Ayanleye *et al.*, (2023) advise that treatment is done before gluing rather than doing a post-treatment intervention since it may be impossible to treat large sections of the timber after gluing and lamination.

4.3 Potential Effect of Nairobi's Climate on MET

As shown, tree species such as *Eucalyptus saligna* have a high density of 730 kg/m^3, meaning that they have lower water absorption rates unlike other species such as *Cupressus lusitanica* Miller which has a lower density of 446 kg/m^3. Waterproofing measures have to be used during the two rainy seasons (March – May & November – December) while using this material. Additionally, MET structures built to the west of the city should include both species with higher densities and higher moisture control measures.

Since Nairobi's temperature is well below 40°C, the adhesives in MET may not be influenced by the temperature. It is only MET using PUR adhesive that will be affected by temperatures above 40°C. The timber loses stiffness and resistance, exuding characteristics of plastic failure. Its mechanical properties decline at a linear proportion to increase in temperature (Verdet, 2016).

However, the high ultraviolet radiation level in the city is a risk to MET structures. Since lignin in wood is a UV absorber, accommodating wavelengths between 250 and 400 nm, mass timber structures to be built in Nairobi will experience UV damage. MET made of species such as *Juniperus procera* with a lignin content of 47.92% will experience more UV damage. Wood is a photosensitive material and will degrade over a certain duration of exposure to both UVB and UVA rays. Mass timber exposed to high levels of UV radiation will eventually degrade, characterised by cracks and changes in colour. It can also look stringy, and the tactile texture becomes rough. The colour change is a result of depolymerised lignin and cellulose present in the timber. Water then leaches away these two components, leaving the timber grey in colour. To protect the material, adequate treatment options should be employed.

5. Conclusion and Further Research

The aim of this study was to evaluate whether Nairobi's climate has any impact on structures made of mass engineered timber. The study has revealed that Nairobi's climate may have an impact on MET structures. Because Nairobi experiences an average rainfall amount of 728.0 mm and a relative humidity of almost 70%, mass timber structures may absorb this moisture and alter the moisture content. If not adequately treated, the alteration in MC will compromise the compressive strength of the MET. MET structures in Nairobi may also face compromised compressive strength due to exposure to high UV radiation levels. However, the extent of risk and potential decline in the strength was not covered in this study, and provides with an opportunity for further research.

Future research may be undertaken to identify the suitable solutions to protect MET structures from UV radiation damage and moisture caused by humidity and rainfall, especially in the months of April to June and November to December. Additionally, further research regarding the type of timber (or tree species) that is most suitable for MET use in the city. As much as there are species currently being widely grown within the country for several uses, there should be more research as to which tree species should be explored, specifically for MET development.

6. References

Aardenne, al. (2017), 'Nairobi Climate Profile', *Urban Africa Risk Knowledge*, 1(1), pp. 1-36.

Ayanleye, S., Quin, F., Zhang, X., Lim, H & Shmulsky, R. (2023), 'Preservatives Penetration and Retention in Post-Treated Cross-Laminated Timber Panels with Different Layup and Thickness', *Journal of Building Engineering*, 67(1), pp. 2352-2380.

Ayanleye, S., Udele, K., Nasir, V., Zhang, Xuefeng. & Militz, H. (2021), 'Durability and Protection of Mass Timber Structures: A review', *Journal of Building Engineering*, 46(1), doi: 10.1016/j.jobe.2021.103731.

Gatsby Africa. (2023). 'Sustainable Mass Timber Construction Transforming Cities, Forests and Livelihoods', *Daily Nation.*

Hemmati, M., Messadi, T., Gu, H. & Seddelmeyer, J. (2024), 'Comparison of Embodied Carbon Footprint of a Mass Timber Building Structure with a Steel Equivalent', *Buildings*,141(1), pp.1276-1296.

Kenya Forestry Research Institute (2021), *Tree Seed Supply Chain for Commercial Tree Species in Kenya*. Kenya Forestry Research Institute.

Kherais, M., Csebfalvi, A. & Len, A. (2020), 'The Climate Impact on Timber Structures', *International Journal of Optimisation in Civil Engineering*, 11(1), pp. 143-154.

Makeka, M. & Sharma, M. (2022), 'African Timber Cities: Carbon Sinks with Development Benefits?', *International Institute for Environment and Development*, 1(1), pp. 1-4.

Makokha, G. & Shisanya, C. (2010), 'Trends in Mean Annual Minimum and Maximum Near Surface Temperature in Nairobi City, *Kenya. Advances in Meteorology*, 1(1), pp.1–6. doi: https://doi.org/10.1155/2010/676041.

Olsson, L. (2021). 'CLT construction without weather protection requires extensive moisture control', *Journal of Building Physics*, 45(1), pp. 5–35. Doi:.1177/1744259121996388.

Omondi, S., Cherotich, L., Chegala, E., Kariuki, J., Mbinga, J., Kimani, P., Cherono, F., Oballa, P., Njuguna, J. & Machua, J. (2020). Status of Tree Breeding for Major Commercial Tree Species in Kenya. KEFRI - Gatsby Africa (KCFP) Commercial Forestry Project Report.

Otiso, K. (2012), 'Profile of Nairobi, Kenya', *Berkshire Encyclopedia of Sustainability: AfroEurasia: Assessing Sustainability*, 1(1), pp. 222-227.

Ren, H., Guo, W., Zhang, Z., Kisovi, L.M. & Das, P. (2020), 'Population Density and Spatial Patterns of Informal Settlements in Nairobi, Kenya', *Sustainability*, 12(18), p.7717-7730.

Shang, G., Pheng, S. & Fai, B. (2023). 'Receptiveness of mass-engineered timber (MET) residential buildings among young stakeholders', *Smart and Sustainable Built Environment*, 1(1), doi:org/10.1108/SASBE-02-2023-0040.

Shirmohammadi, M., Leggate, W., Redman, A. (2021). 'Effects of moisture ingress and egress on the performance and service life of mass timber products in buildings: A review', Construction and Building Materials, 290(1). doi: 10.1016/j.conbuildmat.2021.123176.

Sizirici, B., Fseha, Y., Cho, C., Yildiz, I. & Byon, Y. (2021), 'A Review of Carbon Footprint Reduction in Construction Industry: From Design to Operation.', *Materials*, 14(1). doi:103390/ma14206094.

Tanzania Ministry of Natural Resources and Tourism. (2017), *Tanzania's Forest Reference Emission Level*. Tanzania Ministry of Natural Resources and Tourism.

Teacă, C., Roşu, D., Bodîrlău, R. & Roşu, L. (2013). 'Structural Changes in Wood Under Artificial UV Light Irradiation Determined by Spectroscopy and Colour Measurements – A Brief Review', *BioResources*, 8(1). 1478-1507. doi:10.15376/biores.8.1.

Tukiainen, M. (2024). Nairobi, Kenya - Sunrise, sunset, dawn and dusk times for the whole year. Available at: https://www.gaisma.com/en/location/nairobi.html (Accessed on: 7th June 2024).

Uganda Ministry of Water and Environment. (2007), *Field Guide to the Forest Trees of Uganda: For Identification and Conservation*. Ministry of Water and Environment.

United Nations Environmental Programme. (2022), How Do Greenhouse Gases Actually Warm Up the Planet? Available at: https://www.unep.org/news-and-stories/story/how-do-greenhousegases-actually-warm-planet (Accessed on: 12th December 2023).

Verdet, M., Salenikovich, A., Cointe, A., Coureau, L., Galimard, P., Munoz Toro, W., Blanchet, P. & Delisée, C. (2016), 'Mechanical Performance of Polyurethane and Epoxy Adhesives in Connections with Glued-in Rods at Elevated Temperatures', *BioResources*, 11(4). doi: https://doi.org/10.15376/biores.11.4.8200-8214.

Wasike, N., Soitah, T., Waweru, S. & Kariuki F. (2014). 'Assessment of the Solar Radiation Potential of The Thika and Nairobi Area'. *Journal of Agriculture, Science and Technology*, 16(1), pp. 93-105.

Reliability-Based Assessment of an Existing RC Building

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Abstract:
One method of ensuring the sustainability of historic buildings and engendering innovation is adapting existing structures to a different form or function. However, this requires utmost consideration for the safety and reliability of such structures. This study examined the structural reliability of the beams, slabs, and columns of an existing reinforced concrete building to evaluate its suitability for use after being abandoned for some time. Nondestructive tests were carried out on selected slabs, beams, and columns of the building under evaluation after calibrating a Schmidt Rebound hammer. Limit state equations were developed in accordance with the provisions of BS 8110 (1990) for the assessment of the beam, slabs, and columns. The failure probability and reliability indices for each of the examined structural members were determined with Cal-Reliability (CALREL) software using the First Order Reliability Method (FORM). All the beams assessed showed satisfactory reliability levels. However, one of the slab panels examined showed reliability levels below the target reliability index and a very high probability of failure if the loading is less than half the design load. The examined columns also showed high levels of probability of failure, with their reliability indices well below the target reliability index. It is advised that necessary retrofitting strategies should be adopted to strengthen the columns before adapting the structure for the planned use.
Keywords:
Structural reliability, FORM, Non-destructive testing, Limit State, CALREL

1 Introduction

The fundamental concept of design requires that structures meet the safety and serviceability criteria for their projected purpose during their lifespan. Nevertheless, in actuality, every structure is likely to fail, regardless of the safety measures and factors taken into account or applied during its design and construction. Furthermore, the structural integrity and rigidity of several civil infrastructure facilities gradually decline over time due to their prolonged exposure to harsh operational or climatic conditions during their lifespan (Wang *et al.*, 2017). Several structural failures have been documented due to environmental factors and unforeseen incidents, leading to severe damage and financial losses for the facility owners. Chendo and Obi (2015) observed that many building collapses are a result of human errors such as faulty design, poor construction, and the use of low-quality construction materials. Other causes include carelessness, errors, inexperience, quackery, graft, subversion, and natural events like floods, earthquakes, and strong winds. Hence, assessment of a building’s structural condition is critical in mitigating this rising problem.

While safety is of the essence, one important way of implementing sustainability in construction is through the innovative transformation of existing buildings to suit a new purpose. However, having been constructed over a long period, the safety levels in the many old buildings change with time, and thus, failing to account for such changes may be disastrous when adapting the buildings for a different use. Moreover, the adaptive use of existing buildings (Ajgwi *et al.*, 2023) necessitates assessing the structure's adaptability for an alternative purpose. All these considerations have contributed to the need to assess the structural conditions of existing buildings to ascertain their ability to continue to maintain their functionality.

Evaluating the structural condition of a building can be done using fully destructive, partially destructive, or nondestructive approaches. Nondestructive testing (NDT) technologies have considerably contributed to the evaluation of structures over time. Multiple research initiatives have been undertaken to enhance the evaluation of current structures with this approach. Diaferio and Vitti (2021) investigated reinforced concrete (RC) buildings in Bari (Italy) using both nondestructive (ultrasonic pulse velocity) and destructive (drilled core) tests. The structural safety of an Italian school building was evaluated by Minutolo *et al*. (2019), who applied SonReb, UPV and core-drill methods to assess the strength of structural members in a school building. Rebound hammer and chemical tests were utilised by Jedidi *et al*. (2017) in the diagnosis of an RC building in Tunisia, and a jacketing method was proposed for the repair of the defective columns.

In spite of these records, there have been drawbacks to using only nondestructive methods for evaluating structures. This is because NDT techniques may not always provide a comprehensive assessment of the structure's long-term durability and future performance (Tworzewski *et al*., 2021).

However, by employing structural reliability analysis, it is possible to not only assess the conditional structural integrity and serviceability but also to provide quantitative predictions about a structure's capacity to withstand future events (Wang *et al*., 2017). Structural reliability analysis thus enables the prediction of future development, preservation, and maintenance of infrastructure while minimising possible risks and ensuring safety, sustainability, and innovation in construction.

This study, therefore, sought to evaluate the reliability of an existing RC structure that was proposed for use after being abandoned for a period of time.

2 Literature Review

Reliability refers to the likelihood that a system will successfully carry out its intended function within a defined timeframe and under specific service conditions (El-Reedy, 2013). A building can effectively perform its intended function without experiencing any degradation or loss of functionality within a specific period. Structural uncertainty typically comes from changes in loading and material qualities, proportions, natural and man-made risks, inadequate technical know-how, and human mistakes in the construction and design processes (Ellingwood, 1996). These uncertainties create a legitimate suspicion over the structure's capacity to withstand the anticipated loads, rendering it vulnerable to failure. Structural reliability, therefore, seeks to estimate the probability of failure as a quantitative measure of structural safety. It is important to understand that when we refer to the failure of a structure, it does not necessarily mean a catastrophic breakdown. Instead, the structure does not function as intended (Skrzypczak *et al*., 2017). Reliability-based methodologies combine data on design specifications, material and structural deterioration, accumulation of damage, environmental factors, and nondestructive testing (NDT) approaches to create a decision tool that offers a numerical assessment of structural reliability in anticipated future service conditions (Ellingwood & Mori, 1993; Hackl & Kohler, 2016).

Generally, the benefit of nondestructive testing (NDT) is that it allows for evaluating a structure without causing any harm to it. Furthermore, their utilisation is rapid and uncomplicated, and the examination outcomes are accessible on location. NDT procedures rely on physical or chemical principles that can be observed or measured without causing noticeable changes to the appearance or functionality of the analysed structures. The speed, cost-effectiveness, and non-invasive type of assessment that this approach provides make them a preferred option during structural integrity assessments, compared to the traditional destructive approaches (Almasaeid *et al*., 2022).

However, these NDT techniques have some limitations and yield uncertain results. Some of these uncertainties may arise due to the anisotropy and heterogeneity of tested materials, roughness on the surfaces where the test is applied, small test conduction area, equipment inclination, test direction, and human errors. NDT methods do not consider other uncertainties during the building process, such as unpredictability of loads, calculation errors, use of inadequate materials, construction method, overloading, misuse, and others.

This is where structural reliability techniques offer more unique advantages. Structural reliability, being a probabilistic approach, takes account of uncertainties associated with strength, load evaluation, uncertainties of some design parameters, and human errors (Skrzypczak *et al*., 2017). Thus, it enables the development of a better service life prediction model. Some reliability techniques have been used in evaluating structural reliability, such as the First-Order Reliability Method (FORM), the Second-Order Reliability Method (SORM), Monte Carlo simulation, and Importance Sampling.

Several researchers have studied the structural reliability of existing buildings using different approaches. Ibrahim and Rad (2023) employed Monte Carlo simulation to predict the deflections and probability of failure in RC haunched beams, considering serviceability criteria. The research demonstrates the relevance of probabilistic numerical computation in structural appraisals. Wang *et al.* (2021) utilised spatial correlation in their evaluation of chloride-induced corrosion in reinforced concrete structures to predict the probability of failure. Their study emphasised the significance of spatial effects in accurately assessing the reliability of such systems. Mankar *et al.* (2020) performed a fatigue reliability analysis on the Crêt de l'Anneau viaduct, demonstrating the need to consider fatigue when evaluating reinforced concrete structures. Drukis *et al.* (2017) performed a case study on the structural reliability of existing buildings using lightweight roofs in Liepaja and Riga. The study revealed that the safety levels of elements vary between Latvia's regions due to the relative change in climatic snow maps. A probabilistic risk assessment was carried out on the concrete component of an existing building by Sule *et al*. (2015). The study used a beta model for risk assessment, using concrete strength as the primary variable. It was observed that the structure was potentially unsafe and thus recommended for careful demolition. The present study sought to evaluate the reliability of a standing reinforced concrete structure proposed for a different use.

2 Research Methodology

This research adopted the First Order Reliability Method (FORM) to estimate the reliability indices. This is because of its simplicity and straightforward approach to reliability analysis. It is very computationally efficient and makes quick calculations of reliability indices possible (Chowdhury, 2023). It is an approximate method in which the limit state function (failure function) is linearised, and the failure domain to the half-space is defined by means of the hyperplane, which is tangent to the limit state surface at the design point (Kassem, 2015).

In general, structural reliability is defined by the relationship existing between strength and load parameters as follows (Afolayan & Opeyemi, 2008):

$$M = R - L = g\,(X_1, X_2, \ldots, X_n) \quad (1)$$

where M represents the limit state function, also known as the safety margin or performance function, R represents the resistance, L represents the load, $X = X_1, X_2, \ldots, X_n$. Represent n basic random variables, and g(X) represents a function of all design variables. Generally, the function g(X) takes different forms depending on the structure in consideration, provided that the structure's failure is defined when $M \leq 0$ and the structure's safety is defined when $M > 0$.

The limit state is a condition where a structure or structural element in some way becomes unfit for its intended purposes (El-Reedy, 2013). The limit state function is, therefore, a representation of the boundary between a structure's desired and undesired performance, which is generally represented by equation (1).

When the limit state function has been established, the probability of failure can be calculated by performing the following integration over the region where $M \leq 0$, as given in equation (2);

$$P_f = \iint \int f_x\,(X_1, X_2, \ldots, X_n)\, dx_1, dx_2, \ldots, dx_n \quad (2)$$

where f_x is the joint probability density function for the random variables $X_1, X_2, \ldots, X_n$, as Afolayan and Opeyemi (2008) reported.

Reliability requirements for both new and existing structures can be defined in terms of the reliability index, β, given in equation (3):

$$\beta = -\Phi^{-1}(P_f) \quad (3)$$

where Φ^{-1} is the standard normal probability distribution function,
P_f is the failure probability corresponding to a specified reference period.

When the reliability indices for an existing structure have been determined, they are compared with a specified target reliability index, β_T, which is determined based on two parameters: consequences of failure and incremental cost of safety. ISO 13822 (2010) proposed that for a model structure, the target reliability $\beta \approx 3.8$ might be assumed, the related reference period being "a minimum standard period for safety (e.g. 50 years)".

For this study, nondestructive tests were carried out using a calibrated Schmidt Rebound hammer on randomly selected beams, columns, and slabs in a structure (shown in Figure 1) to evaluate their in-situ strength. The section and dimensional properties of the structural members examined were also recorded and used in the reliability analysis.

Figure 1: The building under evaluation

Limit state equations were then formulated for the beams, slabs and columns, represented by equations (4) - (6), respectively, in accordance with the provisions of BS 8110 (1999).

For doubly-reinforced beams:

$$G = 0.156f_{cu}bd^2 + 0.95f_yA_s'(d - d') - q_kl^2(0.175\alpha + 0.2) \quad (4)$$

For two-way slabs:

$$G = 0.156f_{cu}bd^2 - 0.105(1.4\alpha + 1.6)q_kl_x{}^2 \quad (5)$$

For columns:

$$G = 0.35f_{cu}bh + 0.67\rho bdf_y - N\alpha \quad (6)$$

where α is the load ratio given by: $\alpha = \frac{g_k}{q_k}$

FCU is the characteristic strength of concrete

f_y is the characteristic strength of steel
b is the width of the beam/column
d is the effective depth of the beam/slab
q_k is the characteristic imposed load
l is the effective length of the beam/slab

As' is the area of steel in compression and is given by $A_s' = \rho bd'$

ρ is the reinforcement ratio, where $0.2\% \leq \rho \leq 4\%$ (for beams and columns) and $0.13\% \leq \rho \leq 4\%$ (for slabs)
d′ is the effective depth of the compression reinforcement and is given by $d' = h - d$
N represents the axial load

Using these limit state equations, structural reliability analysis was performed using Cal-Reliability (CalREL), a general-purpose structural reliability software. After that, the reliability levels for the structural members' slabs, beams, and columns at both the design stage and the current as-built state were compared with the target reliability indices. The target reliability index (β_T) level for all slabs was selected as 2.5, for all beams as 3.5, and all columns as 4.0, based on recommendations according to ACI 318-99 (1999) and

Szerszen and Nowak (2003). Table 1 presents the general statistical data used to conduct the reliability analysis of the structural elements.

Table 1: General Statistical Data for the reliability analysis of the structural members

Variable	Mean	Distribution	Assumed Coefficient of Variation (%)
Characteristic Strength of Concrete, f_{cu} (N/mm^2)	Varying: 15.34 - 21.3 N/mm^2	Log-Normal	Varying
Characteristic Strength of Steel, f_y (N/mm^2)	385 N/mm^2	Log-Normal	30
Length, *L* (mm)	Varying	Normal	10
Width, *b* (mm)	Varying	Normal	10
Depth or thickness, *h, d, or d'* (mm)	Varying: Slabs: 150mm Beams: 450 - 600mm Columns: 230 - 500mm	Normal	10
Live load, q_k (kN/m^2)	1.5, 3.0	Log-Normal	30
Load ratio, α	$0.5 \leq \alpha \leq 3.0$	Normal	10
Reinforcement ratio, ρ	$0.2 \leq \rho \leq 4.0$	Normal	10
Column axial load, N, kN	500	Log-Normal	30

3 Findings and Discussion

Reliability levels for the slabs, beams and columns are presented in Figures 2 - 4.

Figure 2: Comparison of the reliability levels for existing and designed slabs

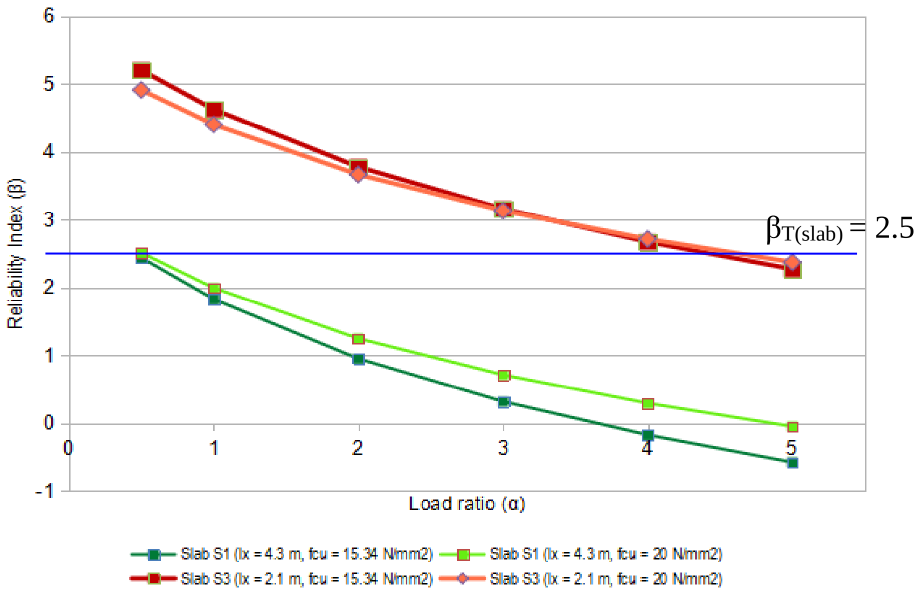


Figure 3: Comparison of the reliability levels for selected existing and designed assumed doubly reinforced beams (α = 1.0)

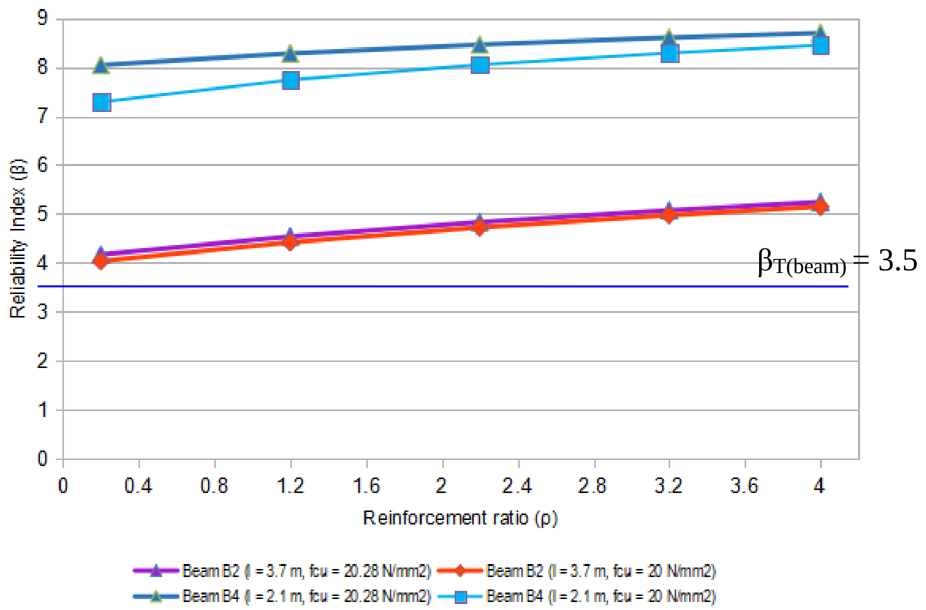
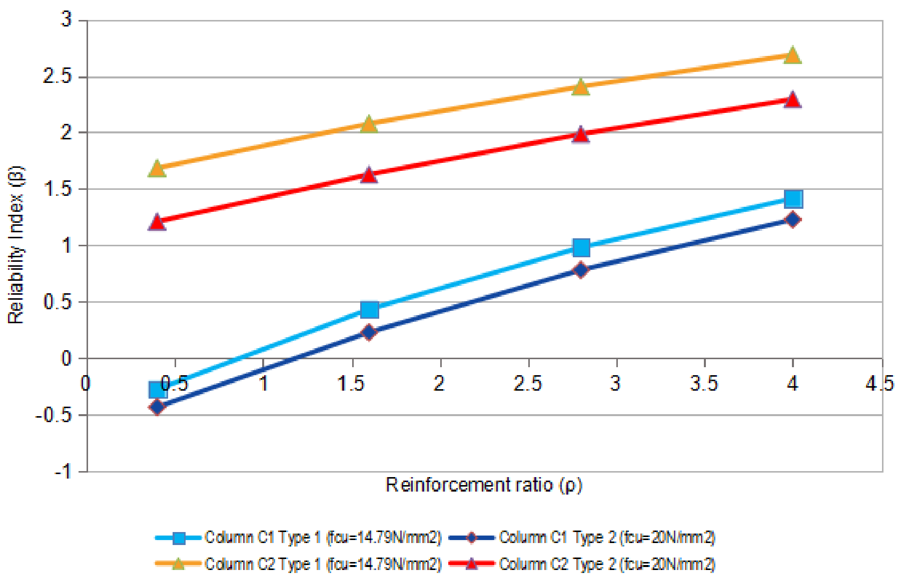


Figure 4: Comparison of implied and expected reliability indices for columns (α = 1.0)



4 Discussion

The results of the reliability estimates for the elements (as shown in Figure 2) show that, generally, as the load ratio increased, the reliability indices decreased. This similar trend was observed by Ozovehe *et al.* (2022). The reliability indices observed from the NDT-measured compressive strength (15.34 N/mm^2) were lower than those obtained from the expected design compressive strength (20 N/mm^2). It was also observed that only Slab S3 met the target slab reliability index of 2.5 beyond a load ratio of 0.5. This suggests that the Slab S1 shows a considerable level of probability of failure beyond half of its designed load and very high failure probability levels, especially beyond a load ratio of 4.0. This implies that attention needs to be paid to the permissible loading on the slab during its working condition. It is proposed that the slab should not be loaded beyond half its designed load. The average compressive strength of the beams based on the Rebound hammer test results was 20.28 N/mm^2. Compared with the expected compressive strength of 20 N/mm^2, the beam reliability estimates show that the assessed beams had reliability indices well above the target reliability index of 3.5 at a load ratio 1.0, indicating satisfactory performance. This suggests that the beams were designed and constructed to standard. However, when subjected to higher load ratios beyond 1.0, beam B2 might show considerable failure probability levels. The reliability estimates of the columns show an increasing trend with reinforcement ratio. However, it is seen that at a load ratio of 1.0 (assumed to be 500 kN), the reliability levels of the columns were below the column target reliability index of 4.0. This suggests that the columns show a high probability of failure, and based on the reliability estimates, the columns should not be subjected to loading beyond 250 kN (i.e. load ratio of 0.5).

5 Conclusion and Further Research

This study has assessed the structural reliability of the beams, slabs and columns of an existing reinforced concrete building to see if it is suitable for use after a period of abandonment. After calibrating a Schmidt Rebound hammer, nondestructive tests were conducted on certain building slabs, beams and columns being evaluated. The limit state equations were formulated in compliance with BS 8110 (1990) specifications to evaluate the structural reliability of beams, slabs, and columns. The failure probabilities and

reliability indices for each analysed structural element were calculated with Cal-Reliability (CalREL) software using the First Order Reliability Method (FORM). The following conclusions were drawn based on the results obtained:

- The slabs showed a general decreasing trend in reliability levels with increasing load ratios. Slab S3 showed satisfactory performance beyond a load ratio of 0.5, while Slab S1 showed a high probability of failure, especially beyond a load ratio of 4.0.
- It was observed that the reliability indices increased with increasing reinforcement ratios for the beams. All the beams assessed performed satisfactorily at a load ratio of 1.0, with all the reliability indices well above the target beam reliability index.
- The column reliability indices fell below the target column reliability index. Column C2 Type 1 particularly shows a high probability of failure beyond a load ratio of 0.5. It is recommended that essential retrofitting measures be implemented to reinforce the columns prior to modifying the structure for use.

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7 References

ACI 318-99 (1999). Building Code Requirements for Structural Concrete, American Concrete Institute, Farmington Hills, Michigan.

Afolayan, J.O. & Opeyemi, D.A. (2008). Reliability Analysis of Static Pile Capacity for Concrete in Cohesive and Cohesionless Soils. *Research Journal of Applied Sciences,* 3(5), pp. 407-411.

Aigwi, I. E., Duberia, A., & Nwadike, A. N. (2023). Adaptive reuse of existing buildings as a sustainable tool for climate change mitigation within the built environment. *Sustainable Energy Technologies and Assessments*, 56, 102945.

Almasaeid, H., Alkasassbeh, A., & Yasin, B. (2022). Prediction of geopolymer concrete compressive strength utilising artificial neural network and nondestructive testing. *Civil and Environmental Engineering*, 18(2), 655-665.

BS 8110: Part 1 (1997). British Standard. Structural Use of Concrete – Part 1: Code of practice for design and construction. British Standards Institution (BSI), London.

Chendo, I.G. & Obi, N.I. (2015). Building Collapse In Nigeria: The Causes, Effects, Consequences And Remedies. *International Journal of Civil Engineering, Construction and Estate Management*, 3(4), pp. 41-49.

Chowdhury, S. (2023). Reassessment of operating engineering steel structures with the first order reliability method and bayesian inference. *Ce/Papers*, 6(3-4), pp. 2683–2688.

Diaferio, M., & Vitti, M. (2021, July). Nondestructive tests for the assessment of RC buildings. In *Quantitative Nondestructive Evaluation* (Vol. 85529, p. V001T09A002). American Society of Mechanical Engineers.

Drukis, P., Gaile, L., & Goremikins, V. (2017). Case Study of Structural Reliability of Existing Building. *Proceedings of the 11th International Scientific and Practical Conference, Environment, Technology, Resources*, Volume III, pp. 47-52.

El-Reedy, M.A. (2013). Reinforced Concrete Structural Reliability. CRC Press, Boca Raton.

Ellingwood, B.R. (1996). Reliability-based condition assessment and LRFD for existing structures. *Structural Safety*, 18(2/3), 67–80.

Ellingwood, B.R. & Mori, Y. (1995). Reliability-based service life assessment of concrete structures in nuclear power plants: optimum inspection and repair. *Transactions of the 13th International Conference on Structural Mechanics in Reactor Technology (SMiRT 13), Escola de Engenharia – Universidade Federal do Rio Grande do Su*l, Porto Alegre, Brazil, August 13-18, 1995, pp. M02-1 – M02-10.

Hackl, J., & Kohler, J. (2016). Reliability assessment of deteriorating reinforced concrete structures by representing the coupled effect of corrosion initiation and progression by Bayesian networks. *Structural Safety*, 62, 12-23.

ISO 13822 (2010). Basis for design of structures – Assessment of existing structures. International Organization for Standardization (ISO), Geneva, Switzerland.

Jedidi, M., Abroug, A., Moalla, B., & Benjeddou, O. (2017). Nondestructive testing for the diagnosis and repair of a reinforced concrete building. *International Journal of Architecture, Engineering and Construction*, 6(1), 20–28.

Kassem, F. (2015). Reliability of reinforced concrete structures: Case of slabs subjected to impact. PhD Thesis, Department of Civil Engineering, Graduate School of Mechanical Energy Engineering Civil Engineering and Acoustics (MEGA), National Institute of Applied Sciences of Lyon.

Khaleel Ibrahim, S., & Movahedi Rad, M. (2023). Reliability-based probabilistic numerical plastically limited analysis of reinforced concrete haunched beams. *Scientific Reports*, 13(1), 2670.

Mankar, A., Rastayesh, S., & Dalsgaard Sørensen, J. (2020). Fatigue Reliability analysis of Cret De l'Anneau Viaduct: a case study. S*tructure and Infrastructure Engineering*, 16(4), 762-771.

Minutolo, V., Ronza, S., Eramo, C., Ferla, P., Palladino, S., & Zona, R. (2019). The use of destructive and nondestructive testing in concrete strength assessment for a school building. *International Journal of Advanced Research in Engineering & Technology*, 10(6). https://doi.org/10.34218/ijaret.10.6.2019.028.

Ozovehe, A. A., Sulaiman, T. A., Ocholi, A., Kaura, J. M., & Mohammed, A. (2022). Effects of Load Ratio Variation on the Safety of Timber Concrete Composite Floor. *FUOYE Journal of Engineering and Technology*, 7(2), 269–273.

Skrzypczak, I., Słowik, M. and Buda-Ożóg, L. (2017). The application of reliability analysis in engineering practice–reinforced concrete foundation. *Procedia engineering*, 193, pp. 144-151.

Szerszen, M.M., & Nowak, A.S. (2003). Calibration of Design Code for Buildings (ACI 318) Part 2: Reliability Analysis and Resistance Factors. Ann Arbor, 1001, 48109.

Wang, C., Zhang, H., Li, Q. (2017). Reliability assessment of aging structures subjected to gradual and shock deteriorations. *Reliability Engineering and System Safety*, 161(2017), 78–86.

Tworzewski, P., Raczkiewicz, W., Czapik, P., & Tworzewska, J. (2021). Diagnostics of concrete and steel in elements of an historic reinforced concrete structure. *Materials*, 14(2), 306.

Design and Fabrication of a Gazebo Using Cross-Laminated Timber Beam and Column Made from Mangifera Indica

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Abstract:
Senescent fruit trees have structural potential but are limited by short trunks and small girths, necessitating their use in engineered wood products (EWPs). However, information on their viability as EWPs for affordable housing is sparse. This study assesses the flexural performance of cross-laminated *Mangifera indica*. Samples were collected and air-dried. The manufacturing process involved crosscutting, planning, adhesive application, panel lay-up and assembly pressing. Preliminary tests were conducted. The samples were loaded in-plane, and their flexural properties were evaluated. ANOVA was performed on the flexural properties of solid wood, CLT (major axis), and CLT (minor axis) at P = 0.05. A gazebo was designed, and a scaled-down model was fabricated. The average MC and density were 10.03% (±1.49) and 579.45 kg/m3 (±70.99) respectively. The average MoE for the solid specimen was 23484.86 MPa (±3238.83), and the average MoR was 64.91MPa (±15.83). The average MoE of CLT samples loaded in the minor strength axis was 16945.821Mpa (±2389.66), and the average MoR was 44.69MPa (±22.62). The average MoE for the CLT in the major strength direction was 13981.72Mpa (±8057.40), and the average MoR was 15.09MPa (±10.41). ANOVA revealed significant differences: solid wood had the highest strength and stiffness, while CLT (major axis) was the weakest. Although solid *M. indica* exhibited significantly higher strength and stiffness, attributable to weak interfacial bonding in glue lines, CLT values remained within the acceptable range for structural applications, indicating that CLT can increase span from short trunk *M. indica* trees without excessively compromising strength, suggesting promising applications for innovative construction.

Keywords: Mangifera indica, CLT, Construction, Affordable housing, innovative construction technologies

1 Introduction

The choice of construction material is determined by its availability, affordability, eco-friendliness, and low energy requirements for manufacturing (Breyer et al., 2006). Compared to concrete and metals, wood fits this category well and has consistently been a vital and sustainable building material for load-bearing structural elements. Different species of wood serve different purposes, and specific salient properties, such as wood's bending and mechanical properties, are of immense significance to their use in structural applications (Dinwoodie, 2000). This has created unparalleled exploitation of familiar economic wood species over the lesser-known species, the escalating decline in wood

supply in Nigeria, driven by overreliance on traditional economic wood species and unsustainable logging practices, which have generated considerable concern for more than two decades (Adewole & Bello, 2013). The diminishing availability of familiar wood species encourages the exploration of non-traditional economic wood alternatives (Lucas et al., 2006; Adewole & Bello, 2013). using lesser-known but potentially viable wood species, such as wood sourced from fruit trees, could augment conventional construction materials (Olorunnisola, 2022).
In Nigeria, various trees produce fruits and wood, making them essential resources that offer economic advantages by producing fruits and Timber. (Areo et al., 2023), one such tree species is Mangifera indica. However, there is sparse information on its strength potential as an affordable building material. The mango tree species available in Nigeria are known for having a relatively short trunk with much branching, resulting in a wide-spreading tree structure. This morphological characteristic is common in mango trees for a strong base and gradual taper along the trunk for stability and fruit production (Balamohan et al., 2010).

Although Mangifera indica are fast-growing and can survive for over 100 years before dying (Bally, 2006), with time, they become senescent and less viable in fruiting between 20 to 50 years of fruiting (Hiwale & Hiwale, 2015). Also, land clearing during building and infrastructure construction often results in the felling of Mangifera indica trees, which are typically disposed of or burned. Therefore, exploring ways to add value to this resource is important. According to Areo et al. (2015), the strength values of Mangifera indica were obtained compared with the strength values of other economic species, revealing properties similar to Antiaris africana and Hildergadia bateri. The researchers also observed a significant variation in strength properties along and across the tree (transversely). Rahmon et al., 2019 reported that M. indica timber with a modulus of elasticity of 20573.88MPa is viable in application as a structural member. However, the morphological characteristics of the species available in Nigeria, such as its short trunk, limit the spans that may be producible for structural members. It is therefore important to assess how this limitation of the use of Mangifera indica in construction can be addressed by engineering the material.

Engineered wood products (EWPs) are manufactured composite materials made from hardwoods and softwoods. These products undergo treatment to improve their quality. EWPs include various product categories, production techniques, and applications. EWPs include plywood, laminated veneer lumber (LVL), glued laminated Timber (GLT) and cross-laminated Timber (CLT) (New Nordic Timber, 2019). The traditional cross-section of CLT panels comprises at least three orthogonal layers of boards. Mass timber structures using CLT components are now commonplace for mid- to high-rise buildings up to 30 stories (Brandner et al., 2016).

The US CLT industry is growing, so the CLT product standard (ANSI/APA PRG 320) was created to provide guidelines for producing CLT panels.

Traditionally, softwood timber is used to make CLT panels. However, the forest products industry is working to establish a CLT manufacturing sector that spans the entire nation in response to the growing demand for CLT products in residential and commercial construction. A range of Indigenous species will need to be used for this (Yunxiang et al., 2021). The possible use of hardwood species in CLT products has been the subject of several global investigations.

Ehrhart et al. (2015) and Ehrhart & Brandner (2018) examined several European hardwood species using planar shear tests and demonstrated that they may be used in the production of cross-laminated Timber (CLT). These species included poplar (Populus spp.), silver birch (Betula pendula Roth), European beech (Fagus sylvatica L.), and European ash (Fraxinus excelsior L.).

Focusing on Mangifera indica, a deciduous tree primarily cultivated for its fruits, this research aims to engineer cross-laminated timber beams using this wood species that is not primarily utilised for that purpose. This study seeks to assess the properties of cross-laminated Mangifera indica with a view to expanding the obtainable span from the trunk and enhancing the structural properties of these species by cross-lamination, particularly when loaded in the plane. This study offers innovative solutions to the challenges of wood supply in Nigeria by investigating the viability of Mangifera indica as CLT structural elements. Ultimately, the study contributes to reducing the knowledge gap regarding the usage of deciduous trees for CLT production.

In this paper, Chapter 1 introduces the study's rationale and objectives. Chapter 2 outlines the methods used in constructing CLT and justifies their selection. Chapter 3 presents comparative findings between various CLT panels and solid wood of the same M. indica species, identifying optimal lamination configurations and potential applications for affordable housing. Finally, Chapter 4 summarises the findings, assesses the suitability of M. indica in affordable housing construction, and proposes recommendations for further research.

2 Research Methodology

This project was conducted in five stages to explore the potential *Mangifera indica* as CLT structural elements to address wood supply challenges in Nigeria and reduce the knowledge gap on deciduous tree use in CLT production and affordable housing construction. The first stage was harvesting senescent *Mangifera indica* wood from the University of Ibadan. The second phase was the processing of the *Mangifera indica* cross-laminated and solid specimens, and the third phase involved the material's testing and the recording of results obtained. The fourth phase entailed the design of components of a typical simple Gazebo using available baseline data of *M. indica* wood. The fifth phase was fabricating a scaled-down model of the typical simple gazebo.
At the collection site, the logs were crosscut into billet sizes of 50.8mm thickness, 152.4mm width and about 1219.2 mm length for fabrication of CLT—also 152.4mm thickness, 152.4mm width and 1219.2mm long for the solid beam production. The lumbers were transported to the wood structures workshop at the University of Ibadan, which doubles as the drying site. The green M.C content was taken using the moisture meter and recorded at 26 °C until nearly uniform moisture content was obtained. This reduced moisture variation across samples, which could introduce strength variations. In compliance with PRG-320 (Standards for Performance-Rated Cross-Laminated Timber, ANSI/APA PRG 320, American National Standard, 2012), the moisture content (MC) was reduced to around 12%. The Timber was then visually graded in accordance with the grading rules established by the National Hardwood Timber Association (NHLA). The

density of M. indica wood at dry moisture content was conducted as per ASTM D198 using Equation 1.

$$p_i = \frac{M_i}{V_i} \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (Equation\ 1)$$

Where P_i = density (Kg/m^3), M_i = Mass (kg), V_i = Volume (m^3)

2.1 CLT Manufacturing and Sample Production

The dimensions of the cross-laminated specimen were dimensionalised in compliance with ANSI/APA PRG-320 2019, "Standard for Performance-Rated Cross-Laminated Timber". Altogether, three layers of laminates made the fabrication of CLT in both the major strength direction, which runs parallel to the laminations' strength direction in the panel's outer layer, and the minor strength direction, which runs perpendicular to the inner layers' grain direction and is the major strength direction of the CLT panel.
M. indica wood was cut into plies to enable CLT production. 45 sizes of 31.225 mm x 16.7 mm x 1080 mm and 255 sizes of 60.45 mm x 16.7 mm x 93.675 mm were cut. This produced 10 CLTs, five of which were in the major strength direction and another five in the minor strength direction.
Three 31.225mm x 16.7mm x 1080mm strips were glued edgewise using a one-component urea-formaldehyde adhesive, Top Bond®, to produce the laminates, which were held together using clamps. Ten replicates of this were made for the faces of CLTs. For the second layer, the core of the CLT production, five replicates of 17 pieces of 60.45mm x 16.7mm x 93.675mm were glued together and laid on the concluded faces, ensuring there was no slip during fabrication.
For the faces of the CLT production, 17 pieces of 60.45mm x 16.7mm x 93.675mm were edge glued using one-component top bond adhesive to form a laminate, and ten replicates were made. Three strips of 31.225mm x 16.7mm x 1080mm were held together using clamps, and five replicates were made for the core of the CLTs in this configuration.
Following the dimensioning of the cross-laminated timber specimen, M. indica wood was cut into dimensions of 93.675mm x 50mm x 1080mm. Five replicates were cut and planned to ensure surface smoothness.

2.2 Flexural Property Evaluation

The 4-point loading of the samples was conducted using an Instron® 3366 Universal Testing Machine. Edgewise bending tests were conducted at an average of 11.61% moisture content for test samples of Solid and Cross-Laminated Timber in both major and minor strength directions per the four-point load method at a 5mm/min loading rate. The on-central span length is approximately equal to 18 times the specimen depth. The process of loading continued until the specimen failed. The loading time, mode of failures and maximum load were recorded for each specimen according to the ASTM D198 (Gromala n.d).

Throughout the tests, the load-deflection data for both solid wood and CLT beams were also recorded. The data obtained were used to calculate the modulus of Elasticity and modulus of rupture.

The Modulus of Elasticity (MOE) and Modulus of Rupture (MOR) were calculated using equations 2 and 3, respectively, according to BS 373:1957.

$$MOE = \frac{3P'a\,L^2}{4\Delta' bh^2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.(Equation\ 2)$$

$$MOR = \frac{3P_{max}L}{4bd^2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(Equation\ 3)$$

Where:
Pmax = the Maximum force (Load) obtained from the maximum load sustained at failure (N); P' = load at the limit of proportionality (N). L = the span of the test sample (mm), b = the breadth of the test samples (mm), and d = the breadth of the test samples (mm). a = the distance between the point of application of load and support.

An analysis of variance was carried out for the flexural properties of solid, cross lam (major axis), and cross lam (minor axis) at P=0.05.

An analysis of variance (ANOVA) was conducted on the flexural property values of solid wood, cross-laminated wood along the major axis, and cross-laminated wood along the minor axis at a significance level of P=0.05.

Plate 3.1: (a) Edgewise loading of the Cross-Laminated Timber in the Minor

Figure 3.4: Model of the Edgewise loading of the Cross-Laminated Timber in the

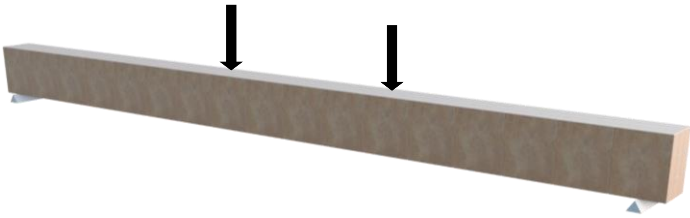
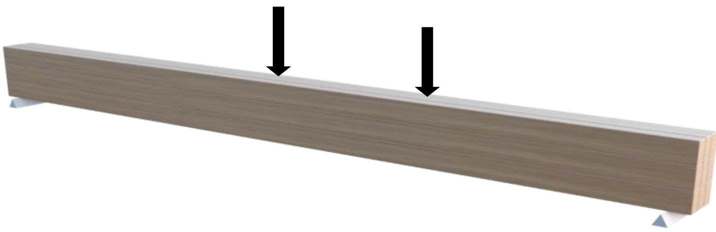


Figure 3.5: Model of the Edgewise loading of the Cross-Laminated Timber in the Major Strength Direction



2.3 Design and Construction of a Gazebo

Using the results of the elastic moduli of M. indica, a Gazebo was designed using the Allowable Stress Design (ASD) method according to Olorunnisola (2018). A 1/10 scaled-down model of the design was fabricated. To satisfy the deflection, bending, and shear criterion for the beam, equations 4, 5 and 6 were used, respectively, along with the baseline data of M. indica obtained from the Wood Database.

$$\frac{L}{180} \geq \frac{5WL^4}{384EI} \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (Equation\ 4)$$

$$\sigma \geq \frac{M}{S} \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (Equation\ 5)$$

$$F_v = \frac{1.5V}{A} \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (Equation\ 6)$$

Where W = uniformly distributed load on the beam (N/mm), L = Span of the beam (mm), E = Modulus of Elasticity (N/mm^2), I = Moment of inertia (mm^4), S = Section modulus, F_V = Shear stress, M = Maximum moment, V = Maximum shear force, A = Area of the beam. As per Equation 5, σ must be greater than $\frac{M}{S}$ for the design to satisfy the bending criterion. Otherwise, a greater trial section or shorter span will be selected, and the design process will be repeated until it satisfies the bending criterion.

Also, for the column calculation, using the modified Euler's formula, the equations used are:

$$\text{Slenderness ratio} = \frac{L_e}{d_{min}} \ldots \ldots \ldots \ldots \ldots \ldots (Equation\ 7)$$

$$k = 0.671 * \sqrt{\frac{E}{\sigma}} \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (Equation\ 8)$$

$$\sigma_c = \frac{0.3 * E}{\left(\frac{L_e}{d_{min}}\right)^2} \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (Equation\ 9)$$

$$\frac{P}{A} \leq \sigma_c \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (Equation\ 10)$$

where Le = Effective length/span (mm), d_{min} = Least lateral dimension (mm), E = Modulus of Elasticity (N/mm^2), σ = Compressive strength (N/mm^2), P = load, and A = cross-sectional area.

As per Equation 10, σ_c must be less than $\frac{P}{A}$ for the design to be safe in compression. Otherwise, a greater trial section or shorter span will be selected, and the design process will be repeated until it satisfies the criterion. The design results were used to construct a scaled-down Gazebo model.

3 Findings and Discussion

The results of moisture content are presented in Table 4.1. The average green moisture content of the lumbers was computed and found to be 27.825%; the average dry moisture content was 10.03%. According to ANSI/APA PRG 320-2019, dry moisture content between ±12% is required to produce Cross-laminated Timber.

Table 1. Moisture Content Test Result

STATISTICAL DATA	Moisture Content (%)
Mean	10.02631579
Median	10
Maximum	12.5
Minimum	7.5
Standard Variation	1.409035172
Coefficient of Variation	14.053461

Table 4.2 summarises the density of M. indica wood at an average dry moisture content of 5.275%, as presented in Appendix 1 and Table 2. The average density was computed to be 579.45 kg/m^3, which shows that M. indica wood is medium-density.

Table 2. Preliminary Density Test Result

STATISTICAL DATA	Density (kg/m^3)
Mean	579.455
Median	600.009
Maximum	662.622
Minimum	434.957
Standard Variation	70.9991
Coefficient of Variation	12.2527

For the densities of the solid and cross-laminated Timber produced, table 3 summarises the results obtained. The density of the solid specimen is higher than that of the CLTs in both configurations. As reported by Rahmon et al., 2019, the higher the density of a material, the higher its strength characteristics; it can be inferred from the results that the flexural strength characteristics of the solid specimen will be higher than that of the Cross-laminated samples.

Table 3. Density Result of Solid and CLT Specimen

Material	Avg Mc (%)	Average Density (Kg/m^3)	Median	Max	Min	Standard Deviation	Coefficient of Variation
Solid	11.04	643.51	644.20	668.75	622.51	19.77	3.07
CLT (Minor)	11.86	602.82	612.82	618.66	569.88	20.83	3.46
CLT (Major)	11.92	593.22	592.83	600.77	583.12	7.70	1.30

3.1 Flexural properties of Solid and CLT Samples

The results of the Modulus of Elasticity and Modulus of Rupture for solid and CLT samples are presented in Table 4 and Table 5, respectively. The solid specimen results

obtained tallies with Rahmon et al., 2019 which reported the modulus of elasticity of M. indica to be 20573.88Mpa. When compared to known species, Xylopia aethiopica has

11951 Mpa, Terminalia ivorensis 4686 Mpa, Neem 4338 Mpa, Vitellaria paradoxa 11136 Mpa, and Hexalobus crispiflorus 4564 Mpa; it was found to be satisfactory to be utilised as timber for utilisation in structural purposes. The results also show that the CLT in the minor strength direction has stronger flexural characteristics than the CLT in the major strength direction when loaded edgewise (loaded in-plane). However, the solid specimen has higher stiffness than CLTs in both configurations

Table 4. Modulus of Elasticity Result of Solid and CLT Specimen

Material	Avg Mc (%)	Mean MOE (N/mm^2)	Median	Max	Min	Standard Deviation	Coefficient of Variation
Solid	11.04	23484.86[a]	25073.49	25731.40	18033.02	3238.83	13.79
CLT (Minor)	11.86	16945.82[b]	16266.86	21076.05	14913.95	2389.66	14.10
CLT (Major)	11.92	13981.73[c]	14007.26	23479.60	1753.54	8057.40	57.63

Mean Moduli of Elasticity with different superscripts are statistically different at P = 0.05

Results presented in Table 5 revealed that solid *M. indica* exhibits higher bending strength properties than the Cross laminated variation when loaded edgewise. Also, the cross-laminated Timber in the minor strength direction exhibits higher bending strength properties than that in the major strength direction when loaded in an edgewise manner. An analysis of variance (ANOVA) was conducted using the flexural property values of solid wood, cross-laminated wood along the major axis, and cross-laminated wood along the minor axis at a significance level of P=0.05. The results indicated that there were statistically significant differences in the flexural properties among the tested specimens. Specifically, the solid wood exhibited the highest strength and stiffness, while the cross-laminated wood along the major axis demonstrated the weakest strength. CLT in the minor strength direction was reduced by 31.2%, and that of CLT in the major strength direction was reduced by 76.8%. The high percentage reduction in load resistance may be attributed to a weaker interfacial bonding along the glue line compared to the natural lignin bonding strength of the solid wood, the specific production techniques employed or the slightly higher moisture content of the CLT samples. Despite this, cross-lamination shows significant promise in enhancing the achievable span of structures made from M. indica wood. This potential makes cross-laminated *M. indica* wood a viable option for constructing simple structures, especially when loaded in the minor axis, where increased span without compromising too much on strength is advantageous. The application of cross-lamination opens new possibilities for utilising M. indica wood more effectively in construction, combining both its natural properties and the benefits of engineered wood products.

Mangifera indica exhibits promising potential to address housing affordability, foster advancements in construction techniques, and promote sustainability within the building sector by mitigating environmental impact and enhancing resource efficiency. Analysis of the investigated Cross-Laminated Timber (CLT) properties underscores *M. indica's* capacity to overcome inherent morphological constraints, albeit with associated processing costs, thus limiting its direct substitution for endangered and scarce timber species, which are progressively scarce and costly. Nonetheless, optimising laminar thickness, glue type, and other relevant processing parameters holds promise for enhancing its efficacy as a structural component in housing applications.

Mangifera indica exhibits promising potential to address housing affordability, foster advancements in construction techniques, and promote sustainability within the building

sector by mitigating environmental impact and enhancing resource efficiency. Analysis of the investigated Cross-Laminated Timber (CLT) properties underscores the potential of *M. indica* to overcome inherent morphological constraints, albeit with associated processing costs, thus limiting its direct substitution for endangered and scarce timber species, which are progressively scarce and costly. Despite the additional processing costs incurred in transforming *M. indica* into CLT to expand obtainable span and width, its comparable strength and availability still render it a feasible option. Nonetheless, optimising laminar thickness and other relevant parameters holds promise for enhancing its efficacy as structural components in housing applications.

Table 5. Modulus of Rupture Result of Solid and CLT Specimen

Material	Avg Mc (%)	Average MOR (N/mm^2)	Median	Max	Min	Standard Deviation	Coefficient of Variation
Solid	11.04	64.91[a]	67.49	83.79	40.37	15.82	24.38
CLT (Minor)	11.86	44.69[b]	57.04	59.51	6.45	22.62	50.61
CLT (Major)	11.92	15.09[c]	16.27	27.34	2.50	10.41	69.02

Mean Moduli of Rupture with different superscripts are statistically different at P = 0.05

For the Gazebo design, all design calculations show that the components meet the requirements to carry the load safely.

Table 6. Beam Design Calculations

Beam Design Calculations	Long Span	Short Span
Load (N/mm)	1.77	1.77
Span (mm)	3657.6	3270
No of Elements	2	2
Factor of Safety	1	1
Width (mm)	125	125
Depth (mm)	150	150

Table 7. Column Design Calculations

Column Design Calculations	
Load (N)	6501.52
Span (mm)	2300
No of Elements	4
Ke	23.89
Effective Length (mm)	2300
Slenderness Ratio	30.67
Width (mm)	434.96
Depth (mm)	71.00

4 Conclusion and Further Research

This study has compared the bending strength properties of solid and CLT of M. indica in both strength directions. The solid specimens were of significantly better flexural properties than the CLT specimens. The flexural strength of the CLTs reduced significantly. Consequent to the results discussed, M. indica are suitable as structural members. It is also evident that solid specimens are more durable than the CLT based on the findings of this study. According to the values obtained from the computed result, M. indica can be classified as the N1 strength group of the NCP 2005, which is the highest strength; this is corroborated by Rahmon et al., 2019.

Future studies should research the development of Standards for performance–rated cross-laminated timber made from hardwoods, as the present standard, the ANSI standard used, focuses on softwood species. Also, further research should be conducted on the influence of adhesive type on the strength of cross-laminated Timber made from M. indica.

It is recommended that delamination tests be conducted to ascertain the glue line strength and how it influences the strength of the laminate. Hot pressing with more pressure and loading of M. indica out of the plane, that is, flatwise bending, could be experimented with.

5 References

Adewole, N. A., and Bello, K. O., 2013. Recycling of Bamboo (Bambusa Vulgaris Schrad) recovered from the scaffold into material for furniture production.

ANSI/APA PRG-320, 2019. Standard for Performance-Rated Cross-Laminated Timber.

APA, Standard for performance-rated cross laminated Timber, ANSI/APA PRG320-2019, Tacoma, WA, 2019.

Areo, O. S., Adejoba, O. R., & Omole, O. A. 2015. Influence of Mechanical Properties on Utilisation Potential of Mangifera indica L. Wood for Furniture Industries.

Areo, O. S., Omole, A. O., Adejoba, A. L., Oyewumi, O. R., & Nduagubam, C. E., 2023. Utilisation Potentials of Forest Fruits Trees for Wood Production. *Pro Ligno*, 19(2).

Balamohan, T.N., Mekala, P., Rajadurai, S., Priyadharshini, G., Prakash, K., Soorianathasundaram, K., & Kumar, N. 2010. Canopy Management in Mango. *Horticultural College and Research Institute*, Tamil Nadu Agricultural University.

Bally, I.S., (2006). Mangifera indica (mango). Species profiles for Pacific Island agroforestry, pp.1–25

Brandner, R., Flatscher, G., Ringhofer, A., Schickhofer, G. and Thiel, A., 2016. Cross laminated Timber (CLT): overview and development. *European Journal of Wood and Wood Products*, 74, pp.331-351.

Breyer, D.E., Fridle, K.J., Cobeen, K.E., Pollock, D.G. (2006). *Design of Wood Structures*.

Dinwoodie, J. M. (2000). Timber: its nature and behaviour. *CRC Press*.

Ehrhart, T., Brandner, R., Schickhofer, G. and Frangi, A., 2015. *Rolling shear properties of some European timber species with focus on cross laminated timber (CLT): test configuration and parameter study*. In International Network on Timber Engineering Research: Proceedings of Meeting 48 (Vol. 2015, pp. 61-76). Timber Scientific Publishing, KIT Holzbau und Baukonstruktionen.

Gromala, DS. (n.d.). "Determination of Modulus of Rigidity by ASTM D 198 Flexural Methods." *Journal of Testing and Evaluation* 13:5, pp. 352 55. https://doi.org/10.1520/JTE10961J.

Hiwale, S., & Hiwale, S. (2015). Mango (Mangifera indica L.). Sustainable Horticulture in Semiarid Dry Lands, 97-114.

Lucas, E.; Olorunnisola, A. and Adewole, N. 2006. Preliminary evaluation of Psidium guajava Tree Branches for Truss Fabrication in Nigeria. *Agricultural Engineering International: the CIGR Ejournal*. Manuscript BC05010. 11pp.

NCP 2005. Nigerian code of practice for structural timber design. The Standards Organisation of Nigeria.

New Nordic Timber, "Engineered wood products," 2019. https://newnordictimber.com/articles/engineered-wood-products. View at: Google Scholar.

Olorunnisola A. O., 2022. The Past, Present, and Future Outlook of the Wood Industry in Nigeria. *Intech Open*. DOI: http://dx.doi.org/10.5772/intechopen. pp. 105794.

Olorunnisola, A. O., 2018. Design of structural elements with tropical hardwoods. *Springer International Publishing*.

Rahmon, R. O., Jimoh, A. A., Babatunde O. Y., 2019. *Evaluation of Strength Classes of Two Selected Less-Used Nigerian Timber Species for Structural Applications*. International Conference on Engineering and Environmental Sciences, Nigeria.

Ehrhart, T., & Brandner, R. 2018. Rolling shear: Test configurations and properties of some European soft-and hardwood species, *Eng. Struct*. 172, 554–572.

The U.S. Edition of the CLT Handbook edited by Ero! Karacabeyli, Brad Douglas., 2013.

Yunxiang, M., Ruizhe, S., Musah, M., Dai, Q., Xie, X., Wang, X., & Ross, R.J., (2021). "Integrated experimental and numerical study on flexural properties of cross-laminated timber made of low-value sugar maple lumber". *Construction and Building Materials* 280. 122508.

Compressive Strength, Water Absorption and Thermal Performance of One-part Geopolymer Concrete-based Alternative Masonry Units

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Abstract:
The reliance on conventional clay and cement-based masonry units in South Africa has demonstrated unfavourable environmental impacts while failing to meet the country's affordable housing (AH) demands. The need for alternative building technologies is critical to addressing the current delivery backlog of AH and achieving sustainability. This work explored the development of an alternative solid maxi concrete block through one-part geopolymer chemistry. The fly ash-blast furnace slag (FABS) and the fly ash-metakaolin (FAMK) based one-part geopolymer concrete alternative masonry unit (AMU), activated by solid sodium hydroxide, powdered calcium hydroxide and solid sodium metasilicate pentahydrate, were developed and evaluated for compressive strength, water absorption, initial rate of absorption (IRA), and thermal performance. A 28-day compressive strength of 18.4 MPa and 6.1 MPa is obtained for the FABS and FAMK units, respectively. Furthermore, a 5.4% and 9.6% cold water absorption, 8.3% and 10% boiled water absorption, 0.2 kg/m²/min and 0.3 kg/m²/min IRA, and thermal resistance (R-value) of 0.11 m²°C/W and 0.13 m²°C/W are found for the FABS and FAMK unit, respectively. These results show that both AMUs have the potential to be used in achieving sustainable construction.

Keywords:
Compressive strength, One-part geopolymer concrete alternative masonry unit, Thermal performance, Water absorption.

1 Introduction

For many years, Masonry has served as a valuable construction material in developing human settlements. However, producing conventional clay and concrete-based masonry has brought challenges against sustainable development, primarily due to the high carbon footprint associated with the clay firing and the limestone calcination operations. In addition to the adverse environmental impacts associated with conventional masonry, its application in affordable housing (AH) schemes has created a housing delivery backlog that is concerning due to both material and land prices. The development of low-carbon alternative masonry units (AMUs) incorporating alternative masonry materials should be considered to address both environmental concerns and inadequate AH delivery targets. Such a candidate, which is considered in this work, is the geopolymer.

Geopolymers are formed through the synthesis of rich aluminosilicate materials by high alkaline reagents whereby a three-dimensional aluminosilicate network structure is formed, having great potential to replace cement as they possess high mechanical strength, good thermal properties, and excellent durability (Cong & Cheng, 2021). Geopolymer cement entails the alkali activation of rich aluminosilicate materials such as typical industry wastes comprising fly ash (FA), ground granulated blast furnace slag (GGBFS) and metakaolin (MK). Such supplementary cementitious materials (SCMs) have been used

in partial cement replacement to reduce conventional cement production and minimise global industry waste disposal. Also, geopolymer cement is frequently produced using the non-user-friendly and prolonged two-part preparation approach. In contrast, the more user-friendly and quicker one-part preparation approach is used less. Furthermore, geopolymers containing FA and MK are predominantly heat-cured instead of ambient cured like the FA and GGBFS blend.
Hence, this work was limited to the exploration of the one-part preparation approach utilising solid alkali reagents comprising solid sodium hydroxide, powdered calcium hydroxide and solid sodium silicate pentahydrate in the development of the fly ash-ground granulated blast furnace slag (FABS) based and the fly ash-metakaolin (FAMK) based geopolymer concrete masonry unit cured under ambient condition. Specifically, the 290 mm long × 240 mm wide × 90 mm high maxi concrete brick alternative was only evaluated for compressive strength, water absorption and thermal performance.

2 Literature Review

2.1 Overview of Affordable Housing in South Africa

The presence of informal settlements in South Africa has been of major concern. Previous reports have indicated that as of 2022, over 2700 informal settlements were present in South Africa (Human Settlements | South African Government, 2024). More recent reports show that 12% of South African households reside in informal dwellings, with these informal dwellings mainly concentrated in Gauteng and Western Cape (Human Settlements | South African Government, 2024). In terms of the Constitution of the Republic of South Africa of 1996, the Department of Human Settlements is mandated to establish a sustainable national housing development process with a focus on creating integrated and transformed human settlements, upgrading informal settlements, and providing AH units (Human Settlements | South African Government, 2024).

AH units are typically constructed as Category 1 single-storey buildings. Category 1 buildings were introduced in South Africa to regulate the requirements of buildings in low-income communities so that the health and safety risks associated with unregulated informal settlements are addressed. These buildings are generally smaller in size and occupancy and have lower performance level allowances relating to serviceability than non-Category 1 buildings (De Villiers, 2019).

However, many South Africans who have qualified for state subsidised housing are still without the adequate housing as initially promised to them. Despite a steady increase in government subsidised housing, the main factors affecting AH delivery encompass high building and material costs, lack of suitable land, and increased land prices (Kota-Fredericks, 2013). Kota-Fredericks (2013) encourages the implementation of alternative development strategies so that these challenges may be addressed. Further investigations into alternative building materials, such as developing alternative masonry units (AMUs), may pave the way for reducing materials costs and increasing AH delivery.

2.2 Environmental Impact of Conventional Masonry

In the context of affordable housing (AH) in South Africa, the two common masonry units used for its construction comprise either the solid maxi concrete block, with dimensions of 290 mm long × 140 mm wide × 90 mm high, or the hollow concrete block, with

dimensions 390 mm long × 140 mm wide × 190 mm high (De Villiers, 2019). The 222 mm long × 106 mm wide × 73 mm high imperial clay brick is also used.

However, clay bricks contribute heavily to carbon dioxide (CO_2) emissions, particularly during their firing stage, whereby the clay material is heated at high temperatures and pressures. The greenhouse gas (GHG) emissions contributing to the environmental burden created by the clay brick industry thus primarily stem from intensive energy consumption through the utilisation of fossil fuels (Kumbhar et al., 2014). Moreover, the production line of concrete masonry units (CMUs) also encompasses significant greenhouse gas emissions attributed to Ordinary Portland cement (OPC) production, which contributes approximately 8% toward global anthropogenic CO_2 emissions primarily due to the calcination of limestone (Hajimohammadi & van Deventer, 2017). The need for AMUs to comply with prescribed performance standards is thus pertinent to the problem.

2.3 Performance Requirements of Masonry Units

2.3.1 Compressive Strength

As per SANS 10400-K (2011), the average compressive strength of solid masonry units for use in a single-storey or the upper-storey of a double-storey building should be at least 4 MPa.

2.3.2 Water Absorption

Water absorption characteristics influence the long-term durability of masonry units. As per IS 2185-1 (2005), a maximum water absorption limit of 10% is stipulated for concrete masonry units. Additionally, SANS 10164-1 (1980) stipulates an IRA between 0.7 and 1.8 $kg/m^2/min$ for adequate mortar and unit bonding.

2.3.3 Thermal Performance

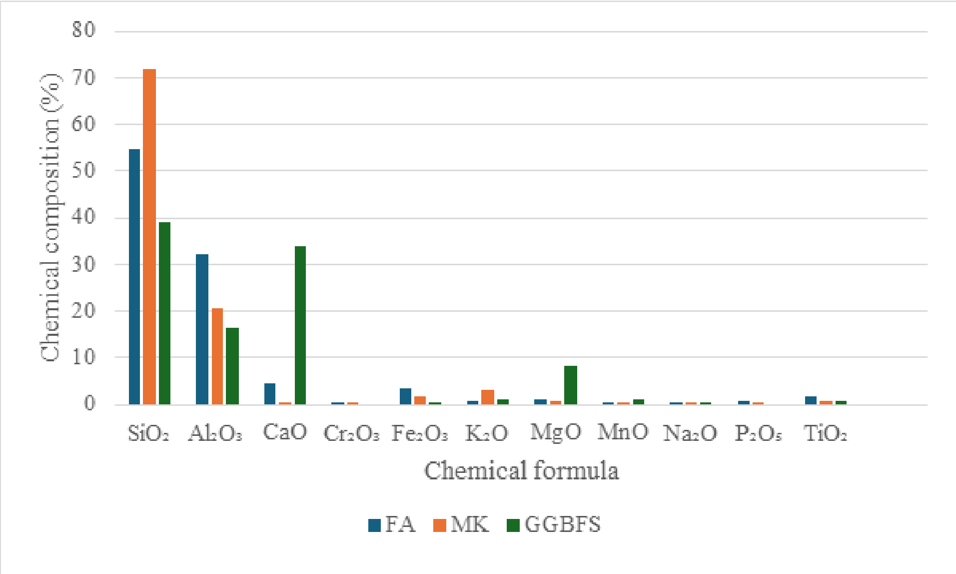
In addition to the thermal conductivity (K-value), the most important thermal property for masonry walling systems is its thermal resistance (R-value), as it describes the ability of the material to resist the transmission of heat flow through the material. This is an essential property during extreme hot and cold periods where sufficient insulation is required for thermal comfort. As per Table 6 and Table 7 in SANS 10400-XA (2021), a minimum R-value is required for walls with a surface density equal to and greater than 270 kg/m^2 or less than 270 kg/m^2, respectively, depending on the energy zone in which the building is located. However, these R-values only apply to non-Category 1 buildings but may be used for comparison.

3 Research Methods

3.1 Materials

The aluminosilicate precursors used in this work comprise Class F FA, GGBFS and MK. The FA, GGBFS, and MK were sourced from Lafarge Pty (Ltd), Western Cape, Meyerton PPC factory, Gauteng, and Kaolin Group Pty (Ltd), Cape Town, respectively. The aggregates comprising natural fine Malmsbury sand and 13 mm Greywacke stone were sourced from GH Building Supplies, Stellenbosch, Western Cape, South Africa. The chemical composition of each precursor was characterised at the Central Analytical Facility (CAF) of Stellenbosch University using X-ray fluorescence (XRF) analysis and is shown in Fig. 1. The XRF results show an abundance of silica and alumina in FA and MK. In contrast, GGBFS shows richness in silica, alumina, and calcium. The chosen solid alkali activators were solid NaOH pellets, powdered ($Ca(OH)_2$) and solid $Na_2SiO_3.5H_2O$, sourced from KIMIX Chemical and Laboratory Supplies, Cape Town, South Africa.

Fig. 1: Percent chemical composition of materials



3.1 Experimental Methods

3.3.1 Mixing, Casting, and Curing

The final mix proportions for both units are shown in Table 1. The one-part mixing procedure, otherwise known as the "just add water" method, was followed during the making of both the FABS and FAMK units. This specific procedure reduces the risks of handling large quantities of alkaline reagents. For the production of both combinations, dry ingredients comprising the selected precursors, solid alkali activators of powdered $Ca(OH)_2$ and solid $Na_2SiO_3.5H_2O$, natural fine Malmesbury sand (a relatively coarse natural sand) and 13 mm Greywacke stone were mixed for 2 minutes. The solid NaOH pellets could not be added to the dry ingredients without first dissolving the pellets in water, as this would result in wasted and unreacted NaOH, with subsequent limited precursor dissolution during mixing. Therefore, the water for mixing constituents was used to dissolve the NaOH pellets and added to the dry ingredients. Afterwards, the wet ingredients were mixed for an additional 2 minutes. The aggregate-to-binder ratios used in the formulations were chosen to maximise the use of South Africa's industrial waste products.

Additionally, the activator dosages and ratios were arrived at based on the precursor requirement, requiring a higher dosage for the FAMK unit than the FABS unit, as MK typically contains more reactive species. Furthermore, as the FAMK combination is low in calcium, a higher $Ca(OH)_2$ dosage was required for reactivity. After mixing, the wet geopolymer concrete mixes were cast in 290 mm long × 140 mm wide × 90 mm high prismatic wooden moulds whilst undergoing compaction on a vibrating table. The units were thereafter left to cure in a climate-controlled room under ambient temperature conditions of 23±2 °C to the desired curing age.

Table 1. Mix proportions for the two masonry unit types

Constituents (kg/m³)	**FABS**	**FAMK**
Water	206	240
Fly ash	321	200
Ground granulated blast furnace slag	214	-
Metakaolin	-	200
Malmsbury fine sand	963	961
13 mm Greywacke stone	642	641
Superplasticizer	3	4
Powdered calcium hydroxide	12	58
Solid sodium hydroxide pellets	12	7
Solid sodium metasilicate pentahydrate	29	15
Total	2402	2326

FABS: Fly ash and ground granulated blast furnace slag-based unit.
FAMK: Fly ash and metakaolin-based unit.

3.3.2 Compressive Strength

The 290 mm long × 140 mm wide × 90 mm units were tested for compressive strength on their bed face, chosen to simulate loading in the orientation in which they will be erected during construction. Six units were tested at 7 and 28 days in accordance with BS EN 772-1 (2011) on a 2-meganewton Instron testing machine with steel plates placed above and beneath the unit, as shown in Fig 2. A 1 mm/min loading rate was used so that the maximum load could not be reached within 1 minute of testing.

Fig. 2: Compressive strength test

3.3.3 Water Absorption

The water susceptibility of each unit was characterised by testing the water absorption in both cold water and boiled water submerged conditions. Additionally, the IRA for both units was measured. Six units were tested for the FABS and FAMK units. The water absorption in cold water temperature conditions, as shown in Fig. 3a, was carried out to determine the water content mass expressed as a percentage of initially dry units after a 24-hour submersion test in accordance with IS 2185-1 (2005). The water absorption in boiled water temperature condition, as shown in Fig. 3b, was carried out to determine the water content mass expressed as a percentage of initially dry units after 5 hours of submersion in boiled water, which was followed by 19 hours of submersion in the same water that was allowed to cool to room temperature by natural loss of heat, totalling a 24-

hour testing duration, tested in accordance with BS EN 772-2 (1998). The IRA test, as shown in Fig. 3c, was carried out to measure the initial rate of capillary suction of the

masonry units by submersing the units at a depth of 5 mm over a submersion time of 1 minute tested in accordance with (BS EN 772-11), (2011).

Fig. 3: Water absorption tests. (a) cold water, (b) boiled water, (c) IRA

3.3.4 Thermal Performance

The thermal properties investigated in this work comprise the K-value and the R-value of a 1 m X 1 m wall for both the FABS and FAMK units. As shown in Fig. 4, a guarded hotbox set-up, designed and tested according to the requirements of ASTM C1363-11 (2011), was used whereby the wall specimen was enclosed in the middle compartment by the metering chamber on the left (set to a temperature of 30 °C) and the climatic chamber on the right (set to a temperature of 5 °C). These temperatures were selected to simulate a high-temperature gradient and, therefore, investigate the insulation capability of the AMUs in such environments. The test was run for about 2 hours, with thermocouples connected around the apparatus and on either side of the specimen, which recorded the steady state temperatures throughout the test. From these readings, the K-value and R-value are determined.

Fig. 4: Guarded Hotbox set-up

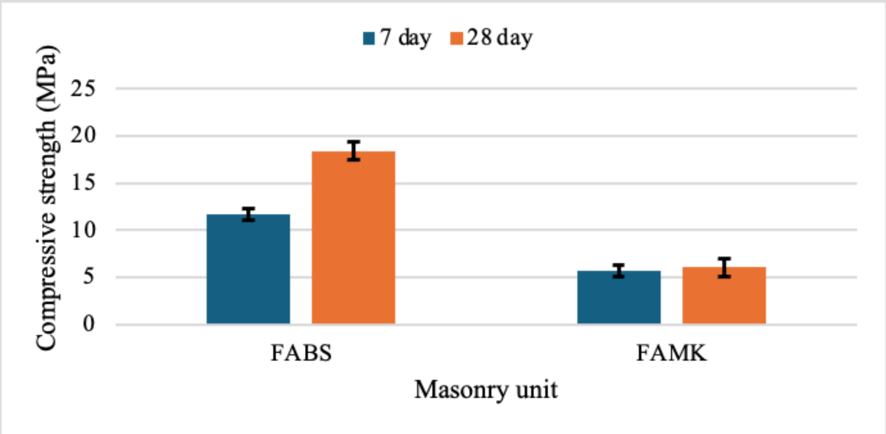
4 Findings and Discussion

4.1 Compressive Strength

The 7 and 28-day compressive strength for both units is presented in Fig.5. The 7-day strength for the FABS unit is 11.7 MPa, and the 28-day strength is 18.4 MPa. A high gain in strength of 58% is thus observed for the unit between its 7 and 28-day age. This is similar to studies in the literature, which have reported a strength gain ranging between 57 and 83% between the 7 and 28-day age for an FA-slag-based geopolymer concrete blend (Deb et al., 2013). The rate of development of strength gain is attributed to the presence of the slag and its calcium bearing compounds, which subsequently contribute to the development of the calcium silicate hydrate (CSH) gel in combination with the geopolymeric gel (Qin et al., 2022).

Moreover, the 7-day and 28-day strength of the FAMK unit is 5.69 MPa and 6.07 MPa, respectively, thus showing no considerable increase in strength between each age. The FAMK unit is a low calcium blend, so elevated curing is typically needed to accelerate the geopolymerisation process and gain strength. However, the calcium content from the $Ca(OH)_2$ assists in the strength development of low-calcium blends (Qin et al., 2022). Hence, both units comply with the minimum required compressive strength of 4 MPa for solid masonry units in single-storey buildings, thus showcasing its potential as an AMU in applying Category 1 single-storey buildings for AH.

Fig. 5: Compressive strength results. FABS: Fly ash-ground granulated blast furnace slag-based unit, FAMK: Fly ash-metakaolin-based unit



4.2 Water Absorption

The water absorption in cold and boiled conditions is presented in Table 2. The FABS unit showed a cold and boiled water absorption of 5.4% and 8.3%, respectively. The cold-water absorption result is comparable to those obtained in the literature, where studies have reported values between 1.0 and 3.25% for FA-slag-based geopolymer blends (Bellum et al., 2022). They attribute the low water absorption to the reduced porosity of the matrix due to the crystalline binding phases developed from the slag. Similarly, for the FAMK unit, a cold water absorption of 9.6% was attained, which can be primarily attributed to the calcium content from the $Ca(OH)_2$. Additionally, the higher boiled water absorption results of 8.3% and 10% for the FABS and FAMK units, respectively, are understandable as hotter fluids are thinner and have more particle kinetic energy to propagate through the voids. These results, however, are acceptable for concrete masonry units as the water absorption does not exceed 10%. The IRA for the FABS and FAMK units was 0.2 kg/m²/min and 0.3 kg/m²/min, respectively. The IRA is an important property of masonry units that indicates the rate of capillary suction within the initial stages in wet environments. This property is important when considering the masonry unit and mortar joint interface. A high IRA indicates high suction of the masonry unit from the adjacent mortar joint, subsequently affecting the mortar joint hydration process and thus weakening the bond. As per SANS 10164-1 (1980), an acceptable IRA for masonry units should fall between 0.7 and 1.8 kg/m²/min. The IRA obtained for both units in this work is thus lower than the specified range. However, this is still favourable as it is low enough not to influence the bond between the unit and mortar. Hence, these results showcase promising serviceability and durability against external factors when applying Category AH units.

Table 2: Water Absorption and IRA Results

Masonry unit	FABS	FAMK
Cold water absorption (%)	5.4	9.6
Boiled water absorption (%)	8.3	10.0
IRA (kg/m²/min)	0.2	0.3

4.2 Thermal Performance

The K-value and the R-value of each FABS and FAMK 1m × 1m wall are presented in Table 3. Additionally, the dry density of both units is also given. The FABS unit obtained 1.31 W/m°C and 0.11 m²°C/W for thermal conductivity and thermal resistance, respectively. The FAMK unit obtained 1.04 W/m°C and 0.13 m²°C/W for thermal conductivity and thermal resistance, respectively. Moreover, heat conductance through a material is directly linked to its density, as denser materials have more particle interaction, increasing heat transmission through the material. Given that the FABS unit exhibits a higher density, it has a higher K-value and lower R-value. Conversely, the FAMK unit, with its lower density, exhibits a correspondingly lower K-value and a higher R-value.

As per Table 6 in SANS 10400-XA (2021), the minimum required R-value for walls having a surface density equal to or greater than 270 kg/m² should be either 0.4 m²°C/W or 0.6 m²°C/W, depending on the energy zone. Similarly, Table 7 in SANS 10400-XA (2021) stipulates a minimum required R-value of either 1.9 m²°C/W or 2.2 m²°C/W for walls with a surface density less than 270 kg/m², depending on the energy zone. Considering the geometry of the wall specimen in this study, the recorded dry densities of the units and the dry density of a standard masonry mortar mix obtained from Thamboo et al. (2019), the surface density for each wall, as presented in Table 3, was obtained. These surface densities thus classify both walls under Table 6 in SANS 10400-XA (2021).

The results, however, exhibit unsatisfactory R-values for both units, not meeting the minimum requirement of either 0.4 m²°C/W or 0.6 m²°C/W for walls situated in the different energy zones of South Africa. These minimum required R-values, however, are specifically for non-Category 1 buildings. The only requirement for single-leaf walls of Category 1 buildings is the minimum thickness requirement of 140 mm. Hence, there is no minimum required R-value set for Category 1 buildings.

However, in comparison to conventional masonry units in South Africa, as given in Table 4, the hollow concrete block, the solid clay brick and the solid concrete brick possess a K-value of 0.98 W/m°C, 0.82 W/m°C and 1.4 W/m°C, respectively (Aerated Autoclaved Concrete Blocks Cape Town South Africa | Aertec, 2024). Additionally, the hollow concrete block, the solid clay brick and the solid concrete brick possess an R-value of 0.09

m²°C/W, 0.13 m²°C/W and 0.08 m²°C/W, respectively (Aerated Autoclaved Concrete Blocks Cape Town South Africa | Aertec, 2024). The R-value of 0.11 m²°C/W for the FABS unit is similar to the imperial clay brick and better than the imperial concrete brick and hollow concrete block. In comparison, an R-value of 0.13 m²°C/W for the FAMK unit is identical to the imperial clay brick and better than the imperial concrete brick and hollow concrete block. Hence, these results showcase the potential of these AMUs to achieve adequate thermal comfort for occupants in AH units. However, it should be noted that the thermal properties depend on the material's thickness. Hence, despite an improvement in R-value, it may still not indicate an improvement over conventional masonry as the walls tested in this study had their units orientated on their bed face as erected in construction, thus having a wall thickness of 90 mm. In contrast, the thickness of the conventional masonry units in Table 4 are slightly different.

Table 3: Dry density of wall components and thermal properties of walls

Masonry wall component	**Dry density of component (kg/m³)**	**Constructed wall surface density, including mortar (kg/m²)**	**Wall K-value (W/m°C)**	**Wall R-value (m²°C/W)**
FABS unit	2017.81	465.8	1.31	0.11
FAMK unit	1903.46	455.7	1.04	0.13
Mortar	2022.0 (Thamboo et al., 2019)	-	-	-

Table 4: Thermal properties of conventional masonry (Aerated Autoclaved Concrete Blocks Cape Town South Africa | Aertec, 2024).

Conventional masonry unit	**Thickness (mm)**	**K-value (W/m°C)**	**R-value (m²°C/W)**
Hollow concrete block	140	0.98	0.09
Imperial clay brick	106	0.82	0.13
Imperial concrete brick	106	1.4	0.08

5 Conclusion

The FABS and FAMK-based geopolymer concrete AMU, activated by solid NaOH, powdered $Ca(OH)_2$ and solid $Na_2SiO_3.5H_2O$, was developed in this work and tested for its compressive strength, water absorption, and thermal performance. After investigation, the following conclusions are drawn.

1. Both units comply with the minimum required compressive strength of 4 MPa for solid masonry units intended for single-storey masonry structures.
2. Both units showcase acceptable water absorption characteristics.
3. The walling systems comprising each AMU type do not meet the required R-value for adequate energy efficiency in buildings. However, the AMUs produced in this work still show promising results when compared to conventional clay and concrete masonry units with an improvement in R-value.

While conventional clay—and cement-based masonry units may meet performance requirements in Category 1 buildings, their contribution to environmental issues and delays in AH delivery is of concern. Alternatives such as the FABS and FAMK units produced in this work are promising as they can satisfy strength, durability, and thermal requirements, thus potentially replacing conventional masonry materials and mitigating environmental impacts and AH delivery shortages.

6 References

Aerated Autoclaved Concrete Blocks Cape Town South Africa | Aertec. (2024). https://www.aertec.co.za/

Bellum, R. R., Al Khazaleh, M., Pilla, R. K., Choudhary, S., & Venkatesh, C. (2022). Effect of slag on strength, durability and microstructural characteristics of fly ash-based geopolymer concrete. *Journal of Building Pathology and Rehabilitation*, 7(1). https://doi.org/10.1007/s41024-022-00163-4

BS EN 772-1. (2011). Methods of test for masonry units Part 1: Determination of compressive strength.

BS EN 772-2. (1998). Methods of test for masonry units Part 7: Determination of water absorption of clay masonry damp proof course units by boiling in water.

BS EN 772-11. (2011). Methods of test for masonry units Part 11: Determination of water absorption of aggregate concrete, autoclaved aerated concrete, manufactured stone and natural stone masonry units due to capillary action and the initial rate of water absorption of clay masonry units.

Cong, P., & Cheng, Y. (2021). Advances in geopolymer materials: A comprehensive review. *Journal of Traffic and Transportation Engineering* (Vol. 8, Issue 3, pp. 283–314). Chang'an University. https://doi.org/10.1016/j.jtte.2021.03.004

De Villiers, W. I. (2019). Computational and experimental modelling of masonry walling towards performance-based standardisation of alternative masonry units for low-income housing. https://scholar.sun.ac.za

Deb, P. S., Nath, P., & Sarker, P. K. (2013). Properties of fly ash and slag blended geopolymer concrete cured at ambient temperature.

Hajimohammadi, A., & van Deventer, J. S. J. (2017). Characterisation of one-part geopolymer binders made from fly ash. *Journal of Waste and Biomass Valorization*, 8(1), 225–233. https://doi.org/10.1007/s12649-016-9582-5

Human settlements | South African Government. (2024). https://www.gov.za/about-sa/humansettlements

IS 2185-1. (2005). Concrete masonry units, Part 1: Hollow and solid concrete blocks.

Kota-Fredericks, Z. (2013). Deputy Minister Zou Kota-Fredericks: South Africa Nederlands research programme on alternatives in development conference | *South African Government*. https://www.gov.za/news/speeches/deputy-minister-zou-kota-fredericks-south-africa-nederlands-research-programme

Kumbhar, S., Kulkarni, N., Rao, A. B., & Rao, B. (2014). Environmental life cycle assessment of traditional bricks in western Maharashtra, India. *Journal of Energy Procedia*, 54, 260–269. https://doi.org/10.1016/j.egypro.2014.07.269

Qin, Y., Qu, C., Ma, C., & Zhou, L. (2022). One-part alkali-activated materials: State of the art and perspectives. Journal of Polymers (Vol. 14, Issue 22). *MDPI*. https://doi.org/10.3390/polym14225046

SANS 10400-K. (2011). The application of the national building regulations. Part K, walls. (3rd ed.). *SABS Standards Division*.

SANS 10400-XA. (2021). The application of the national building regulations. Part XA: Energy use in buildings. *South African Bureau of Standards (SABS)*.

SANS 10164-1. (1980). The structural use of masonry. Part 1: Unreinforced masonry walling. *SABS Standards Division*.

ASTM C1363-11. (2011). Standard test method for thermal performance of building materials envelope assemblies by means of a hot box apparatus. *ASTM international*.

Thamboo, J., Jayarathne, N., Bandara, A. (2019). Characterisation and mix specification of commonly used masonry mortars. *Journal of Applied Sciences*. https://doi.org/10.1007/s42452-019-0312-z

ANNEXES

WE AIM TO PRODUCE GRADUATES WHOSE QUALIFICATIONS ARE INTERNATIONALLY RECOGNISED AND LOCALLY APPLICABLE, UNDERPINNED BY VALUES OF ENGAGED CITIZENSHIP AND SOCIAL JUSTICE