

ASSESSING THE INTEGRATION AND UTILISATION OF ROBOTICS IN THE SOUTH AFRICA CONSTRUCTION INDUSTRY

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Abstract

Purpose: This study assesses the integration and utilisation of robotics in the South African construction industry by examining the major operational, technological, and cost-related barriers affecting adoption, as well as strategies for improving effective implementation.

Design/Methodology/Approach: A qualitative research approach was adopted using a systematic literature review (SLR). Fifty-five peer-reviewed journal articles, industry reports, and policy documents were analysed using thematic analysis to identify recurring patterns relating to robotics adoption, cost implications, and implementation strategies within the South African construction context.

Findings: The findings reveal that robotics utilisation in South African construction remains limited and largely pilot driven. Economic and financial barriers emerged as the most significant challenge, cited in 54.5% of reviewed studies, followed by skills and organisational readiness constraints (49.1%) and technological and infrastructural limitations (41.8%). Cost-related impacts were dominated by upfront capital investment (50.9%) and maintenance and lifecycle costs (47.3%). The study further identified key adoption strategies, including financial incentives, skills development initiatives, technological infrastructure readiness, and regulatory reforms to support Construction 4.0 implementation.

Practical Implications: The study provides actionable insights for policymakers, contractors, and professional bodies by highlighting the need for funding support, workforce upskilling, infrastructure improvement, and supportive regulatory frameworks.

Originality/Value: The study contributes context-specific evidence on robotics adoption in South Africa, addressing a gap in African construction research by integrating operational, technological, and financial perspectives.

Research Limitations: The study relies on secondary data and lacks empirical validation from live construction projects. Future research should incorporate quantitative surveys and case studies to evaluate the performance and return on investment of robotics in construction projects.

Keywords: Automation in Construction, Construction Robotics, Robotics Adoption, South African Construction Industry

1. Introduction

The construction industry has traditionally been labour-intensive, heavily reliant on manual processes and often challenged by inefficiencies, safety concerns, and time overruns. Globally, the advent of robotics and automation has started transforming construction operations, offering solutions that can improve productivity, precision, and worker safety. Robotics has been increasingly utilised in developed countries for tasks such as bricklaying, concrete dispensing, demolition, 3D printing of building components, and site monitoring, reflecting significant strides in Construction 4.0 (Bock, 2015). However, in many developing countries, including South Africa, and particularly in the province of South Africa, the integration of robotics in construction remains minimal, sporadic, and poorly documented (Aghimien et al., 2020).

In the recent time, the global construction industry is experiencing a paradigm shift with the integration of robotics and advanced automation technologies aimed at improving productivity, safety, and efficiency. In countries such as Japan, Germany, and the United States, robotics are being increasingly employed to perform repetitive, hazardous, or precision-based tasks (Olatunde et al.2023). Recent literature has emphasized the global benefits of robotics in construction, such as reductions in workplace accidents, enhanced quality control, and better time management (Zhou et al., 2013). However, most existing studies focus on technologically advanced regions, with limited empirical data available for emerging markets like South Africa. Moreover, while theoretical discussions exist about Construction 4.0 in Africa, the actual evidence of implementation, challenges, and drivers for adopting robotics is scarce (Oesterreich and Teuteberg, 2016).

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Despite growing awareness of digital transformation in the South African construction industry, there remains a gap in the understanding and practical implementation of robotic technologies, especially at the provincial and municipal project levels. South Africa, as one of the country's major construction hubs due to ongoing infrastructure development, faces constraints such as limited technological capacity, high costs of robotic systems, and lack of skilled personnel to operate advanced tools (Harty et al., 2020). These limitations hinder the sector's ability to adapt to technological innovation, leaving opportunities for robotics underexplored in terms of enhancing efficiency and reducing project risks. There is a pressing need to investigate the extent to which robotics is being integrated and utilised within this specific regional context (Aibinu and Venkatesh, 2014).

Despite the global evidence of productivity improvements through robotics, the construction industry in South Africa continues to face persistent challenges including labour inefficiencies, safety incidents, and low productivity (CIDB, 2020). South Africa, as one of the country's key economic and construction hubs, provides a pertinent regional case study to explore whether and how robotics could contribute towards addressing these challenges. The research is therefore driven by the need to bridge the gap between global best practices and local realities, offering insight into the readiness of local construction firms, policy constraints, skill levels, and infrastructural limitations.

The study is situated in the broader context of South Africa's push toward modernising its construction sector amid declining productivity and global competitiveness. The government's National Development Plan (NDP) and the Construction Industry Development Board (CIDB) have underscored the importance of technological advancement in improving infrastructure delivery (CIDB, 2020). South Africa, with its urban expansion and ongoing mega-projects in transport and housing, provides a rich environment to examine whether robotics is being used effectively to meet strategic construction goals. Yet, industry stakeholders often cite barriers such as capital investment limitations, cultural resistance to change, and insufficient training as hindrances to adopting advanced technology (Aigbavboa, et al., 2020).

The COVID-19 pandemic further emphasized the need for contactless and automated solutions in construction, prompting a re-evaluation of manual processes and worker density on sites (Gbadamosi et al., 2021; Aghimien et al., 2022). However, post-pandemic recovery plans in South Africa have not clearly outlined strategies to scale robotic technologies, revealing a potential disconnect between policy and practice. This study will investigate how these global and national

drivers translate into real actions on the ground in South Africa's construction environment.

The study is worth conducting for several reasons. Firstly, it contributes to the limited body of academic literature on construction robotics in the African context, where labour-intensive methods still dominate. Secondly, it informs policymakers and industry stakeholders on how to align construction sector development with the Fourth Industrial Revolution (4IR) goals. Lastly, understanding the level of integration of robotics may also help construction firms prepare for inevitable digital transformations, potentially leading to cost reductions, safer worksites, and time efficiencies (Balaguer and Abderrahim, 2008). Although several international studies have examined robotics adoption in construction, limited research has focused specifically on the South African construction industry, particularly from an operational, technological, and cost-related perspective. This study addresses this gap by synthesising evidence on the barriers, cost implications, and implementation strategies influencing robotics utilisation within South Africa. The study therefore contributes context-specific insights that support policy development and industry transition towards Construction 4.0.

2. Literature Review

The adoption of robotics in construction has accelerated globally due to increasing demands for productivity, safety, and efficiency within the Construction 4.0 agenda. In developed economies such as Japan, Germany, and the United States, robotics has been successfully deployed for activities including bricklaying, demolition, autonomous site monitoring, and additive manufacturing (Bock, 2015; Zhou et al., 2013). These technologies have demonstrated the potential to reduce workplace accidents, improve construction precision, and minimise project delays. However, the extent of robotics integration varies significantly between developed and developing economies due to differences in technological readiness, infrastructure, and investment capacity (Oesterreich and Teuteberg, 2016).

In South Africa, robotics adoption remains relatively limited despite growing discourse surrounding digital transformation in the construction industry. Existing studies indicate that the sector continues to rely heavily on labour-intensive practices because of cost sensitivities, fragmented project delivery systems, and limited technological maturity (Mpofu and Kajimo-Shakantu, 2020). While global literature frequently presents robotics as a pathway to productivity improvement, such assumptions are not easily transferable to the South African context where firms, particularly SMEs, operate under constrained financial conditions. This highlights an important gap between international best practices and local industry realities.

Economic and financial barriers are consistently identified as the most significant constraints to robotics utilisation in construction. The procurement, operation, and maintenance of robotic systems require substantial capital investment, which many South African contractors are unable to sustain (Smallwood and Allen, 2019). Unlike large firms in developed economies that benefit from economies of scale and repetitive project workflows, South African contractors often undertake short-term and fragmented projects, making the return on investment uncertain. Oke et al. (2020) further argue that lifecycle costs, including software upgrades, maintenance, and imported spare parts, significantly increase the total cost of ownership. Consequently, robotics adoption remains concentrated in pilot projects rather than mainstream implementation.

Beyond financial barriers, the shortage of skilled human capital limits the effective deployment of robotics technologies. Studies have shown that the South African construction workforce lacks specialised competencies in automation, coding, systems integration, and digital project management (Aghimien et al., 2022). This skills deficit is exacerbated by weak collaboration between universities, technical institutions, and industry stakeholders, resulting in limited exposure to practical robotics applications. Although some scholars advocate increased investment in training and professional development, there is limited evidence demonstrating how existing educational frameworks can adequately support large-scale robotics integration within construction environments.

Technological and infrastructural limitations also undermine robotics adoption in South Africa. Robotics systems depend heavily on stable digital infrastructure, reliable electricity supply, and integrated data environments such as Building Information Modelling (BIM) platforms. However, the inconsistent adoption of BIM and persistent load-shedding challenges reduce operational reliability and increase downtime risks (Aigbavboa et al., 2016; Akinradewo, 2020). While studies acknowledge these infrastructural constraints, limited research critically evaluates how energy instability specifically affects the long-term economic sustainability of robotics in construction projects.

Regulatory and socio-technical factors further complicate robotics implementation. Existing occupational health and safety frameworks in South Africa provide limited guidance on the operation and regulation of collaborative robotics systems, forcing firms to rely on international standards such as ISO 10218 (ISO, 2016). This regulatory uncertainty contributes to cautious adoption by contractors and insurers. Furthermore, labour unions and workers often perceive robotics as a threat to employment

opportunities within an already labour-intensive industry (Haupt and Smallwood, 2018). Such resistance illustrates that robotics adoption is not solely a technological issue but also a socio-economic and organisational challenge requiring effective change management strategies.

Although prior studies have examined isolated aspects of robotics adoption, much of the literature remains descriptive and fragmented, with limited synthesis of operational, technological, financial, and socio-technical dimensions within the South African construction context. Existing research largely focuses on developed economies, leaving insufficient context-specific evidence for emerging African markets. This study addresses this gap by critically synthesising literature on the challenges, cost implications, and strategic interventions influencing robotics utilisation in South African construction projects. By integrating these dimensions, the study contributes a more holistic understanding of the readiness of the South African construction industry for robotics-driven transformation under Construction 4.0.

3. Research Methodology

This study adopted a qualitative research approach anchored in a Systematic Literature Review (SLR). The qualitative approach was considered appropriate because the study sought to explore the contextual realities, perceptions, and operational challenges associated with robotics integration in the South African construction industry. Qualitative research enables the interpretation of socio-technical issues that cannot be fully explained through numerical analysis alone (Denzin and Lincoln, 2017). Since robotics adoption involves organisational readiness, financial constraints, technological capacity, and regulatory issues, the qualitative approach provided a holistic understanding of the phenomenon.

The study employed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework to ensure transparency, rigour, and replicability throughout the review process. The PRISMA process consisted of four stages: identification, screening, eligibility, and inclusion. During the identification stage, literature was sourced from reputable databases including ScienceDirect, Taylor & Francis, Emerald Insight, Google Scholar, and institutional publications. Search keywords included “construction robotics,” “automation in construction,” “Construction 4.0,” “robotics adoption,” “digital construction,” and “South African construction industry.” The inclusion criteria comprised peer-reviewed journal articles, conference papers, policy documents, and industry reports published in English between 2015 and 2025 that focused on robotics adoption, operational challenges, cost implications, or implementation strategies in construction. Studies

unrelated to construction robotics, non-English publications, duplicate articles, opinion pieces without empirical or conceptual relevance, and studies outside the selected timeframe were excluded.

The PRISMA screening process resulted in 70 initially identified records, of which 5 duplicates and irrelevant articles were removed during title and abstract screening (Figure 1). Thereafter, 59 articles were assessed for eligibility through full-text review, while 2 studies were excluded for insufficient relevance and methodological limitations. Ultimately, 55 publications were retained for the final review and thematic analysis. Data extracted from the selected studies were analysed using thematic analysis following the procedures proposed by Braun and Clarke (2006). The analysis involved repeated reading of articles, coding of recurring concepts, grouping related codes into themes, and synthesising findings into major thematic

categories aligned with the study objectives. The main themes identified included operational and technological challenges, cost-related impacts, and strategies for improving robotics utilisation.

To ensure reliability and validity, the study adopted several measures. First, only credible and peer-reviewed sources from established databases were included to improve data reliability. Second, the use of explicit inclusion and exclusion criteria minimised selection bias and enhanced consistency in the review process. Third, data triangulation was achieved by comparing findings across academic publications, industry reports, and policy documents (CIDB, 2020; World Bank, 2022). Lastly, maintaining a transparent PRISMA procedure and systematic coding process enhanced the dependability and replicability of the findings (Tranfield et al., 2003).

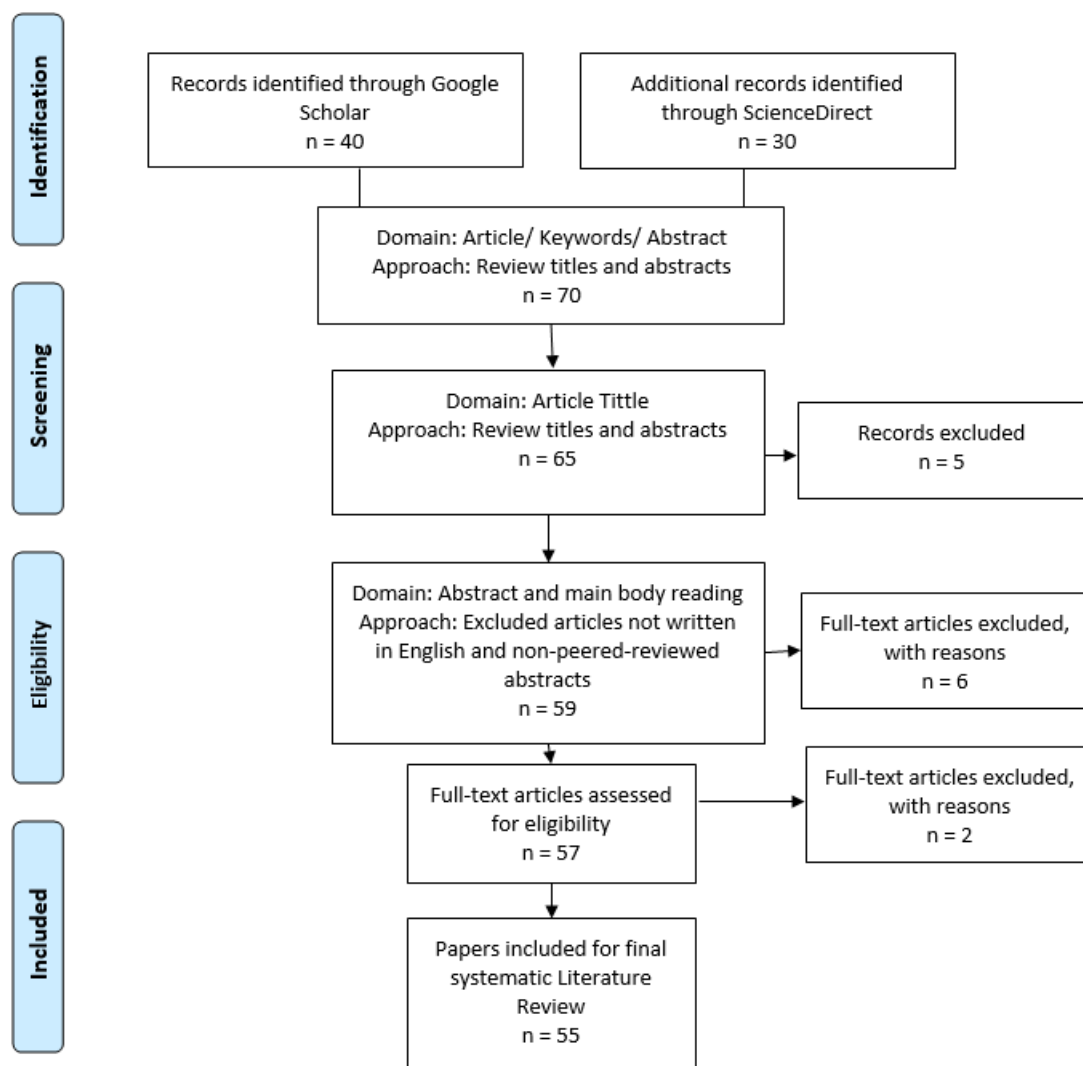


Figure 1: Research PRISMA Flow diagram

4. Results

Key Operational and Technological Challenges Affecting the Utilisation of Robotics in Construction Projects in South Africa

The results represented in Figure 2 are based on the key operational and technological challenges with the highest frequency rates affecting the utilisation of robotics in South African construction projects.

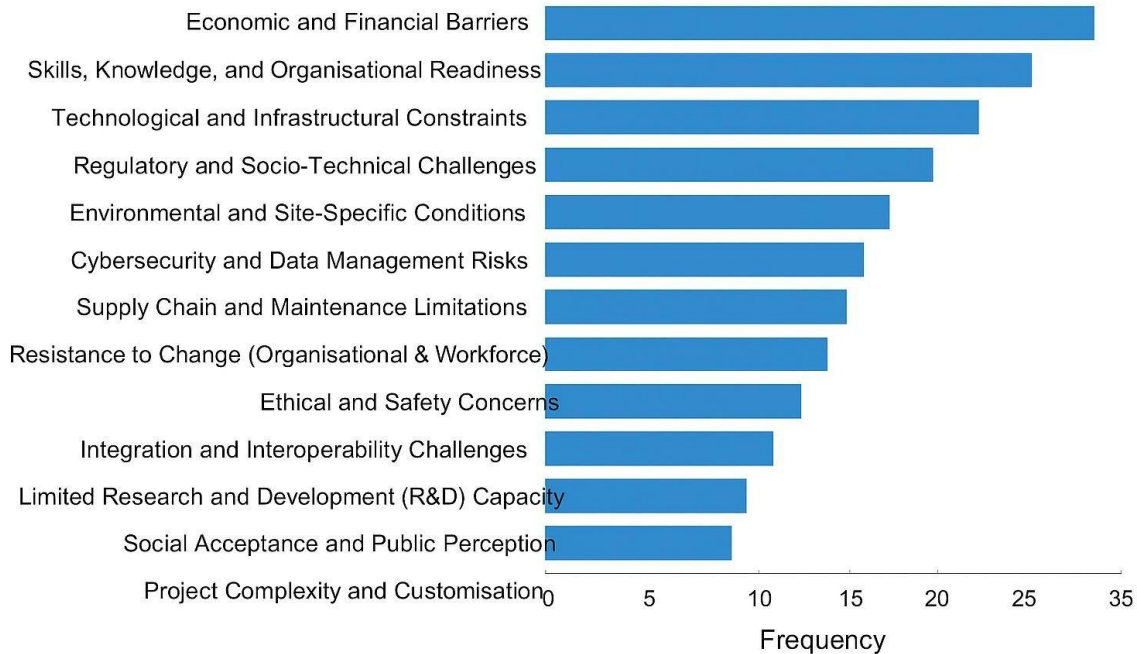


Figure 2: Key Operational and Technological Challenges Affecting the Utilisation of Robotics in Construction Projects in South Africa

According to the analysis of 55 publications, challenges such as economic and financial barriers (30/55 = 54.5%), skills, knowledge, and organisational readiness (27/55 = 49.1%), technological and infrastructural constraints (23/55 = 41.8%), and regulatory and socio-technical challenges (21/55 = 38.1%) emerged as the most frequently cited barriers. These are followed by environmental and site-specific conditions (19/55 = 34.5%), cybersecurity and data management risks (18/55 = 32.7%), supply chain and maintenance limitations (15/55 = 27.3%), resistance to change (organisational & workforce) (14/55 = 24.45%), ethical and safety concerns (13/55 = 23.6%), integration and interoperability challenges (12/55 = 21.8%), limited research and development (R&D) capacity (9/55 = 16.4%), and social acceptance and public Perception (7/55 = 17.7%).

From the analysis, economic and financial barriers remain the most dominant challenge, largely due to the high procurement and maintenance costs of robotic systems, which discourage adoption among small and

medium-sized enterprises (SMEs) that dominate the South African construction market. This challenge is compounded by limited access to funding, a lack of government incentives, and uncertainty regarding return on investment. Similarly, skills shortages and weak organisational readiness further constrain adoption, as limited technical expertise, insufficient training, and minimal collaboration between academia and industry hinder effective implementation and long-term sustainability of robotics in construction

(Akinradewo et al., 2020; Aghimien et al., 2022).

Cost-Related Impacts Resulting from Challenges in the Implementation and Maintenance of Robotic Technologies in the South Africa Construction Industry

The results represented in Figure 3 are based on cost-related impacts with high frequency rates identified across the reviewed publications. According to the analysis, major cost challenges include upfront capital investment (28/55 = 50.9%), maintenance and lifecycle costs (26/55 = 47.3%), infrastructure and integration costs (24/55 = 43.6%), social and regulatory compliance costs (19/55 = 34.5%), high initial investment and financing constraints (18/55 = 32.7%), maintenance costs and long-term economic sustainability (17/55 = 30.9%), financing and capital structure impacts (15/55 = 27.3%), maintenance, spare parts, and supply-chain cost impacts (14/55 = 30.9%), downtime, reliability, and contingency cost impacts (13/55 = 23.6%), training, upskilling, and human capital cost impacts (12/55 = 21.8%), integration,

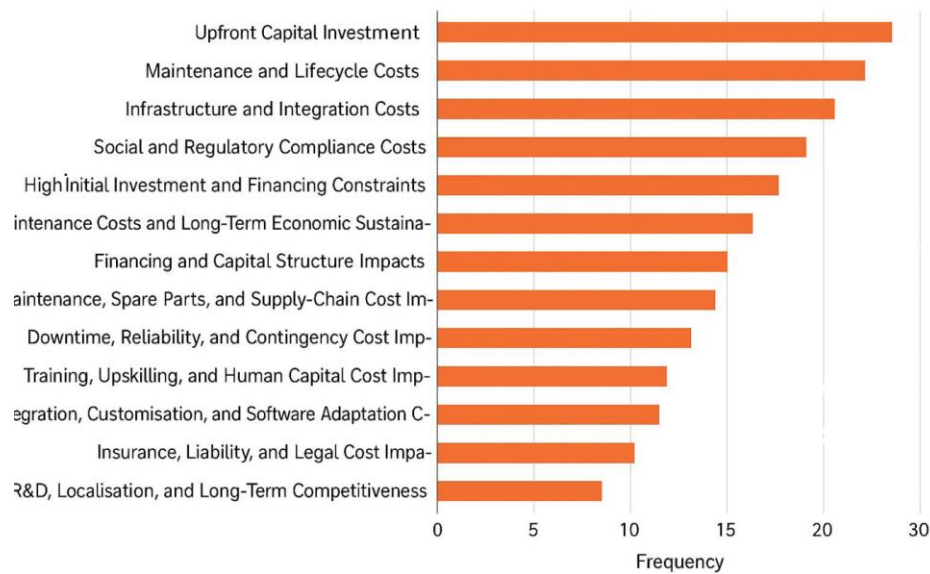


Figure 3: Cost-Related Impacts Resulting from Challenges in the Implementation and Maintenance of Robotic Technologies

customisation, and software adaptation cost impacts ($11/55 = 20.0\%$), insurance, liability, and legal cost impacts ($10/55 = 18.2\%$), and R&D, localisation, and long-term competitiveness cost impacts ($9/55 = 16.4\%$).

From the result analysis, upfront capital investment emerges as the most significant cost-related impact influencing robotics adoption in South African construction. The high initial expenditure required to procure and deploy robotic technologies limits accessibility for small and medium-sized enterprises (SMEs) and reduces the financial feasibility of large-

scale implementation. This, coupled with maintenance and lifecycle costs, underscores the financial strain associated with the integration and sustainability of robotics within the local construction industry (Mpofu and Kajimo-Shakantu, 2020).

Strategies that can be Employed to Overcome the Major Challenges in the Adoption and Effective Use of Robotics in Construction Projects within South Africa

The results represented in Figure 4 are based on the strategies with the highest frequency rate identified



Figure 4: Strategies to Overcome the Major Challenges in the Adoption and Effective Use of Robotics in Construction Projects

across 55 reviewed publications. According to figure 3, the most frequently cited remedies include financial support and incentives (30/55 = 54.5%), skills development and human capacity building (28/55 = 50.9%), technological and infrastructural readiness (27/55 = 49%), regulatory and socio-technical measures (25/55 = 45.5%), financial innovation and alternative funding mechanisms (24/55 = 43.6%), localisation and indigenous innovation in robotics (22/55 = 40%), awareness creation and change management strategies (21/55 = 38.2%), financing innovations and shared asset models (20/55 = 36.4%), localisation, supplier development and maintenance ecosystems (19/55 = 34.5%), curriculum reform, TVET and continuous professional development (18/55 = 32.7%), standards, certification and regulatory sandboxes (17/55 = 30.9%), procurement reform and value-based contracting (15/55 = 27.3%), and energy resilience and power supply interventions (14/55 = 25.45%).

From the result analysis, financial support and incentives emerged as the most frequently emphasised remedy, underscoring the significant role that fiscal measures and government-backed funding play in enabling robotics adoption within the South African construction industry. This finding aligns with international evidence suggesting that financial mechanisms such as tax incentives, subsidies, and leasing models substantially lower entry barriers and promote wider adoption among small and medium-sized enterprises (Mpofu and Kajimo-Shakantu, 2020; Oke et al., 2021)

5. Conclusion and Recommendations

This study assessed the integration and utilisation of robotics within the South African construction industry, with emphasis on the operational, technological, and cost-related challenges limiting widespread adoption. The findings demonstrate that although robotics has the potential to significantly improve productivity, safety, precision, and project efficiency, its utilisation in South Africa remains limited, fragmented, and largely experimental. Economic and financial barriers emerged as the most dominant challenge, particularly high procurement, maintenance, and lifecycle costs, which disproportionately affect small and medium-sized enterprises (SMEs). These findings support the studies of Mpofu and Kajimo-Shakantu (2020) and Oke et al. (2021), which identified cost and financial uncertainty as major impediments to technological innovation in developing construction economies.

The study further revealed that weak organisational readiness, inadequate technical expertise, unstable energy supply, and limited digital infrastructure continue to hinder effective robotics deployment. These findings reinforce the arguments of Aigbavboa

et al. (2020) and Aghimien et al (2022), who emphasised that digital transformation in construction is not solely dependent on technology acquisition, but also on institutional capacity, workforce competence, and supporting infrastructure. The persistence of regulatory uncertainty and socio-technical resistance also suggests that robotics adoption in South Africa is shaped as much by social and policy conditions as by technological capability. This demonstrates that the transition towards Construction 4.0 within developing economies is significantly more complex than the experiences reported in technologically advanced countries.

Critically, the study contributes to knowledge by providing context-specific evidence on robotics integration within the South African construction industry, an area that remains underexplored in existing literature. Unlike previous studies that primarily focus on developed economies, this study synthesises operational, financial, technological, and socio-technical dimensions of robotics adoption within an African construction context. The study therefore extends Construction 4.0 discourse beyond technologically mature environments and highlights the importance of contextual realities such as energy instability, limited digital maturity, and labour-market sensitivities in shaping robotics adoption outcomes.

The study also contributes methodologically by demonstrating the value of systematic literature review and thematic synthesis in consolidating fragmented evidence relating to construction robotics in emerging economies. The findings provide a foundation for policymakers, contractors, and professional bodies to formulate targeted interventions such as financial incentives, localised innovation strategies, skills development programmes, and regulatory reforms that can accelerate sustainable robotics adoption in South Africa. Beyond its practical relevance, this study contributes theoretically to the growing scholarship on Construction 4.0 and technology adoption in developing economies. The findings reinforce existing socio-technical and innovation diffusion theories by demonstrating that robotics adoption in construction is not determined solely by technological availability, but also by the interaction between economic capacity, organisational readiness, institutional support, and workforce acceptance. While previous studies on robotics adoption have largely focused on technologically advanced economies, this study extends the discourse by providing context-specific evidence from South Africa, where infrastructural instability, labour market sensitivities, and financial constraints significantly shape technology uptake.

Despite these contributions, the study is limited by its reliance on secondary data and the absence of empirical project-level validation. Future studies should therefore adopt mixed-method or quantitative approaches to

evaluate the practical performance, cost-benefit implications, and long-term return on investment of

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