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The Social and Economic Development Implications of 4IR Technologies in African Housing Production Systems: Review of 3D Printing

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1 ABSTRACT

Digital transformation, associated with the Fourth Industrial Revolution (4IR), is reshaping planning paradigms across Africa, signaling a departure from traditional housing delivery mechanisms toward digitally enabled and data-driven systems. This transition has prompted intensified scholarly interest in how automation, artificial intelligence, geospatial intelligence, and digital land administration may alter housing access, production models, and governance relations. However, the pace of technological innovation far exceeds the evolution of social development systems, creating a tension between digital optimisation and social equity. This research is motivated by the growing disparity between technological capabilities and socially inclusive housing outcomes. While 4IR demonstrates potential to enhance transparency, streamline land-use planning, strengthen tenure security, and support participatory decision-making, the absence of rights-based frameworks risks reproducing existing socio-spatial inequalities within digital infrastructures. The study aims to interrogate how 4IR technologies can be leveraged to advance, not undermine, socially just housing outcomes in African cities. A combined bibliometric analysis and qualitative systematic review was employed to map patterns, identify conceptual gaps, and analyse governance and implementation dynamics through cases in South Africa due to the no-representation of other African countries. The findings reveal three distinct trends: increasing technological experimentation without adequate regulation, insufficient institutional capacity to manage digital transformation, and growing potential for tech-driven co-creation of housing solutions. The research proposes a Digital Social Innovation Housing Framework centred on ethical governance, community empowerment, and institutional readiness.

Keywords: Digital housing systems, Fourth Industrial Revolution, Social development policy, Bibliometric analysis, Africa.

2 INTRODUCTION

Rapid urbanization and population growth, informal settlements form a major part of the urban fabric globally (Mndzebele & Gumbo, 2023). Africa continues to grapple with a multifaceted and persistent housing crisis marked by a severe shortage of affordable housing, substandard living conditions in informal settlements, and rapid urban population growth. The continent's housing challenge is further compounded by poor construction quality, slow delivery rates, and high material wastage, particularly within the low-income housing sector (Bah, Faye, & Geh, 2018). These challenges are exacerbated by limited technical capacity and inadequate awareness of innovative construction technologies, which have constrained the construction industry's ability to respond effectively. Consequently, the sector has been slow to adopt technological innovations capable of addressing the inefficiencies inherent in conventional construction methods, resulting in low levels of sustainability and delayed housing delivery across many African countries. Against this backdrop, this study interrogates the social and economic development implications of Fourth Industrial Revolution (4IR) technologies, specifically 3D printing, within African housing production systems. It seeks to move beyond techno-optimistic narratives by critically assessing how emerging construction technologies intersect with issues of governance, institutional capacity, and social equity. Through a combined bibliometric analysis and qualitative systematic review, the study maps existing scholarly trajectories, identifies conceptual and empirical limitations, and examines selected case experiences from South Africa, Morocco, and Kenya. In doing so, the research contributes to debates on digitally enabled housing delivery by proposing a Digital Social Innovation Housing Framework that foregrounds ethical governance,

community empowerment, and institutional readiness as essential conditions for inclusive and sustainable adoption of 4IR technologies in African cities.

3 CONTEMPORARY DISCOURSES ON 4IR IN HOUSING

Conventional housing delivery models, largely dependent on labour-intensive, material-heavy construction techniques, have proven incapable of meeting demand at scale, particularly for low-income and marginalised households (Moghayedi & Awuzie, 2025). As a result, informal settlements have become a dominant mode of urbanisation across the continent, often characterised by insecure tenure, inadequate infrastructure, and exposure to environmental risks (Ouma et al., 2024). Within this discourse, technological transitions, particularly those associated with the Fourth Industrial Revolution (4IR), are framed as potential disruptors capable of transforming housing delivery processes, improving efficiency, and reducing costs (Lopes & Silva Filho, 2024). However, the uneven diffusion of technology across African settings raises concerns about deepening socio-spatial inequalities if innovation is not embedded within inclusive development frameworks. The Fourth Industrial Revolution is defined by the convergence of digital, physical, and biological systems, driven by advances in automation, artificial intelligence, robotics, big data, and additive manufacturing (Alarcón & Alarcon, 2025). In the Global South, including Africa, scholars note that 4IR technologies offer opportunities to enhance transparency in land-use management, improve coordination across planning institutions, and enable more participatory forms of urban governance (Mbatha, 2025). Despite these opportunities, critical literature cautions against technological determinism. Without adequate regulatory oversight, institutional readiness, and social safeguards, 4IR-driven systems risk reinforcing exclusion by privileging technically skilled actors and formalised property regimes. This tension highlights the need to interrogate not only the technical capabilities of 4IR technologies but also their governance, ethical, and distributive implications, particularly in housing systems serving low-income communities.

4 METHODOLOGY IMPERATIVES

This study employed a qualitative-dominant mixed-methods research design that integrates bibliometric analysis with a qualitative systematic review to explore the trajectories, governance considerations, and socio-institutional debates surrounding the application of Fourth Industrial Revolution (4IR) technologies in African housing production systems. This methodological combination was intentionally selected to capture both the macro-level structure of knowledge production. Such as publication trends, collaboration networks, and geographic concentration, and the micro-level thematic content shaping discussions on 3D printing, additive manufacturing, and socially just housing delivery. Peer-reviewed journal articles were systematically retrieved from indexed academic databases using carefully constructed search strings that combined terms related to 4IR, 3D printing, additive manufacturing, housing, and construction. To ensure analytical consistency, only English-language publications were included. The resulting dataset was analysed using bibliometric mapping software to generate visual representations of temporal publication patterns, co-authorship networks, and country-level collaboration dynamics, enabling the identification of dominant research clusters, asymmetries between Global North and Global South knowledge production, and shifts in scholarly focus over time.

In parallel, a qualitative systematic review was conducted to interrogate how 4IR technologies, particularly 3D printing, are conceptualised, governed, and operationalised within housing production systems. This review extended beyond academic literature to include policy documents and documented pilot projects that explicitly engaged with social, economic, governance, and institutional dimensions of digital construction technologies. Studies were screened based on their relevance to housing delivery processes, governance frameworks, and social development outcomes, with particular emphasis placed on implementation realities rather than purely technical innovation. A thematic analysis approach was applied to synthesise recurring concepts, constraints, and enabling conditions, paying close attention to issues of regulatory readiness, institutional capacity, social inclusion, and the uneven spatial diffusion of technological innovation within African settings. Given the limited empirical documentation of 3D printing housing initiatives across the continent, selected experiences from South Africa were used to contextualise the findings. South Africa was selected due to its relatively advanced research infrastructure, emerging experimentation with digital construction technologies, and greater availability of publicly accessible documentation. These cases were not positioned as representative of Africa as a whole but were instead treated as illustrative lenses through

which governance preparedness, institutional arrangements, and socio-economic implications of 4IR-driven housing interventions could be critically examined. Insights generated from both the bibliometric analysis and the qualitative systematic review were subsequently integrated through a qualitative synthesis process that informed the development of the Digital Social Justice Housing Framework (DSJHF).

5 ANALYSIS AND DISCUSSIONS

This section presents and interprets the empirical results of the bibliometric analysis, examining temporal trends, collaboration patterns, and geographic distributions in scholarship on 4IR technologies and housing production. The discussion situates these findings within broader debates on governance, institutional capacity, and social justice in digitally enabled housing systems from an African perspective.

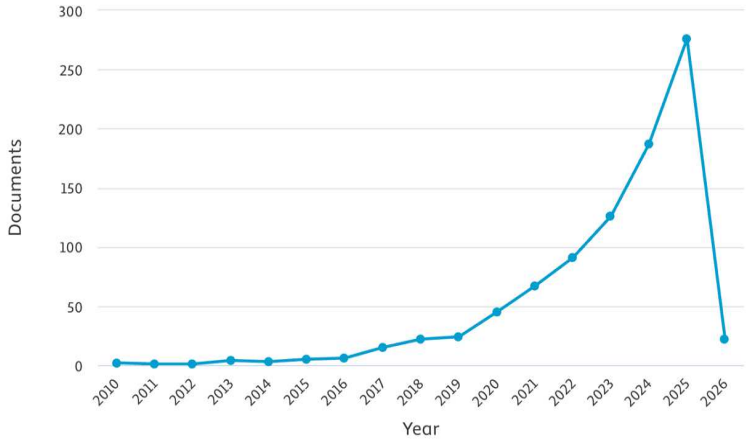

Figure 1: Publication trend

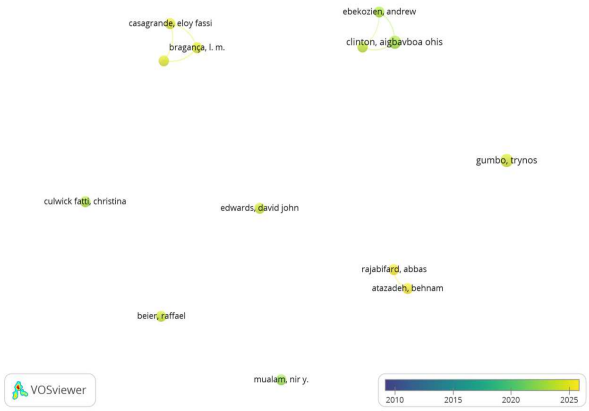

Figure 2: Co-authorship (Authors)

The bibliometric analysis reveals a clear, accelerating growth trajectory in scholarly output on 4IR-related technologies for housing production between 2010 and 2025 (Figure 1). From 2010 to approximately 2016, publication activity remained relatively low and fragmented, indicating that additive manufacturing and digital construction were still positioned as niche or experimental topics within the broader construction and housing literature. This early phase aligns with global accounts that position 3D printing in construction primarily as laboratory testing and pilot demonstrations rather than as applied housing systems (Lyu et al., 2021). A notable inflection point occurs from 2017 onwards, with a sharp increase in publications accelerating further after 2020. This surge corresponds with the global consolidation of Fourth Industrial Revolution discourse following Schwab's (2016) formalisation of the 4IR, as well as growing industry interest in automation as a response to housing shortages, climate pressures, and construction inefficiencies. The exponential rise between 2021 and 2025 suggests that 3D printing and digitally enabled housing production have transitioned from speculative innovation to a recognised research frontier within the built environment domain (University of Johannesburg, 2023). The apparent decline in 2026 should be interpreted cautiously, as it likely reflects incomplete indexing rather than a substantive reduction in scholarly interest. Overall, this temporal pattern confirms that the field is rapidly expanding yet remains emergent, reinforcing

the relevance of this study's critical interrogation of social and governance implications, which often lag behind technological development.

The co-authorship network analysis (Figure 2) reveals a relatively fragmented scholarly landscape characterised by small, loosely connected author clusters. Several micro-clusters, such as those involving Casagrande and Bragança, Rajabifard and Atazadeh, and Clinton and Aigbavboa, indicate strong collaboration within specialised subfields, including digital land administration, construction innovation, and smart infrastructure. However, the limited interconnection between these clusters suggests weak cross-fertilisation between technical, planning, and social development research streams. This fragmentation reflects a broader pattern in 4IR scholarship, where engineering-led research often advances independently of urban governance and social policy debates. The relative isolation of scholars working on housing justice, participation, and informality from those focused on additive manufacturing highlights a critical limitation: technological innovation is progressing faster than integrative frameworks capable of addressing social equity outcomes. The presence of African scholars, most notably Trynos Gumbo, within the network is significant but limited in scale, indicating that African perspectives remain underrepresented in global debates on digitally enabled housing systems. This finding supports existing critiques that Global South settings are frequently treated as sites of technological experimentation rather than sources of theory and normative guidance. The results, therefore, highlight the need for more interdisciplinary and transregional research collaborations that foreground African housing realities within 4IR innovation discourses.

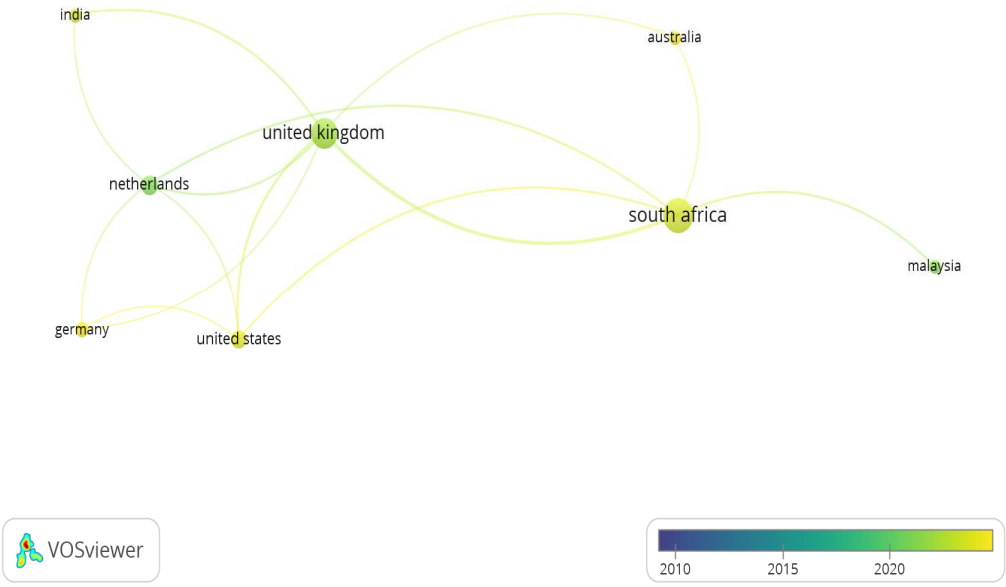

Figure 3: Co-authorship (Countries)

The country co-authorship network (Figure 3) demonstrates a pronounced concentration of research output and collaboration in the Global North. These countries function as central nodes within the network, facilitating transnational knowledge flows and shaping dominant research agendas in digital construction and housing technologies. South Africa emerges as the most prominent African contributor and the primary bridge between Global North research hubs and the African continent. The limited representation of other African countries suggests that research on 3D printing and 4IR housing remains geographically uneven, despite the continent's disproportionate exposure to housing deficits and informal urbanisation (UN-Habitat, 2020). This asymmetry raises critical questions about epistemic justice and technological transfer. While African cities are frequently framed as ideal testing grounds for rapid, low-cost housing technologies, the conceptualisation, regulation, and evaluation of these technologies are largely driven externally. The findings thus reinforce concerns that without strong local institutional capacity and participatory governance, 4IR housing interventions risk reproducing neo-colonial development dynamics rather than enabling locally grounded innovation.

6 TOWARDS THE DIGITAL SOCIAL JUSTICE HOUSING FRAMEWORK (DSJHF)

This section outlines targeted recommendations to support the socially just adoption of Fourth Industrial Revolution (4IR) technologies in African housing production systems. The recommendations respond directly to observed limitations in governance, institutional capacity, knowledge production, and community engagement, and are structured to inform planning practice and future research. Collectively, they operationalise the principles of the proposed Digital Social Justice Housing Framework by translating important findings into actionable guidance for stakeholders involved in digitally enabled housing delivery.

Findings	Implications for African Housing Systems	Targeted Recommendations
Rapid growth in publications on 4IR and 3D printing since 2017, with accelerating interest post-2020	Technological development is advancing faster than governance, regulation, and social safeguards	Develop proactive, rights-based regulatory frameworks that guide the adoption of 3D-printed housing, ensuring alignment with social equity, housing rights, and sustainability objectives
Dominance of techno-centric research with limited engagement on social development outcomes	Risk of technocratic housing delivery models that marginalise community needs and lived realities	Embed social development indicators (equity, participation, tenure security, livelihoods) into digital housing policies and project evaluation frameworks
Fragmented author collaboration networks with weak interdisciplinary integration	Limited cross-learning between engineering, planning, and social policy disciplines	Promote interdisciplinary research and implementation teams combining planners, engineers, social scientists, and policymakers in 4IR housing projects
Concentration of knowledge production in the Global North, with South Africa as the main African node	African settings risk being sites of experimentation rather than knowledge generation	Strengthen African-led research, South–South collaboration, and locally grounded innovation agendas in digital housing systems
Limited institutional capacity to regulate and scale 3D-printed housing	Difficulty transitioning from pilot projects to large-scale implementation	Invest in institutional readiness through digital literacy training, regulatory reform, and updated building codes accommodating additive manufacturing
Potential labour displacement due to construction automation	Risk of job losses in low-skilled construction sectors	Integrate inclusive skills development and labour transition programmes linked to 3D printing and digital construction technologies
Weak community participation in digital housing innovation	Housing solutions may fail to reflect socio-cultural and spatial needs	Institutionalise community co-creation and participatory digital tools in housing design and delivery processes
Experimental nature of most African 3D-printed housing projects	Limited empirical evidence on long-term social and economic impacts	Support setting-sensitive pilot projects with stout social, economic, and environmental impact assessments

Table 1: Digital Social Justice Housing Framework (DSJHF)

As indicated on table 1, there is a need to reposition digital housing innovation within rights-based and ethically grounded governance frameworks that prioritise social equity, accountability, and inclusivity alongside efficiency gains. Across all recommendation areas, institutional readiness emerges as a critical enabling factor. Strengthening regulatory capacity, updating planning and building control systems, and investing in digital competencies within public institutions are necessary to move beyond isolated pilot projects towards scalable and sustainable implementation. Equally important is the alignment of technological innovation with inclusive skills development strategies, ensuring that automation in housing production contributes to employment transition and local economic development rather than labour displacement. Meaningful engagement of end-users in design and decision-making processes enhances contextual relevance and social legitimacy, while mitigating the risks of technocratic and exclusionary housing outcomes. Importantly, the recommendations highlight the need for African-led and interdisciplinary knowledge production to address existing geographic and conceptual asymmetries in 4IR housing research. Strengthening South–South collaboration and locally grounded innovation is essential for advancing socially just, digitally enabled housing systems aligned with the principles of the Digital Social Justice Housing Framework.

7 CONCLUSION

This study examined the social and economic development implications of Fourth Industrial Revolution (4IR) technologies, specifically 3D printing, within African housing production systems. Through combining bibliometric analysis with a qualitative systematic review, the research demonstrated that while digital construction technologies are rapidly gaining scholarly and policy attention, their integration into housing delivery remains uneven, fragmented, and insufficiently attuned to social equity concerns. The findings reveal a persistent disconnect between technological experimentation and the governance, institutional

capacity, and participatory mechanisms required to support inclusive housing outcomes in African cities. The analysis highlights that 3D printing should not be understood as a standalone solution to Africa's housing crisis, but rather as part of a broader socio-technical transformation that demands deliberate institutional and ethical alignment. Without rights-based governance frameworks, inclusive skills development, and meaningful community engagement, digitally enabled housing initiatives risk reproducing existing socio-spatial inequalities within new technological infrastructures. The study advances the Digital Social Justice Housing Framework as a normative and analytical contribution that re-centres social equity, ethical governance, and institutional readiness in debates on digital housing innovation. The framework provides a basis for guiding policy, planning practice, and future research towards housing systems that harness technological advancement while remaining grounded in African urban realities. Future research should build on this foundation by empirically evaluating long-term social outcomes of 3D-printed housing projects and further exploring locally driven models of digital housing innovation across diverse African settings.

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