

Drivers and Barriers to the Adoption of Robotics and 3D Printing in Construction in the Global South: A Systematic Review

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Abstract

This study used a systematic literature review guided by the PRISMA approach to identify and critically analyse the main drivers and barriers affecting the adoption of robotics and three-dimensional (3D) printing in construction across the Global South. Peer-reviewed articles, book chapters, and books were examined from the Scopus and Web of Science databases covering 2020 to 2026. The review framework facilitated the systematic identification of enabling factors, such as productivity improvements, design flexibility, and sustainability goals, as well as major obstacles, including high capital costs, limited technical skills, infrastructural gaps, and socio-cultural resistance. The results show that while the technological potential of robotics and 3D printing (additive manufacturing) is widely recognized, adoption is mainly hindered by structural and institutional issues rather than technical limitations. By highlighting specific context-related factors, this review advances construction innovation research and offers practical insights for policymakers, industry leaders, and development partners working in the construction sector in the Global South.

Keywords: Automation, Construction Technology, Global South, Robotics, 3D Printing.

1. Introduction

The construction industry remains among the most labour-intensive and technologically conservative sectors worldwide, characterized by fragmented processes, limited standardization, and persistent inefficiencies that constrain productivity, safety, and environmental performance (Banihashemi et al., 2025; Dindorf & Wos, 2024). These structural limitations have intensified calls for transformative innovations capable of redefining project delivery and operational efficiency. Within this context, robotics and three-dimensional (3D) printing have emerged as core components of the Construction 4.0 paradigm, integrating automation, digitization, and additive manufacturing to enhance precision, reduce material waste, and improve occupational safety (Casini, 2021; Mishra, 2025). Empirical evidence indicates that these technologies can streamline workflows, accelerate project timelines, and enable complex architectural forms that are difficult to achieve through conventional methods (Banihashemi et al., 2025).

Despite their demonstrated potential, adoption patterns remain geographically uneven. Advanced economies in East Asia, Europe, and North America have achieved comparatively higher levels of integration, supported by robust research and development ecosystems, industrial automation capacity, and enabling policy frameworks (Lopes de Aquino Brasil & Carmo Pena Martinez, 2025). In contrast, uptake across the Global South has been slower and more fragmented, constrained by high capital costs, skills deficits,

regulatory uncertainty, and institutional limitations (Akinradewo et al., 2023a; Okangba et al., 2025). Yet, rapid urbanization, housing deficits, and infrastructure demands in these regions simultaneously create strong incentives for technological leapfrogging (Akinradewo et al., 2023b).

Notwithstanding the growing scholarly interest in construction automation, existing research remains disproportionately centred on Global North contexts, limiting insight into region-specific determinants shaping adoption trajectories in developing economies. To address this gap, this study undertakes a systematic review to synthesize evidence on the drivers and barriers influencing the adoption of robotics and 3D printing in construction across the Global South. By critically mapping technological, organizational, and environmental determinants, and contrasting adoption dynamics across global contexts, the study advances context-sensitive policy and industry strategies to support sustainable digital transformation in construction.

2. Conceptual and Theoretical Framework

Given the fragmented and socio-technical nature of construction systems, understanding automation adoption requires an integrative perspective that extends beyond individual-level explanations. At the foundational level, Rogers' Diffusion of Innovation (DOI) theory explains how innovation attributes, such as relative advantage, compatibility, complexity, trialability, and observability influence adoption

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decisions and differentiate adopter categories across social systems (Yu, 2022; Yadegari et al., 2024). Complementing DOI, behavioural models such as the Technology Acceptance Model (TAM) and the Unified Theory of Acceptance and Use of Technology (UTAUT) highlight the importance of perceived usefulness, ease of use, performance expectancy, and behavioural intention in shaping technology acceptance among organisational actors (Okangba et al., 2025).

While diffusion and behavioural theories provide important insights into technology acceptance, the institutional complexity and project-based characteristics of the construction sector necessitate a broader organisational perspective. Accordingly, the Technology–Organization–Environment (TOE) framework offers a robust basis for understanding adoption as an outcome of interactions among technological, organisational, and environmental contexts (Prakash, 2025). This framework is particularly relevant in heterogeneous and resource-constrained construction environments where technological investments are strongly conditioned by institutional and infrastructural realities.

Beyond technological and organisational considerations, the integration of robotics and additive manufacturing technologies constitutes a broader socio-technical transformation of construction systems. Accordingly, this study is further informed by socio-technical theory, which emphasises the reciprocal and co-evolutionary relationship between technological systems and social arrangements (Stephen, 2023). Empirical evidence from digital transformation initiatives in construction demonstrates that organisational culture, communication networks, labour relations, and workforce dynamics significantly mediate the effectiveness and sustainability of technological implementation (Zomer et al., 2021). Consequently, the adoption of robotics and 3D printing should be understood as a process of socio-technical reconfiguration rather than merely technological substitution.

By integrating the Diffusion of Innovation theory, the Technology–Organization–Environment framework, and socio-technical theory, this study advances an interdisciplinary and multi-level conceptual framework for examining the adoption of robotics and 3D printing technologies in the construction sector of the Global South. The framework recognises that technology diffusion emerges from the interaction among innovation attributes, organisational preparedness, institutional environments, and socio-cultural dynamics. This theoretical synthesis enables a holistic understanding of the drivers and barriers influencing construction automation in institutionally complex and economically constrained contexts.

3. Research Methodology

This study adopted a systematic literature review (SLR) design guided by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework (Page et al., 2021) to ensure methodological transparency, rigour, and replicability. A structured search was conducted in the Scopus and Web of Science databases using Boolean operators and wildcard combinations of keywords related to robotics, 3D printing (additive manufacturing), construction automation, digital construction, and the Global South, engaging the theoretical frameworks of diffusion of innovations, technology acceptance model (TAM) and the unified theory of acceptance and use of technology (UTAUT), technology–organization–environment (TOE) framework, and socio-technical theory. The review covered publications from 2020 to 2026 to capture recent technological and adoption trends within the construction industry.

Inclusion criteria comprised peer-reviewed journal articles, conference papers, books, and book chapters published in English that empirically examined the adoption of robotics and/or 3D printing in the construction sector. Conceptual studies without empirical grounding and studies addressing digital technologies without explicit focus on robotics or additive manufacturing were excluded. The initial search yielded 752 records. After conducting relevance screening of the records, 193 records were assessed for eligibility. Thereafter, duplicates records were removed together with the low relevance and inaccessible records using “The Evidence Review Accelerator (TERA)” tool, which resulted in the final included records of 27 publications (21 journal articles, 4 book chapters, and 2 books). The study’s systematic review flow is represented in Figure 1 with the embedded PRISMA approach flow.

Data were extracted using a predefined coding framework capturing conceptual, contextual, and adoption-related dimensions. A thematic analysis was subsequently conducted to identify recurring patterns, drivers and barriers of robotics and 3D printing in construction, interrelationships, and dominant narratives. Methodological quality was appraised using the Critical Appraisal Skills Programme (CASP) Qualitative Checklist, with appraisal outcomes informing study inclusion and evidential weighting to enhance the reliability and integrity of the synthesis.

4. Findings

4.1. Overview of Robotics and 3D Printing in Construction

The landscape of robotics and 3D printing within the construction industry represents a paradigm shift from traditional manual processes toward automated, digitally driven fabrication. Construction robotics



Figure 1: The Study's Systematic Review Flow Embedding PRISMA Flow (Source: Authors)

refers to the integration of automated machines and robotic systems to perform site-based and off-site tasks that historically relied on human labour to improve precision, safety, productivity, and quality in construction workflows. These systems encompass autonomous and semi-autonomous manipulators, mobile robotic platforms, and collaborative robots (cobots) capable of performing construction tasks such as bricklaying, material handling, structural assembly, inspection, and demolition (Liu et al., 2024)

Similar to robotics, 3D printing, also known as additive manufacturing (AM), is defined as the layer-by-layer fabrication of physical components from three-dimensional digital models. In the construction context, this includes concrete printing, gantry-based systems, and robotic arm-based extrusion technologies that deposit cementitious mixtures, polymers, or composite materials to build structural elements or entire buildings (Lopes de Aquino Brasil & Carmo Pena Martinez, 2025). Techniques such as robocasting and contour crafting illustrate the range of methodologies where material is extruded or bound with precision, offering high design flexibility, reduced waste, and rapid construction compared to conventional cast-in-place techniques (Vanaei & Elahinia, 2024).

In recent years, global trends and innovations have showcased the maturation of these technologies. Robotics research in construction continues to grow with expanding hardware capabilities, AI-enhanced control systems, and multi-robot and mobile platforms, enabling complex geometries and automated quality monitoring in real time (Li et al., 2025). Likewise, 3D printing has transitioned from prototyping to full-scale building projects, with concrete printers capable of producing walls, structural elements, and bespoke architectural forms with improved sustainability profiles and reduced labour demands (Agegn et al., 2026).

Although the majority of research and industrial deployment has been concentrated in North America, Europe, and parts of Asia, there are emerging applications and pilot initiatives in the Global South. For example, Latin America has witnessed the construction of regionally significant 3D-printed concrete structures, such as the first 3D-printed home in Chile built in under 30 hours using industrial robotic printers, signifying a shift toward rapid digital construction methods to address housing needs in diverse climates and seismic zones (Rojas et al., 2025). Similarly, non-profit programmes in Mexico and Haiti have used 3D printing to deliver affordable housing communities, demonstrating the potential social impact of additive technologies in developing contexts.

Research in Africa also highlights interest in leveraging 3D printing as a mechanism for addressing housing shortages and sustainability challenges, while acknowledging economic and regulatory barriers that currently limit widespread adoption in countries such as South Africa (Moghayedi et al., 2024).

These trends therefore illustrate that robotics and 3D printing in construction are not only expanding technologically but are increasingly being tested and adapted within diverse regional contexts. Nonetheless, the diffusion of these innovations into the Global South faces unique constraints and opportunities, underscoring the importance of contextualised research on drivers, barriers, and strategies for adoption in emerging economies.

4.2. Robotics and 3D Printing Adoption Drivers in Construction

The adoption of robotics and 3D printing in construction across the Global South is propelled by interrelated technological, organizational, and environmental drivers that are collectively shaping firm-level and project-level decision-making. These drivers operate as enablers, highlighting the value propositions of advanced construction technologies in contexts marked by resource constraints, rapid urbanization, and evolving policy landscapes. Rather than functioning in isolation, they operate synergistically to position advanced construction technologies as instruments of productivity enhancement, quality improvement, and systemic modernization.

Technological drivers centre on demonstrable gains in efficiency, precision, and safety. Robotic automation and concrete 3D printing streamline repetitive and labour-intensive tasks, enable continuous operations, and significantly compress project timelines (Olatunde et al., 2023; Okangba et al., 2025). In concrete 3D printing, layer-by-layer fabrication enhances dimensional accuracy and structural integrity, reducing variability and human error while meeting rising performance standards in mass housing and urban infrastructure (Xu et al., 2022; Su et al., 2024). Additionally, robotic systems mitigate occupational risks by undertaking hazardous tasks, thereby reducing worker exposure to high-risk environments and addressing persistent safety challenges in developing construction sectors (Wang et al., 2025; Li et al., 2025).

Organizational drivers further reinforce adoption through clear economic and strategic benefits. Firms increasingly recognize long-term cost efficiencies derived from reduced labour dependency, minimized material waste, and shorter delivery cycles, thereby improving return on investment and financial sustainability (Banihashemi et al., 2025; Akinradewo et al., 2023b). Besides cost considerations, early adopters gain competitive differentiation through enhanced

production flexibility, accelerated execution, and the capacity to deliver complex and customized designs (Olatunde et al., 2023). The integration of these technologies also stimulates workforce upskilling, strengthening innovation capacity and long-term organizational resilience.

Environmental and policy drivers provide critical enabling conditions. Regulatory incentives, innovation grants, and digital transformation agendas aligned with Construction 4.0 reduce uncertainty and legitimize technological experimentation (Okangba et al., 2025). Concurrently, sustainability imperatives and escalating urban demand intensify pressures for resource-efficient and low-waste construction practices, for which robotics and 3D printing offer viable solutions (Su et al., 2024; Akinradewo et al., 2023b). Overall, these drivers explain the growing traction of automation and additive manufacturing as transformative enablers of construction modernization in the Global South.

4.3. Barriers to the Adoption of Robotics and 3D Printing in Construction

Despite the transformative potential of robotics and 3D printing, their adoption across construction sectors in the Global South remains constrained by interrelated technological, organizational, and institutional barriers. Adoption challenges extend beyond technical feasibility to encompass financial capacity, skills readiness, regulatory clarity, and socio-cultural acceptance. These layered constraints limit the transition from pilot experimentation to scalable industrial deployment, underscoring the need for context-sensitive policy and industry responses.

Technological barriers significantly constrain the adoption of robotics and 3D printing in construction, particularly in developing economies. High upfront capital costs associated with acquisition, installation, calibration, and system integration pose significant obstacles, especially for small and medium-sized enterprises that dominate construction markets in developing economies (Akinradewo et al., 2023a). Limited access to affordable financing further restricts firms' risk-bearing capacity. In addition, the absence of standardization and interoperability across proprietary hardware and software platforms complicates integration with existing digital infrastructures such as Building Information Modelling systems (Xu et al., 2022; Liu et al., 2024). Concerns regarding system reliability in harsh site conditions, unstable power supply, and limited local maintenance expertise further heighten perceived implementation risk (de Soto & Skibniewski, 2020).

Organizational barriers also impede adoption. Resistance to change often linked to fears of job displacement and skills obsolescence reduces workforce acceptance of automation technologies (Rojas et al., 2025). The scarcity of structured training

and capacity-building initiatives reinforces technical skill gaps, limiting firms' preparedness for digital transformation. Moreover, inadequate managerial awareness of the operational, financial, and strategic implications of robotics and additive manufacturing constrains informed decision-making (Olatunde et al., 2023; Agegn et al., 2026). These challenges are exacerbated by the fragmented and informal structure of construction industries in many developing economies.

The environmental barriers, comprising institutional and socio-cultural factors further contribute to the adoption limitation. For example, weak or ambiguous regulatory frameworks, coupled with the absence of clear standards governing safety, certification, and liability in automated construction, generate uncertainty for early adopters (Dindorf & Wos, 2024). Furthermore, cultural preferences for traditional construction practices and scepticism toward automation reduce stakeholder buy-in and slow implementation (Akinradewo et al., 2023a). Conclusively, these barriers signify that adoption in the Global South constitutes a complex socio-technical transition requiring coordinated policy reform, standardization, financial instruments, and sustained investment in human capital development.

4.4. Comparative Analysis: Global North vs. Global South

The adoption of robotics and 3D printing in construction exhibits marked disparities between the Global North and the Global South, driven by differences in economic capacity, institutional maturity, technological infrastructure, and industry organization. In the Global North, adoption has advanced from pilot experimentation to scalable commercial deployment, supported by mature R&D ecosystems, regulatory clarity, and high levels of digital integration across the construction value chain (Lopes de Aquino Brasil & Carmo Pena Martinez, 2025; Banihashemi et al., 2025). By contrast, adoption in the Global South remains predominantly nascent and project-based, frequently confined to demonstration initiatives or donor-supported schemes, with limited evidence of sustained industrial-scale integration (Okangba et al., 2025).

In advanced economies, robotics and additive manufacturing are increasingly embedded within Construction 4.0 strategies, leveraging BIM, digital twins, and automated fabrication to address labour shortages, demographic shifts, and sustainability imperatives (Banihashemi et al., 2025). More so, adoption in the Global North is largely firm-driven and market-oriented, facilitated by private investment, standardized processes, and interoperable digital systems. On the contrary, in the Global South, integration is shaped by cost sensitivity, infrastructural deficits, fragmented supply chains, and the prevalence

of informal construction practices (Agegn et al., 2026). In the Global South, technology adoption is often problem-driven, motivated by urgent housing or infrastructure needs, rather than embedded within long-term automation roadmaps.

These structural asymmetries underscore the limits of direct policy transfer. While lessons from the Global North highlight the importance of regulatory coherence, skills development, and phased implementation pathways (Mishra, 2025), contextual adaptation remains critical. In labour-abundant settings, automation may be perceived as a threat to employment, requiring socially inclusive transition strategies centred on workforce upgrading and job transformation (Olatunde et al., 2023). Accordingly, effective adoption in the Global South requires context-sensitive policy design, hybrid business models, and socio-technical alignment attuned to local economic and institutional realities rather than replication of Global North models.

5. Discussion

5.1. Synthesis of Key Findings

The review indicates that the adoption of robotics and 3D printing in the construction industries of the Global South is driven by a tension between substantial technological potential and deeply embedded contextual limitations. Reported benefits, particularly improvements in efficiency, productivity, occupational safety, and environmental sustainability, constitute the principal motivations for adoption and align with broader Construction 4.0 evidence from developed and developing contexts (Okangba et al., 2025). These benefits, however, do not translate automatically into widespread implementation because adoption is mediated by the institutional, financial, and human-capital conditions within which construction firms operate.

High capital requirements, shortages of specialised skills, fragmented industry structures, and underdeveloped regulatory frameworks collectively restrict firms' capacity to integrate, sustain, and scale these technologies. Consequently, the adoption trajectory in the Global South differs markedly from that of the Global North, where stronger organisational readiness and greater policy alignment facilitate diffusion across the construction sector. In the Global South, implementation remains predominantly incremental, experimental, and concentrated in isolated pilot projects, with substantial disparities across geographical regions and firm sizes (Akinradewo et al., 2023a).

5.2. Interrelationships Between Drivers and Barriers

The review highlights that drivers and barriers are interdependent rather than isolated forces. For example,

while robotics and 3D printing can generate long-term cost savings and productivity gains, high upfront investments and uncertain ROI constrain organizational commitment, particularly among small and medium-sized enterprises which are prevalent in the Global South construction sector (Rojas et al., 2025). Similarly, potential gains in safety and quality are undermined by limited technical capacity, lack of maintenance expertise, and inadequate digital infrastructure (Agegn et al., 2026). These dynamics align with the Technology–Organization–Environment (TOE) and socio-technical frameworks, emphasizing that technological advantages alone are insufficient without supportive organizational capabilities and enabling institutional conditions (Yadegari et al., 2024; Prakash, 2025).

5.3. Implications for Policy and Practice

The findings from the study signify that policy interventions must be context-sensitive to address the uncertainties in automated construction methods while motivating innovation adoption. Governments in the Global South can play a catalytic role through targeted subsidies, public procurement strategies, and workforce development programmes that reduce entry barriers and mitigate investment risk (Mishra, 2025). Regulatory frameworks should also facilitate incremental experimentation and the integration of automated technologies into existing construction practices while ensuring safety and quality compliance (Won et al., 2022).

For practitioners, phased or hybrid adoption strategies, such as off-site 3D printing, semi-automated robotics, and pilot-scale projects, will be more viable than immediate full automation. Workforce development should focus on skills transformation rather than displacement, fostering human–machine collaboration and enhancing long-term industry resilience (Oke et al., 2025). By aligning technological capabilities with organizational readiness and policy support, construction firms in the Global South can gradually scale adoption while mitigating financial, technical, and operational risks.

5.4. Recommendation

The evidence synthesized in this systematic review indicates that the effective adoption of robotics and 3D printing in construction across the Global South requires coordinated, context-sensitive action across strategic, policy, industry, academic, and research domains. Rather than pursuing immediate full-scale automation, construction stakeholders should adopt phased and hybrid implementation pathways that align technological ambition with organisational readiness and financial capacity (Bou Hatoum & Nasserredine, 2025). Off-site additive manufacturing, semi-automated robotic systems, and pilot-scale demonstration projects can reduce implementation risks, strengthen institutional expertise, and generate

credible evidence of technological and economic value. These measures should be supported by sustained capacity-building in technical competence, digital literacy, and change management to address skills deficits and workforce resistance while promoting productive human–machine collaboration rather than technological displacement.

Governments should complement these organisational strategies by establishing clear regulatory frameworks covering the safety, quality assurance, certification, and liability requirements of automated and additive construction methods. Targeted policy instruments, including tax incentives, innovation grants, preferential public procurement, and support for local manufacturing, can lower entry barriers, stimulate investment, and strengthen market confidence. Equally important is the development of robust industry–academia–government partnerships capable of supporting the co-design of locally appropriate technologies, applied demonstration projects, and industry-responsive training programmes. Such collaboration would accelerate knowledge transfer, strengthen domestic technological capabilities, and foster sustainable innovation ecosystems adapted to the socioeconomic, infrastructural, and institutional realities of the Global South.

6. Conclusion and Further Research

This systematic review shows that the adoption of robotics and 3D printing in the Global South construction industry is shaped by interconnected technological, financial, institutional, regulatory, and labour-market conditions. Although these technologies can improve productivity, precision, safety, material efficiency, and sustainability, their diffusion remains limited by high investment costs, skills shortages, weak digital infrastructure, fragmented industry structures, and uncertain regulatory frameworks. The review contributes to knowledge by extending Construction 4.0 and innovation-adoption scholarship to underexamined Global South contexts and demonstrating that adoption is not simply a matter of technology transfer, but a socio-technical process dependent on local capability, institutional readiness, financing, regulation, and workforce adaptation.

The findings have concrete implications for policy and practice. Governments should introduce innovation grants, tax incentives, import-duty relief, regulatory sandboxes, and public procurement provisions that support tested and locally appropriate construction technologies. Standards bodies, building authorities, and professional councils should establish clear requirements for structural integrity, safety, equipment certification, liability, and quality assurance. Contractors, technology providers, materials suppliers, financial institutions, insurers, universities, technical colleges, and trade unions should collaborate through shared fabrication centres, demonstration projects,

workforce reskilling, equipment-leasing schemes, and locally adapted technology development. Institutional reforms should also integrate robotics, additive manufacturing, digital design, maintenance, and technology governance into construction-related education and professional training.

Future research should move beyond exploratory studies towards longitudinal, cross-country, and project-level investigations of costs, productivity, safety, environmental performance, and scalability. Greater attention should be given to employment effects, informal labour, small and medium-sized

contractors, gender inclusion, local materials, maintenance capacity, and unequal access to training and finance. Comparative studies should also assess alternative adoption models, including equipment-as-a-service, shared fabrication hubs, public-private partnerships, and university-industry innovation centres. Such research is necessary to determine how robotics and 3D printing can be institutionalised in ways that support inclusive industrial development, employment resilience, infrastructure delivery, and sustainable urban transformation.

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