

## 3D PRINTING ADOPTION IN THE MANUFACTURING SECTOR AND SUSTAINABLE INFRASTRUCTURE DEVELOPMENT IN AFRICA

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### Abstract

The paper is a systematic analysis of how 3D printing can be adopted to promote sustainable manufacturing infrastructure in the developing economies. Based on 90 peer-reviewed articles published in the period between 2015 and 2025, the review underscores the positive transformative advantages of using 3D printing and the ongoing limitations linked to its adoption. The analysis indicates that 3D printing boosts material efficiency, decentralised manufacturing, cost-reduction, and local innovation (which is a major factor of sustainability). However, uptake is still hampered by infrastructural issues which include unstable energy, high capital, poor policy provisions, and poor digital capacity. The paper highlights the necessity of combined industrial, energy and innovation policies to facilitate mass implementation of 3D printing. These are essential interventions that are required to transform the developing regions to have sustainable industrial change and inclusive economic growth.

**Keywords:** 3D Printing Adoption, Innovative Technology, Sustainable Manufacturing, Sustainable Manufacturing Infrastructure

### 1 INTRODUCTION

The recent decade has been characterised by rapid advancements in manufacturing technology, which has led to the gradual transformation of the manufacturing sector. This gradual transformation is further contributed to by the emergence of digitalised manufacturing, in which 3D printing technology is found to be a significant component. In the last five years, literature has shown 3D printing to have garnered global recognition because of its capacity to build intricate structures and designs whilst ensuring that wastage in production processes is minimal, production periods are shorter, and features of products are customised (Naghshineh & Carvalho, 2022). Much of this literature, however, is focused on firm-level productivity, prototyping efficiency, and supply-chain optimisation, with little evidence on how 3D printing adoption can interact with larger systems of the manufacturing infrastructure, particularly in developing nations.

The manufacturing sector in Africa has been characterised by inadequate infrastructural capabilities to foster its development (Dlaminin et al., 2024). Therefore, the integration of 3D printing into the manufacturing procedure in Africa presents the advantage of benefiting from the potential opportunities presented by the adoption of 3D printing to develop substantial sustainable infrastructure. The African manufacturing industry is further found to have maintained its conventional production system, which often leads to high production costs and production

wastage, thus causing environmental destruction (Opawole, Olojede, & Kahului-Shakantu, 2022). Thus far, deficiencies, including high costs of imports and complex infrastructure for logistics and production systems, which are energy-consuming, have been the results of the combination of traditional manufacturing (Truant, Broccardo & Dana, 2021). This, therefore, has made it difficult for Africa to fulfil its expanding infrastructure requirements.

The adoption and integration of 3D printing technology have the capability to tackle multiple industrial challenges. This is based on its capability to enable localised manufacturing, eliminating import penalties and lessening waste accumulation (Prashar, Vasudev & Bhuddhi, 2022). 3D printing also presents the benefit of optimised resource usage, therefore capacitating it to contribute efficiently to the development of sustainable infrastructure (Balogun, Otonocha & Ibhado, 2018). The process of 3D printing involves the construction of layers, which eliminates the incorporation of subtractive manufacturing, which initially allows material wastage (Malik, Ul Haq, Raina & Gupta, 2022). The successful use of recycled materials and bio-based filaments for printing presents the opportunity for Africa to reach its sustainability targets through circular economy operations and decreased environmental effects (Gift et al., 2024).

Regardless of these positive features, the scope of the application of 3D printing as a sustainable manufacturing infrastructure enabler in Africa is not yet synthesised adequately in literature. This paper fills this gap by carrying out a systematic review of available empirical and theoretical literature concerning 3D printing adoption and its effects on sustainable manufacturing infrastructure development in Africa.

## **2 CONCEPTUAL AND THEORETICAL LITERATURE**

The literature about sustainable infrastructure focuses on the creation of the physical and industrial structures that can facilitate the long-term economic growth and reduce the environmental degradation. In the early research, sustainability in infrastructure is mainly viewed as the efficiency of the environment and environmental conservation (Holzmann et al., 2020). Contributions more recent are systems-focused and acknowledge the contribution of industrial production, logistics, and technological capacity to the consequences of sustainability (Claussen & Halbinger, 2021). Nevertheless, much of this body of literature puts urban services and transport infrastructure in the forefront and little analytical emphasis on the manufacturing infrastructure, especially in the developing and African economies. This induces a conceptual vacuum of how the production technologies can transform the infrastructure systems structurally to make them more sustainable. Additive manufacturing, including 3D printing, is a highly-focused area of research, particularly because of the capability to decrease the amount of waste material, flexibility in design, as well as decreased production time (Shahrudin et al., 2019). The prevailing branch of the literature has a technical orientation, which is based on materials, processes and performance optimisation (Ngo et al., 2018; Jandyal et al., 2022). Though these studies indicate efficiency, they tend to view 3D printing as a separate instrument and not a part of the manufacturing infrastructure. Recent research redefines 3D printing as a system-level innovation that has the potential to facilitate decentralised and localised production, and sustainability benefits (Gebler et al., 2022). However, this is mostly evidenced in developed economies, hence implying less applicability to less developed regions with infrastructural constraints.

Studies on the adoption of 3D printing have emphasise that the cost, availability of technologies, access to competencies, and regulatory frameworks should be considered as key determinants (Tsai & Yeh, 2019; Dlamini et al., 2024). Current literature in the African contexts is considered to be fragmented, case-oriented, and mostly descriptive which does not provide a lot of theoretical

integration between adoption behaviour and the sustainability outcomes. Technology adoption models like UTAUT rationalise adoption choices, but assume a relatively small role of environment and infrastructure impact, and green economics deals with sustainability without necessarily involving adoption processes. The fact that the two views are not integrated as much as they should highlights the importance of coming up with a systematic synthesis that would enable the connectivity of 3D printing adoption to the development of sustainable manufacturing infrastructure in developing economies.

### 3 METHODOLOGY

The PRISMA guideline is used in this research. The adherence to the requirements and practises of conducting systematic reviews adds strength to the review. The relevant literature is retrieved using keywords and search terms connected to the adoption of 3D printing, sustainable manufacturing, and sustainable development of infrastructure. The study uses a thematic analysis as a data synthesis method to reveal similar themes, tendencies, and inconsistencies between researches, and to discuss the overall efficiency of the 3D printing adoption in the development of sustainable manufacturing infrastructure.

This paper uses a coverage period of 10 years (2015 -2025) to encompass the period when 3D printing ceased being a prototyping technology but a feasible manufacturing and infrastructure platform, especially in the developing world. In spite of its roots being tracked back to the 1980s, scholars and policymakers became particularly interested in 3D printing as a sustainable manufacturing and infrastructure development method only after 2015, after the development of materials, digital design, and cost reduction. This time period is also matched by more dialogue on sustainable industrialisation, digital manufacturing, and implementation of Agenda 2063 in the African context. As a result, the limited scope of review to this time frame should guarantee an analytical topicality without considering preliminary research with minimal implications to the current infrastructure issues.

The major sources for search include Google Scholar, Scopus, Web of Science, and Science Direct. For the inclusion criteria, the following is utilised: focused on 3D printing, additive manufacturing, sustainable manufacturing and sustainable manufacturing infrastructure; published between 2015 and 2025; easy accessibility of the full article. For exclusion, the following were the criteria: Older article than 10 years, Articles not available in English language, Articles that do not include the keywords for inclusion. For the extraction of data, the following information was used: Author, Title, Year of publication, Abstract, concepts definition, theories utilised, result discussion and conclusion. Duplication among the databases was approached by exporting all the retrieved records to a reference management system where automated and manual screening would be applied in the elimination of duplicate titles, abstracts and Digital Object Identifiers (DOIs) before the assessment of eligibility. The result from this analysis is presented by the PRISMA Model graphically in Figure 1.

The SWOT analysis presented in figure 2 shows that, even though the technological capabilities and sustainability potential of 3D printing are well presented, the literature as well as policy environment in the context of Africa is still under-developed. The primary areas of weakness, including the lack of empirical data, interdisciplinarity, and inadequate infrastructure, are also opportunities of future studies and intervention. The future of 3DP to the sustainable manufacturing infrastructure in Africa will, thus, be to exploit these strengths, eliminate the weaknesses, and take advantage of the opportunities and reduce the threats through sound policy coordination, funding and inclusivity strategies.

The PRISMA framework is utilised to guide the systematic identification, screening, and synthesis of the available studies, while the SWOT analysis is employed as an analytical tool used to organise the interpretation of the reviewed evidence. The SWOT framework made it possible to categorise recurring themes into strengths, weaknesses, opportunities and threats related to 3D printing implementation as sustainable manufacturing infrastructure. Therefore, whilst PRISMA guarantees the rigour of the methodology, SWOT promotes the clarity of analysis and practicality.

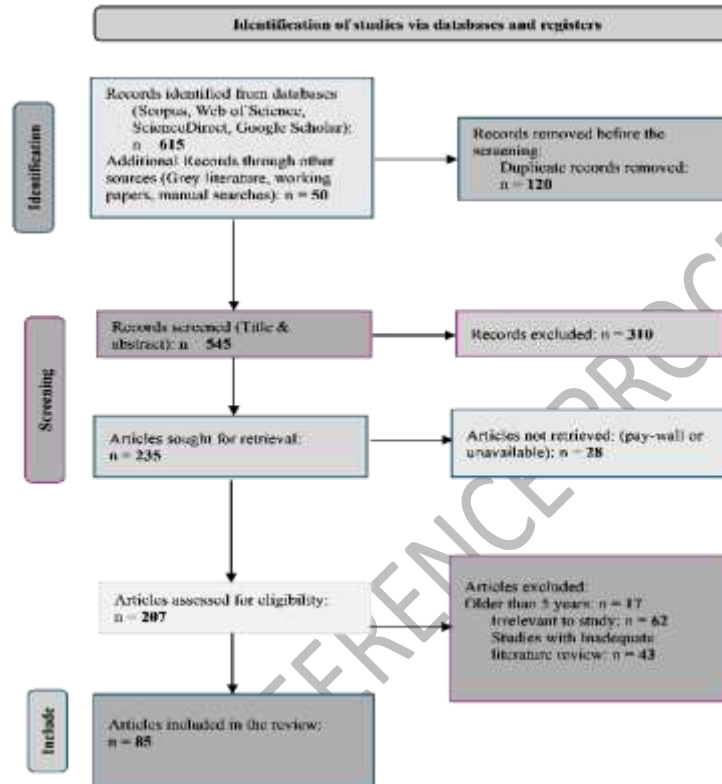


Figure 1: Presentation of PRISMA Model

Source: Authors' Computation  
SWOT analysis

<p><b>Strengths</b></p> <ul style="list-style-type: none"> <li>Established consensus that 3D printing (3DP) enhances sustainability through reduced material waste, shorter supply chains, and decentralised production (Gebler et al., 2014; Despeisse et al., 2017).</li> <li>Methodological maturity: increasing use of Life Cycle Assessment (LCA), techno-economic, and circular economy models to evaluate outcomes (Attaran, 2020).</li> <li>Emerging African case studies demonstrating local adaptation of 3D printing for housing, medical, and agricultural infrastructure (Klenam, 2022; Moghayedi et al., 2024).</li> <li>Growing interdisciplinary collaboration between engineering, environmental science, and economics.</li> </ul>	<p><b>Weaknesses</b></p> <ul style="list-style-type: none"> <li>Limited economic and infrastructural analysis; research dominated by materials science and process optimisation (Morrar &amp; Arman, 2017).</li> <li>Scarcity of empirical African data: most evidence is from South Africa, thus, weak generalisability.</li> <li>Fragmented frameworks: weak integration of governance, innovation systems, and financing in 3DP research (Olawumi et al., 2023).</li> <li>Technical capacity and data collection gaps; under exploration of labour, ethics, and equity issues.</li> </ul>
<p><b>Opportunities</b></p> <ul style="list-style-type: none"> <li>Expansion of Africa's digitalisation and Fourth Industrial Revolution (4IR) agenda supports 3DP integration with AI, IoT, and digital twins (UNECA, 2024).</li> <li>Circular economy and sustainability transition open new research on recycled and bio-based materials (Gebler et al., 2022).</li> <li>AfCFTA offers platform for harmonising additive manufacturing standards and fostering cross-border R&amp;D collaboration.</li> <li>Maker spaces and FabLabs enable inclusive, grassroots manufacturing and innovation (Despeisse et al., 2017).</li> </ul>	<p><b>Threats</b></p> <ul style="list-style-type: none"> <li>Underfunding of research and innovation infrastructure; dependence on donor or private funding (Attaran, 2020).</li> <li>Technological dependency on imported materials and machines exposes local production to global shocks.</li> <li>Absence of harmonised standards, IP protection, and certification frameworks.</li> <li>Potential labour displacement and inequality if automation expands without inclusive reskilling policies.</li> <li>Fragmented academic silos and weak interdisciplinary networks.</li> </ul>

Figure 2: SWOT Analysis

## 4 ANALYSIS

### 4.1. Factors influencing the Adoption of 3D printing

Haleem and Javaid (2019); Tsai and Yei (2019); Opawole, et al. (2022); Naghshineh and Carvalho (2022); as well as Dlamini et al. (2024) assessed the adoption of 3D printing across diverse manufacturing affiliated sectors in an economy. These studies found the adoption of 3D printing to have been influenced by numerous factors such as the cost of the machines, capabilities of the softwares, expectancy on accuracy, and so on. Some of these studies revealed that the rate of adoption differed across geographic regions while the benefits and challenges to adoption were also country specific. Yadav et al. (2020); Hindratmo, et al. (2022); Pichagonakesit, et al. (2023); Elemure et al. (2023); as well as Yang, et al. (2023) investigated sustainable manufacturing highlighting components such as 3D printings, Internet of Things (IoT), Artificial Intelligence (AI) as the major contributors to sustainability in the manufacturing sector. These studies further highlighted that some of the key factors to the enhancement of sustainability in the manufacturing sector included automation of production processes, digital transformation, as well as decision making based on data.

### 4.2. Benefits of 3D printing Adoption for Developing Sustainable infrastructure

3D printing (3DP), or additive manufacturing (AM) as referred to in literature, is a phenomenon that is becoming recognised as a driver of sustainable manufacturing which is capable of contributing to sustainable infrastructural development in the world. Identified benefits of 3D printing adoption in literature include resource and material efficiency, in terms of waste minimisation both carbon and solid waste (Ngo et al., 2018; Tsai & Yei, 2019; Gebler et al., 2022; Olawumi et al., 2023; Curth et al., 2024); Efficiency in time and cost of production (Holcom, 2023; Moghayedi et al., 2024); contributions to localised and decentralised production infrastructures,

which enables the rising economies to enhance resilience and decrease the dependency on imports (Thompson et al., 2016; Klenam, 2022); designing flexibility and innovation through topological optimisation (Despeisse et al., 2017; Gebler et al., 2022; Lipson & Kurman, 2023); and lastly, ability to boost the capacity to develop skills and local innovations, especially among developing economies (Attaran, 2020; Klenam, 2022). Literature, therefore, confirms that 3D printing offers the advantages that are multidimensional, reduces environmental impact, increases efficiency of projects, promotes localisation, and reinforces knowledge economies. These results confirm its contribution to the provision of sustainable manufacturing infrastructure in developing environments (Berman, 2021).

#### **4.3. Identified Key Infrastructural Barriers to the widespread Adoption of 3D printing**

In spite of the technological potential, there are a number of infrastructural and systematic issues that are found to have continually persisted. One is the unreliability of the energy infrastructure affecting precision and reliability (Attaran, 2020; Klenam, 2022; Moghayedi et al., 2024; Gershon, et al., 2024). Another major challenge is the shortage of certified raw materials and feedstock (Ngo et al., 2018; Olawumi et al., 2023). The third weakness is lack of skills and human capital needed for mechanical design, software functioning and process optimisation (Attaran, 2020; Gebler et al., 2022). The adoption is also impeded by regulatory and institutional barriers (Despeisse et al., 2017; Moghayedi et al., 2024). Financial barriers can also be identified from literature because of the capital-intensive nature of 3D printers (Thompson et al., 2016; Ngo et al., 2018). This financing gap is increased by lack of awareness and risk aversion among the investors. Last is structural barriers posed by digital infrastructure shortcomings like insufficient broadband, inadequate data protection structures and substandard cloud infrastructure (Klenam, 2022).

### **5 DISCUSSION**

This review results support the emerging belief that 3D printing has a significant influence on developing sustainable manufacturing infrastructure especially towards material efficiency, decentralised manufacturing, and industrial systems based on innovation. In the African setting, these advantages in particular are applicable due to the continued lack of infrastructure, reliance on imports, and environmental strain linked with traditional manufacturing. Nevertheless, the analysis also shows that the benefits can be realised only to a significant degree on the condition of enabling factors, which include uninterrupted energy supply, qualified human resource base, digital networks, and favourable regulatory environment. This is due to the preponderance of studies in advanced economies pointing to a lack of relevance between the context of knowledge creation in 3D printing and the place of greatest need of sustainability gains. This highlights the need to have coordination of policies within the region and institutional assistance to ensure that there are no duplicates of the current trends of technological dependency. On the whole, the results put 3D printing not as a solution to itself, but rather as an element of a larger manufacturing and infrastructure ecosystem that needs to be carefully synchronised with the goals of sustainability in Africa.

### **6 IMPLICATIONS OF FINDINGS AND CONCLUSION**

The adoption of 3D printing into the manufacturing system in Africa is both a revolution and a challenge. The literature review indicates that 3D printing could be used as an enabler of inclusive industrialisation, sustainable production, and integration into the circular economy, towards achieving the Agenda-2063 of the African Union and Sustainable Development Goals (SDGs) (Olawumi et al., 2023; UNECA, 2024). The identified potential benefits of 3D printing adoption

present it as an enabling factor for developing resilient and cost-effective infrastructure (Gebler et al., 2022; Olawumi et al., 2023; Moghayedi et al., 2024).

This study has both theoretical and practical implications of the findings. In theory, the combination of technology adoption theory and green economics broadens the scope of existing literature by indicating how adoption behaviour relates to the sustainability-based infrastructure results in developing countries. In practise, the findings imply that 3D printing ought to be integrated into larger industrial, energy and digital infrastructure policies and not considered a separate technological intervention. Specific investments in skills building, material provision chains located in the country, and harmonisation of regulations are essential in order to scale the adoption and reach the full benefits of sustainability. To the stakeholders in the industry, the results indicate the existence of decentralised production models that can boost resilience and mitigate environmental impact.

The paper has conducted a literature review on the adoption of 3D printing and how it can be used to develop sustainable manufacturing infrastructure in emerging economies. The results have disclosed that 3D printing has a huge potential sustainability impact, which can include enhancing material efficiency, decentralising manufacturing, reducing the cost, and encouraging innovation ecosystems that are vital to the competitiveness of industries. The adoption is however limited by the infrastructural bottlenecks including, unreliable energy supply, lack of technical expertise, accessibility of certified materials and underdeveloped digital and institutional structures. To overcome these barriers, it would be necessary that policy interventions incorporate technological capability building, industrial financing and harmonisation of regulations. Enhancing these enabling infrastructures will enable the developing economies, especially Africa, to use 3DP as a revolutionary tool of sustainable industrialisation and inclusive economic growth.

For further studies, it is recommended that quantitative analysis on models that relate 3D printing adoption with other economic variables like productivity, value addition and infrastructure investment should be included. Longitudinal and cross-country research would reveal cause and effect relationships of additive manufacturing ecosystems and industrial sustainability outcomes. In order to develop the field, researchers can also use mixed-method solutions that incorporate both technical tests, economic modelling and institutional analysis.

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