Reshaping Africa's Sustainable Future through 3D Printing

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Abstract. Africa faces a significant sustainable development crisis characterized by rapid urbanization, population growth, and poor housing conditions. Traditional construction methods usually do not support innovative technologies, resulting in housing shortage and inadequate home conditions. Construction 3D Printing emerges as a promising solution aligned with global initiatives for climate resilience and reduced ecological impact. This paper provides some insights on recent 3D printing technology advancements in African construction projects, with a focus on earth-based materials and sustainability. This work highlights the paradigm shift from traditional construction techniques to construction innovation driven 3DP solutions, particularly the potential to use earthen materials for 3D printing, this way boosting Africa's sustainable development, driving construction productivity and circularity. and ultimately fostering urban sustainable development and African living standards.

Keywords: Construction 3D Printing, Africa digital revolution, Urban Sustainable Development. Earth-based materials

1 Introduction

Africa stands as a well-equipped continent for economic development, supported by favourable factors for sustainable growth and prosperity (Ofori et al., 2023). Africa holds the foundation for a robust economic activity, with its abundant natural resources, including key minerals, fertile land, and renewable energy sources. The continent's rapidly growing population, characterized by an expanding youth demographic trend, represents an impressive workforce to drive innovation, entrepreneurship, and productivity. Coupled with a vibrant entrepreneurial spirit and a growing consumer market driven by a fast urbanization and expanding middle-class segments, Africa offers fertile ground for investment and business expansion (Gaglio et al., 2022). Promising efforts for infrastructure development, regional integration, and institutional reforms emphasize the commitment to creating a nurturing environment for economic growth. However, the African continent faces a persistent and complex housing crisis defined by a deficit in affordable housing, substandard living conditions in informal settlements, and a growing urban population. The housing dilemma on the continent underlines an urgent unease by the present slow construction processes, and significant

waste, notably inside low-income housing population (Mahachi, 2021). Sadly, a deficiency in technical expertise and awareness on innovative construction methodologies has hampered the efficacy of African construction sector in tackling these difficulties.

Digital fabrication, aligned with Industry 4.0 practices, is pivotal for advancing the construction sector in Africa (Fahfouhi et al., 2023). Industry 4.0, often called the fourth industrial revolution, implies the integration of digital technologies, automation, and data exchange in manufacturing and other industries. In a comprehensive review of the adoption of 3D Printing (3DP) by the African construction sector, Moghayedi et al. (2024) stress the crucial role of 3DP as a sustainable building solution in Africa by optimising resource use, improving efficiency and productivity, and ensuring high precision in building performance. Furthermore, when coupled with 3DP technology, the automatisation of construction practices can significantly enhance the feasibility and effectiveness of using local earth-based materials for construction projects (Perrot et al., 2018). 3DP in construction offers a revolutionary approach, enabling the fabrication of building components layer by layer, reducing construction times and minimising material waste and labour costs (Ma et al., 2022). In a review on construction 3D printing in Africa, mainly in Morocco, South Africa, and Kenya, Fahfouhi et al. (2023) highlight the initiatives incorporating local earth-based materials, such as adobe or rammed earth, into 3DP processes aligned with sustainability principles, promoting economic empowerment within local communities. The benefits of this approach are comprehensive, including:

1. Reduced dependency on imported construction materials, thereby supporting local economies and fostering self-sufficiency;
2. Adopting earth-based materials reduces the environmental impact associated with traditional construction methods, contributing to Africa's efforts towards sustainable development;
3. Integration of robotics and 3DP technology enhances construction quality and efficiency, improving housing conditions and infrastructure across the continent.

The integration of 3DP into construction can assist in lessening Africa's housing crisis and rapid urban growth, as highlighted through various transformative initiatives across the continent. South Africa's MedAdd project, Nigeria's Stampar3D, and Togo's Woelab Lomé demonstrate the versatile application of additive manufacturing in addressing local challenges and fostering innovation. The implementation of projects like the University of Johannesburg's 3D Printed Houses and The Gambia’s 3D Printing Farm, show the potential of 3DP to revolutionise traditional industries and create sustainable solutions for critical socio-economic needs (AfricaLive, 2024). Other initiatives, such as Metal Heart and Iroko by 14Trees, point out a concerted effort towards leveraging 3DP technology to drive economic development and social progress (Gadzala, 2018). Thus, embracing these innovative practices can represent a transformative opportunity for Africa's construction industry, driving economic growth while promoting environmental sustainability and social development.

There is an increased need to implement technological innovation into the building sector in the design and construction of affordable housing, mainly due to the persisting demands for adequate housing conditions and sustainable building solutions, there is

an increased need to implement technological innovation into the building sector in the design and construction of affordable housing. Although the benefits of 3DP technology are apparent, its applicability and viability within the African context must yet be established. This paper seeks to explore the potential of 3DP technology in facilitating cost-effective housing solutions in Africa, assessing its practicality regarding traditional construction techniques.

2 Affordable housing crisis in Africa

Rising interest rates and the pandemia hampered house affordability worldwide, African Housing crisis and affordability challenges are a prevalent global issue, as rising interest rates and the pandemia hampered housing affordability worldwide,

However, as abovementioned, Africa faces unique circumstances shaped by rapid urbanisation, fast population growth, and economic disparities. According to the UN-Habitat, the continent's urbanisation rate increased from 15% in 1960 to 40% in 2010, and it is expected to reach 60% by 2050, deeply reshaping its landscape. This exponential urban increase is set to triple Africa's urban populations over the next 50 years, amplifying the demand for affordable housing (UN-Habitat, 2023). The Centre for Affordable Housing Finance in Africa (CAHF) reports 85% of African nations are facing significant affordability challenges, particularly impacting low-income urban households. Despite governmental efforts and international support, as the ones outlined by Agenda 2063, aiming to transform Africa into a global powerhouse of the future, the continent deals with a substantial deficit of at least 51 million affordable housing units (Moghayedi et al., 2024). This deficit, coupled with prevailing issues, such as informal settlements and substandard living conditions, highlights an urgent need for effective strategies and interventions to address Africa’s housing crisis.

Today, these huge challenges persist despite the implementation of various affordable housing schemes and subsidies, slow delivery processes due to financial constraints and the lack of digitalisation and innovation in construction practices (Fahfouhi et al., 2024). To overcome these barriers, there's a growing need to integrate new locally available materials and innovative construction technologies to enhance the quality, efficiency, and sustainability of housing solutions across Africa. This shift toward sustainable and environmentally conscious practices aligns with global initiatives, representing a fundamental step toward addressing the pressing housing needs for Africa's swiftly expanding urban population. In The African Development Bank’s report called “Promoting affordable housing in African Cities”, there is a thorough investigation on housing crisis challenges in Nigeria, Cameroon, and Zambia, where most households are in inadequate conditions according to the SDG 11 definition. Figure 1 shows the percentage of households in poor conditions.

Most urban households, particularly those classified as low-income, lack the financial resources to get newly built houses provided by the private sector, even if they are inexpensive, even when mortgage funding options are available. There is an urgent need for comprehensive strategies to address this affordability gap, ensuring that large

amounts of population can access suitable housing solutions, reducing this way the impact of rapid urbanisation on house prices and affordability.

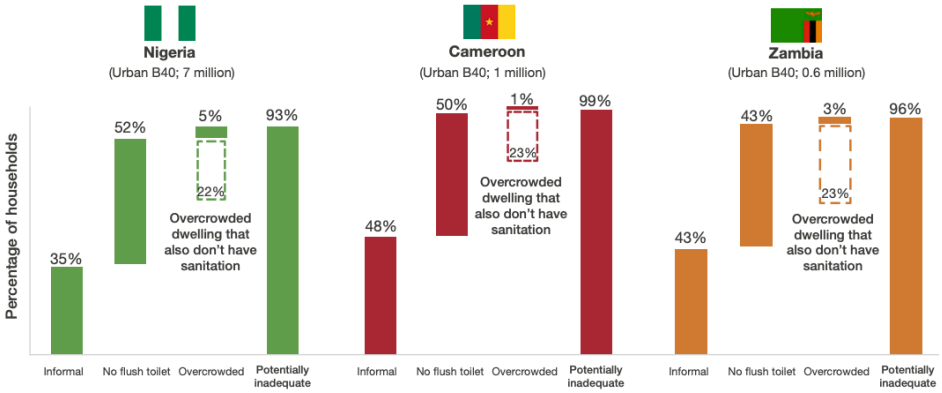

Fig. 1. Housing conditions among the bottom 40th percentile in urban Nigeria, Cameroon, and Zambia, adapted from (African Development Bank, 2023).

Figure 2 shows the proportion of householders who can afford the cheapest newly built homes by private contractors.

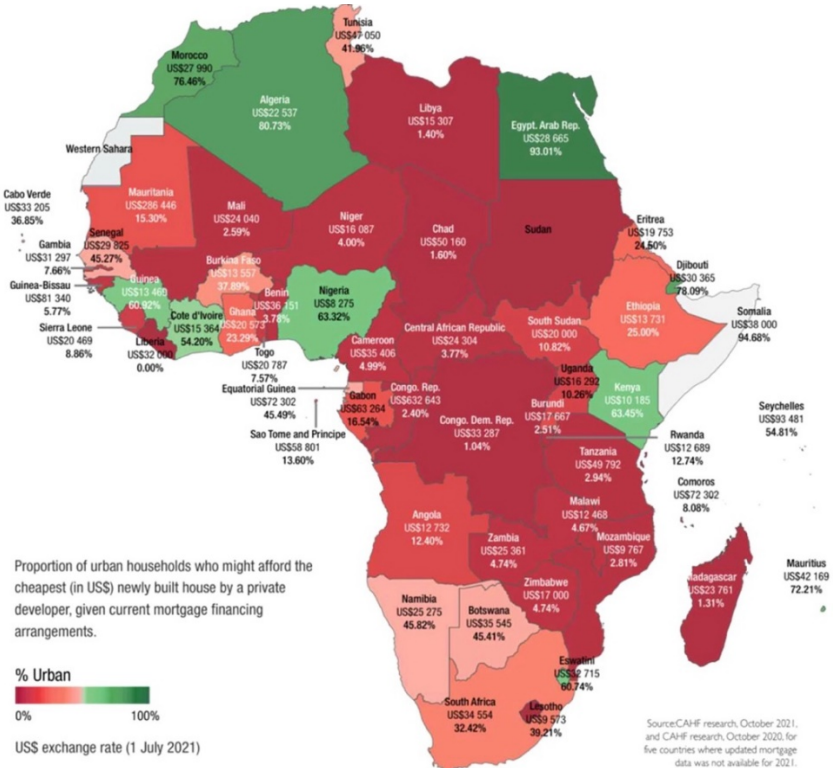

Fig. 2. Percentage of affordability of cheapest newly built houses in African countries, adapted by (CAHF, 2021)

There are other complex challenges in Africa to overcome, such as the link between poverty and conflict, which, combined with the affordability crisis, results in a significant shortfall in government-provided affordable housing. Recent data suggests an alarming deficit of at least 51 million affordable housing units across the continent (CAHF, 2023). Nigeria bears a substantial burden with a housing deficit of 28 million units, while the Democratic Republic of Congo faces an estimated shortage of 3.9 million, requiring the construction of over 260 thousand housing units annually. Similarly, South Africa struggles with an affordable housing shortage of approximately 3.7 million units.

Despite the implementation of several national and international housing schemes in Africa, the housing crisis persists, largely due to financial limitations and a slow delivery process. These challenges arise primarily from the absence of digitalisation and innovation in planning, design, and construction practices (Moghayedi et al., 2022). Incorporating alternative new local materials and modern construction methodologies is crucial for solving affordable housing problems. It will also help mitigate housing conditions while reducing waste and accidents. This can be a paradigm shift aligned with global initiatives for climate resilience.

3 3D Printing for the housing sector in Africa

In recent years, Africa has been at the forefront regarding technological innovation in the housing sector, which comes from the urgent need to mitigate complex construction challenges. Many African governments, including Kenya, Nigeria, South Africa, and Ghana, have stressed the importance of using innovation to speed up housing delivery while improving quality and efficiency (Mahachi, 2021). Conversely, the construction sector has been criticised for its environmental impactful activities that result in material waste, misuse of natural resources, and huge amounts of waste, this way impeding the fulfilment of the Sustainable Development Goals (SDG) (Ogunmakinde et al., 2022). Franco et al. (2022) argue that it is important to recognise that the civil construction sector faces numerous challenges in maintaining its operations and, as a result, in achieving sustainable development goals, as the construction production chain has a significant impact on the three pillars of sustainability. According to the Mckinsey Global Institute Industry Digitization Index (Agarwal et al., 2016), construction remains one of the least digitalised and innovative industries in terms of the implementation of Industry 4.0 technologies.

Digital processes allow not only optimising the use of resources (energy and materials) and waste but also the incorporation of recycled materials for 3D deposition (Tahmasebinia et al., 2020). Table 1 shows selected Industry 4.0 technologies (Advances in Materials, 3D Printing, and BIM) impacts in the Triple Bottom Line.

Fahfouhi et al. (2023) point out the use of earth-based materials in Morocco, Tunisia, and Algeria, where houses were built for centuries using earthen materials and traditional construction techniques, ranging from rammed earth to cob houses, which hold a great architectural heritage and culture. Using raw earth, a local natural material, for digital constructions dates back to 2004, when Khoshnevis (Khoshnevis, 2004)

investigated the contour crafting technology for houses that could be automatically built with 3DP technologies, using only local materials. Other similar works, such as (Craveiro et al., 2018; Curth et al., 2024; Faleschini et al., 2023; Tarhan & Perrot, 2023; Fahfouhi et al., 2022), also have used more environmentally friendly 3DP construction material formulations.

Table 1. Industry 4.0 impacts on social, economic, and environmental sustainability (adapted from Franco et al., 2022).

Industry 4.0 Technologies	**Triple Bottom Line**		
	Social	Economic	Environmental
Advances in Materials	Income generation for construction waste recycling plants and employees	Beneficial use of solid waste technological treatment and saving of natural resources	
3D Printing	Low-income housing	Mass customisation and fast implementation reducing construction costs due to less waste	Optimisation of resources and waste management
Building Information Modelling (BIM)	Monitoring health and safety issues – reduction of work accidents	Increase the productivity and efficiency of operations and processes and improve the quality of projects	Improve energy performance; CO2 emissions; resource efficiency and waste management; air quality
Digital Twin	Facilities management by improving societal quality of life following the principles of sustainability	Digital Twin can be used to learn and suggest new scenarios before building a product and planning for development with better management of time, quality, and natural resources	

Currently, the use of earth-based materials for digital fabrication by 3DP technologies has been growing worldwide, while some earth-based composites have been developed. The utilisation of digital fabrication techniques together with earth-based materials is currently undergoing a rapid transformation within the construction industry. The precision of digital fabrication allows consistent quality and structural integrity of earth-based components, mitigating concerns on its variability (Zaid & El Ouni, 2024). The adoption of digital fabrication for earth construction has been supported by advances in material science and sustainable practices (Gomaa et al., 2022). Researchers have been investigating ways to optimise earth-based materials for 3DP, enhancing its strength and durability while minimising environmental impact, sometimes incorporating recycled materials or integrating natural fibers into the earth mixture.

WASP most well-known projects are Gaia and Tecla House (WASP , 2023). These projects include printing houses using only sustainable and recyclable construction

materials, mainly earth. These projects were carried out in collaboration with RiceHouse, an enterprise specialising in sustainable construction using rice production waste, for the construction of Gaia (Figure 3a). Gaia represents a significant milestone as it is the first sustainable housing model created from earth-based materials, sourced from locally available materials and natural by-products from rice cultivation. This innovative project aimed to achieve an efficient, bio-climatic building, considering ecological factors. Gaia's construction involved a unique composite, incorporating 25% on-site soil (comprising 30% sand, 30% clay, and 40% silt), 25% rice husk, 40% straw derived from rice, and 10% hydraulic lime (Chiusoli, 2018). Tecla House (Figure 3b), a fusion of "Technology" and "Clay," stands as a groundbreaking circular housing model entirely made by 3D-printed locally sourced, reusable, and recyclable materials.

a) b)

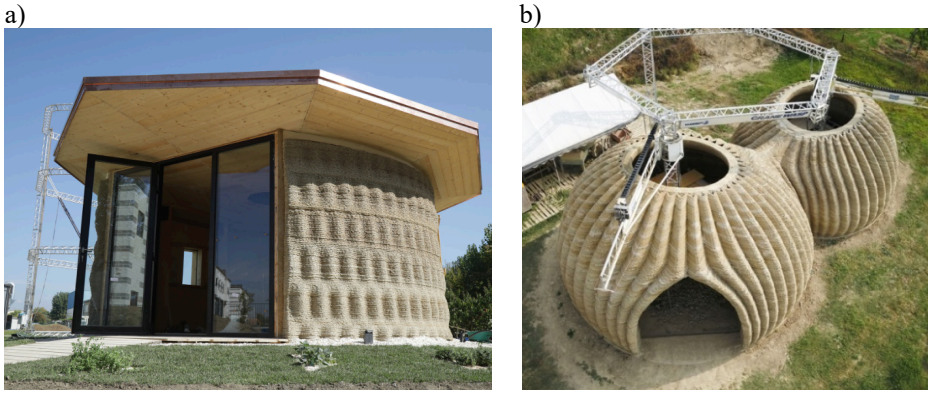

Fig. 3. WASP projects: a) Gaia Project, and b) Tecla House (WASP., 2023).

4 Conclusions

Africa's economic transformation is progressing fast, new opportunities are thriving for a talented young population and a booming digital revolution, despite the negative impacts of rapid urbanization and climate change.

This paper highlights the importance of coupling earthen materials with 3DP technologies to promote its wider adoption by the construction sector for delivering sustainable and affordable housing in Africa. To support this transition, it is crucial to systematically evaluate the current building performance and costs in the African context, offering valuable insights into the practical challenges and advantages of this Additive Manufacturing technology.

3DP technology holds immense potential to address Africa's affordable housing crisis for a rapid urban population growth. By adopting 3DP, Africa can overcome challenges related to affordability, quality, and sustainability in housing construction. This AM technology offers a transformative solution, allowing for an efficient utilization of local materials, increasing safety, reducing waste and resource consumption, and enabling faster construction processes. Moreover, 3DP aligns with global initiatives for climate resilience and sustainable development. Even though

benefits of 3DP are apparent, its widespread adoption in Africa requires further research, investment, and collaboration among governments, industries, and academia. Despite the challenges ahead, embracing innovative practices like 3DP represents a critical step towards building resilience and inclusive communities across the continent. Ultimately, the integration of 3DP technology has the potential to revolutionize the construction industry in Africa, driving economic growth, environmental sustainability, and social progress.

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