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A Digital Transformation Assessment on the Role of Building Information Model Training in Built Environment Institution Programmes: Lessons from South Africa

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1 ABSTRACT

Digital transformation in the Built Environment is increasingly underpinned by the adoption and maturity of Building Information Modelling (BIM), a critical tool for enhancing technological skills and addressing complex infrastructure and service delivery challenges. However, the availability of comprehensive BIM training programs in higher education remains inadequate, limiting graduates' and practitioners' capacity to apply and integrate BIM effectively in professional contexts. This study adopts a mixed-methods approach to evaluate the maturity and integration of BIM training in South African Built Environment higher education programmes. The findings reveal that most available programs focus on introducing basic BIM concepts and adoption strategies, advanced training necessary for higher levels of BIM maturity is largely absent. While short learning programs have been developed to upskill industry practitioners, formal curricula face persistent barriers, including limited access to state-of-the-art facilities, software and licensing costs, and structural rigidities within module offerings. The study argues that these challenges undermine both the digital transformation within the Built Environment and the competitiveness of graduates entering professional practice. Ultimately, the findings underscore the urgent need for policy and institutional reforms to accelerate digital transformation and ensure that the Built Environment workforce is equipped with the skills required to meet the demands of contemporary urbanisation and infrastructure development.

Keywords: Digital transformation, training, higher institutions, Building Information Modelling, Built environment

2 INTRODUCTION

Adoption and maturity of revolutionary technologies such as Building Information Modelling (BIM) are critical in the Built Environment (BE) for improving project performance and enhancing infrastructure delivery. Digital Transformation (DT), driven by the principles of Industry 4.0, has advanced building systems significantly since the industrial revolution towards hybridised, intelligent and interconnected systems (Hazrat et al., 2023). Within the BE, Industry 4.0 technologies including big data analytics, artificial intelligence, virtual modelling and integrated project delivery are reshaping traditional infrastructure management approaches. This shift is particularly relevant in contexts facing infrastructure backlogs, rapid urbanisation and service delivery pressures, such as South Africa.

BIM occupies a central position within this digital transformation agenda. It provides innovative, effective and collaborative digital processes and management tools that equip professionals with the technological skills required to address complex infrastructure and service delivery challenges (Akintols et al., 2020; Omar & Dulaimi, 2023; Obi et al., 2024). According to McAuley and Behan (2019), BIM can be utilised for multiple analyses and performance predictions, particularly in projects requiring collaborative three-dimensional design applications. It reshapes and simplifies the BE by enhancing professional roles and responsibilities across the planning, design, construction, operation, and maintenance phases (Whyte & Hartmann, 2017). Furthermore, DT interventions contribute to notable productivity gains by supporting professionals with comprehensive, accurate, and real-time information for day-to-day decision-making (Kaushalya et al., 2024).

Numerous scholars argue that the evolution of DT has contributed significantly to mitigating climate and sustainability challenges in the BE by moving beyond traditional infrastructure management approaches (Muzi et al., 2022; Samuelson & Stehn, 2023). The shift from fragmented, time-consuming and financially costly traditional techniques towards multidisciplinary, digitally enabled processes enhances value creation across the infrastructure chain (Hajj et al., 2021). The adoption of DT further supports sustainable strategies and green practices in urban BE contexts experiencing considerable environmental and social pressures (Stroumpoulis & Kopanaki, 2022). For example, large volumes of social and environmental data can be modified and virtualised in real time to identify potential threats, simulate predictive scenarios and recommend resilient infrastructure interventions (Daniotti et al., 2020; Muzi et al., 2022; Saka, 2022). Understanding information through data analytics thus provides multiple pathways for improving infrastructure performance and service delivery (Whyte & Hartmann, 2017).

Despite these advantages, graduates' and practitioners' capacity to effectively apply and integrate BIM in professional contexts remains constrained. Training programmes on BIM adoption are more critical than ever in responding to the demands of big data and rapid urban development. However, many higher education institutions experience inadequate BIM integration within their curricula, resulting in graduates who are insufficiently prepared for digitally enabled practice. Rather than expecting industry to shoulder the responsibility of upskilling graduates, scholars argue that students should be trained during their educational journey to become BIM-ready professionals, thereby avoiding additional financial and time burdens on industry (Iqbal et al., 2022; Olowa et al., 2022; Hazrat et al., 2023). At the same time, Yusuf et al. (2017) highlight that higher education institutions face challenges related to limited knowledge, skills, finances, and resources, which constrain the development of a high-standard BIM workforce. Iqbal et al. (2022) therefore advocate for stronger industry participation in collaborative seminars, workshops and international engagements to facilitate skills transfer to educators.

In developing countries, the adoption and maturity of DT, including BIM, big data analytics, virtual modelling, artificial intelligence, and green building technologies, remains comparatively slow (Saka, 2022). Although university–industry research collaboration is recognised as a key driver of technological innovation and BIM maturity (Iqbal et al., 2022), limited attention has been given to systematically evaluating the scope, depth and maturity of BIM training within university programmes, particularly in the South African context. This gap has significant implications for digital transformation and graduate readiness within the BE sector.

Accordingly, this study aims to evaluate the maturity and integration of BIM training in South African BE higher education programmes. To achieve this aim, the study employs a mixed-method approach comprising a literature review, surveys and semi-structured interviews involving students, academics and professionals in Urban and Regional Planning, Construction, Civil Engineering and Architecture. Through this investigation, the research seeks to provide empirical insights into strengthening BIM education as a strategic enabler of digital transformation in the South African Built Environment.

3 LITERATURE REVIEW

3.1 Digital Transformation in the Built Environment

In recent years, DT has increasingly differentiated performance across industries within BE, particularly in infrastructure construction and service delivery. Improvements in organisational capabilities and production efficiency have largely been driven by the integration of digital technologies (Samuelson & Stehn, 2023). Globally, regions such as the European Union have capitalised on the growth potential of DT technologies, including artificial intelligence (AI), robotics, advanced manufacturing, blockchain technologies, three-dimensional (3D) printing and the Internet of Things (IoT), particularly in managing and extracting value from big data (Daniotti et al., 2020). These technologies strengthen sustainable strategies across supply chains, enable real-time operational monitoring, and support resilience-oriented green practices (Stroumpoulis & Kopanaki, 2022). Consequently, the adoption of Information Technology (IT) is no longer optional but necessary to enhance stakeholder performance and infrastructure delivery outcomes (Kaushalya et al., 2024).

In developed countries, higher education institutions have increasingly aligned curricula with Industry 4.0 technologies, producing graduates who are digitally competent and responsive to evolving BE industry demands (McAuley & Behan, 2019; Daniotti et al., 2020; Stroumpoulis & Kopanaki, 2022; Hazrat et al., 2023). This alignment has strengthened the dominance of digital approaches in many developed contexts. However, the transition is not universally consistent. For example, in Italy, traditional construction management practices still dominate certain stages of the BE operational cycle despite the availability of DT technologies (Muzi et al., 2022). In developing countries, adoption is generally slower and more fragmented.

Although DT technologies form part of contemporary industrial discourse, higher education institutions in many developing contexts continue to lag in implementation (Benavides et al., 2020; Badran et al., 2022). Structural challenges, including corruption, weak governance, limited funding, and shortages of skilled personnel, restrict institutional capacity to modernise curricula and infrastructure (Hannan, 2023). In extreme cases, geopolitical instability further constrains digital adoption, as illustrated in conflict-affected contexts such as Syria (Habib, 2023).

These global dynamics resonate with realities in South Africa, where higher education institutions operate under financial constraints, uneven digital infrastructure and significant student enrolment pressures. While national policies promote digital innovation and infrastructure development, practical implementation within BE programmes remains uneven. As a result, digital transformation in the South African BE sector continues to be characterised by pockets of excellence rather than systemic maturity.

3.2 BIM Adoption and Training in Higher Education

Contemporary research positions BIM as a central enabler of digital transformation in the BE. Increasingly, BIM is integrated with emerging technologies such as IoT, augmented and virtual reality (AR/VR), AI, drones, robotics, 3D printing, and laser scanning (Prabhakaran et al., 2021; Liu et al., 2021). When integrated effectively, these technologies extend BIM beyond three-dimensional modelling into a dynamic decision-support ecosystem. For instance, IoT sensors embedded within buildings enable real-time data collection on structural performance, energy consumption, and environmental conditions. When linked to BIM platforms, these datasets support predictive maintenance and lifecycle optimisation. Similarly, AR/VR technologies enhance stakeholder engagement by enabling immersive visualisation of design alternatives prior to construction, reducing costly revisions. AI and machine learning algorithms applied to BIM datasets improve risk identification, detect design inefficiencies, and optimise scheduling processes (Bunse et al., 2025). Drone and laser scanning technologies facilitate the development of accurate as-built models, improving monitoring and quality control.

Despite these advances, the integration of BIM with advanced technologies remains uneven across regions and sectors. While BIM research continues to expand ranging from design coordination improvements to automation and robotics integration (Jayasena et al., 2024; Adegoke et al., 2026) the field has evolved in an incremental and fragmented manner, often lacking a coherent digital transformation narrative (Azhar, 2011; Volk et al., 2014; Yalcinkaya & Singh, 2015). Much of the literature focuses on adoption strategies, implementation barriers and best practices, yet comparatively limited attention has been given to educational maturity and curriculum integration, particularly in developing country contexts.

A recurring challenge identified in the literature is the difficulty of integrating BIM into existing organisational systems and workflows (Volk et al., 2014; Schroeder et al., 2020). Technical interoperability constraints, institutional resistance to change, and insufficient digital infrastructure frequently inhibit progress. These challenges are amplified in resource-constrained environments, where managing large-scale, data-intensive models places significant demands on hardware, software licensing, and specialist expertise.

The concept of BIM maturity provides a useful framework for evaluating implementation depth. Maturity models generally conceptualise BIM development along progressive levels:

- Level 0: A pre-BIM environment dominated by two-dimensional CAD drawings and paper-based documentation, with minimal digital collaboration. In many South African small and medium-sized enterprises, this level still characterises routine practice, particularly in municipal infrastructure projects.
- Level 1: Partial digitalisation through isolated 3D modelling tools. While visualisation improves, collaboration remains siloed, and data exchange is limited. Some South African universities introduce BIM at this level through standalone modelling modules without interdisciplinary integration.
- Level 2: Collaborative workflows supported by standardised data exchange formats (e.g., Industry Foundation Classes, IFC). Stakeholders share coordinated models, improving clash detection and reducing errors. Larger South African firms involved in commercial developments increasingly operate at this level, although adoption is inconsistent across sectors.

- Level 3 (and beyond): Fully integrated digital environments linking design, construction and operation across the entire project lifecycle. Cloud-based platforms, real-time collaboration, AI-driven analytics and automated processes define this level. In South Africa, examples remain limited and are typically confined to high-budget or multinational projects.

These maturity levels highlight that BIM adoption is not solely a technical issue but also an organisational and educational one. Institutional readiness, curriculum design, educator competence and industry collaboration are critical determinants of progression across levels. Although numerous studies examine BIM implementation in practice, fewer critically assess the scope and maturity of BIM training within higher education institutions, particularly in developing contexts. Existing research often assumes that educational institutions are adequately preparing graduates for digital transformation, yet empirical evidence from resource-constrained settings suggests otherwise. In South Africa, limited curriculum integration, insufficient interdisciplinary collaboration, and uneven access to digital infrastructure may hinder the production of BIM-ready graduates.

Therefore, a clear research gap exists in systematically evaluating the scope, depth, and maturity of BIM training within BE programmes in developing country contexts. This study addresses that gap by assessing BIM training across disciplines, identifying curricular and institutional barriers, and analysing implications for digital transformation and graduate readiness within the South African Built Environment sector.

4 METHODOLOGY

This study adopted a mixed-methods research design to systematically examine the role, delivery, and perceived effectiveness of BIM training BE programmes offered by higher education institutions. The use of a mixed-methods approach was justified on the basis that BIM adoption and maturity encompass both measurable structural elements (such as training exposure, curriculum content, and resource availability) and experiential dimensions (such as perceptions of competence, institutional readiness, and preferred learning platforms). Integrating quantitative and qualitative data, therefore, enabled triangulation, enhanced validity, and provided a more comprehensive understanding of BIM training dynamics (Whyte et al., 2017; Badran et al., 2022). While quantitative data offered measurable indicators of BIM maturity and training scope, qualitative insights contextualised these findings by capturing stakeholder experiences and institutional realities.

An online survey was administered in 2025 to capture patterns of BIM training provision, utilisation, associated challenges and levels of BIM maturity across professional and academic groups in the BE sector. The survey instrument was structured around four key thematic areas, namely Exposure to BIM training, Scope and content of BIM training, BIM maturity and advanced digital skills and Resources and institutional support. The development of the questionnaire followed a multi-stage process to ensure contextual relevance and methodological rigour. Initially, a draft instrument was developed based on a review of existing literature on BIM adoption, maturity models and digital transformation in higher education. Thereafter, the instrument was refined through consultation with key stakeholders from government departments, professional councils, industry associations and academic institutions. To enhance reliability and content validity, a series of focus group discussions were conducted prior to full deployment. These discussions served to verify the clarity of questions, align terminology with industry standards, and ensure that the instrument reflected both educational realities and professional expectations. Feedback from the focus groups informed revisions to question wording, response scales, and thematic categorisation, thereby strengthening the robustness of the final survey tool.

A total of 90 respondents participated in the study. Participants were purposively selected to reflect the multidisciplinary nature of the Built Environment sector. The sample comprised of Undergraduate and postgraduate students enrolled in BE programmes, Academics involved in curriculum development and BIM instruction and Industry professionals, including practitioners from Urban and Regional Planning, Construction Management, Civil Engineering and Architecture, as well as representatives from professional bodies and government departments. This distribution ensured representation across the education–industry continuum, enabling the study to assess both training provision and professional expectations regarding graduate readiness.

Data collection was conducted in 2025. The study adhered to established ethical standards and received formal approval from the University of Johannesburg Ethics Committee prior to commencement. Participation was voluntary, and informed consent was obtained from all respondents before completing the survey and participating in the focus group. Respondents were assured of confidentiality and anonymity, and data were securely stored in accordance with institutional research governance policies. Quantitative survey data were analysed using descriptive and inferential statistical techniques. Descriptive statistics (including frequencies, percentages and mean scores) were used to assess levels of BIM exposure, training scope and perceived maturity. Comparative analysis across participant groups (students, academics and professionals) was undertaken to identify alignment or discrepancies in perceptions of BIM competence and institutional readiness.

Qualitative data derived from open-ended survey responses and focus group discussions were analysed using thematic analysis. Responses were coded inductively to identify recurring themes relating to curriculum gaps, institutional barriers, infrastructure constraints and training needs. These themes were then compared with quantitative findings to enable triangulation and deepen interpretation. By integrating quantitative indicators with qualitative insights, the mixed-methods design provided a holistic evaluation of BIM training maturity, institutional barriers and implications for digital transformation and graduate preparedness within the Built Environment sector.

5 FINDINGS

5.1 Exposure to BIM Training

The survey findings indicate limited and uneven exposure to BIM training within Built Environment (BE) programmes. Approximately 60% of respondents reported that BIM is insufficiently integrated into core curricula and is often offered only as an elective or introductory module (see Figure 1). This suggests that BIM is not yet positioned as a foundational competency within many institutions. Early-stage exposure remains particularly limited, with students typically encountering BIM concepts late in their academic trajectory.

This delayed introduction restricts the progressive development of competence and confidence, undermining cumulative skills acquisition. The quantitative results therefore indicate that BIM training remains peripheral rather than embedded within programme structures.

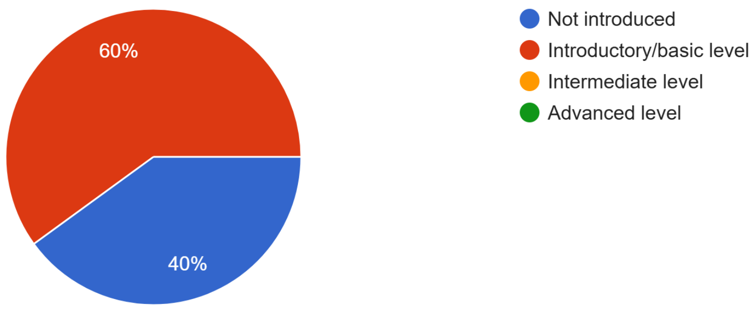

Fig. 1: Student Exposure to BIM Training

5.2 Scope and Content of BIM Training

Approximately 60% of respondents indicated that current BIM training is narrow in scope and insufficiently aligned with industry practice (see Figure 2). Training was reported to be predominantly software-centric, focusing on basic modelling functions rather than process integration across the full project lifecycle. Furthermore, respondents highlighted limited interdisciplinary collaboration within modules. This restricts students' understanding of coordinated workflows between architecture, civil engineering, construction management, and urban planning, a core requirement of BIM-enabled environments.

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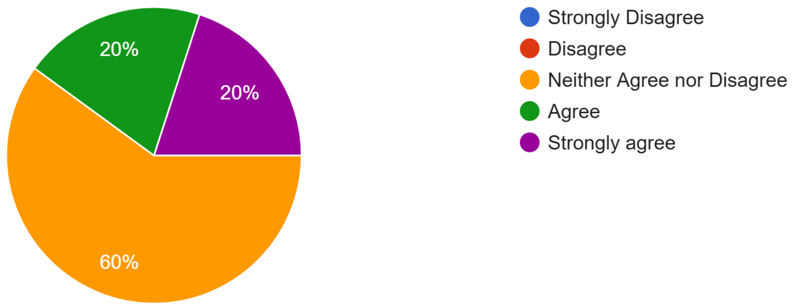

Fig. 2: Level of Training Resources and Curriculum Integration

These findings align with previous studies that identify fragmentation and incremental adoption in BIM education (Azhar, 2011; Volk et al., 2014). While institutions may introduce modelling tools, they often fail to integrate BIM as a collaborative, lifecycle-oriented process consistent with digital transformation narratives (Yalcinkaya & Singh, 2015).

5.3 BIM Maturity and Advanced Skills

Survey responses revealed generally low levels of BIM maturity, particularly in relation to advanced competencies such as:

- Multidisciplinary coordination
- Data management and interoperability
- Lifecycle integration
- Collaborative digital workflows

Although basic modelling skills were reported, progression towards Level 2 and Level 3 maturity (collaborative and fully integrated environments) remains limited. This finding echoes literature highlighting persistent institutional and technical barriers to BIM integration (Volk et al., 2014; Schroeder et al., 2020). The quantitative evidence, therefore, suggests a substantial disconnect between academic training and industry expectations, where BIM increasingly supports integrated decision-making and performance optimisation.

5.4 Resources and Institutional Support

Qualitative findings strongly emphasised institutional constraints. Figure 3 shows several participants cited High software licensing costs limiting student access, Outdated computer laboratories unable to support large BIM datasets, Limited cloud-based collaboration platforms and Insufficient continuous professional development for lecturers

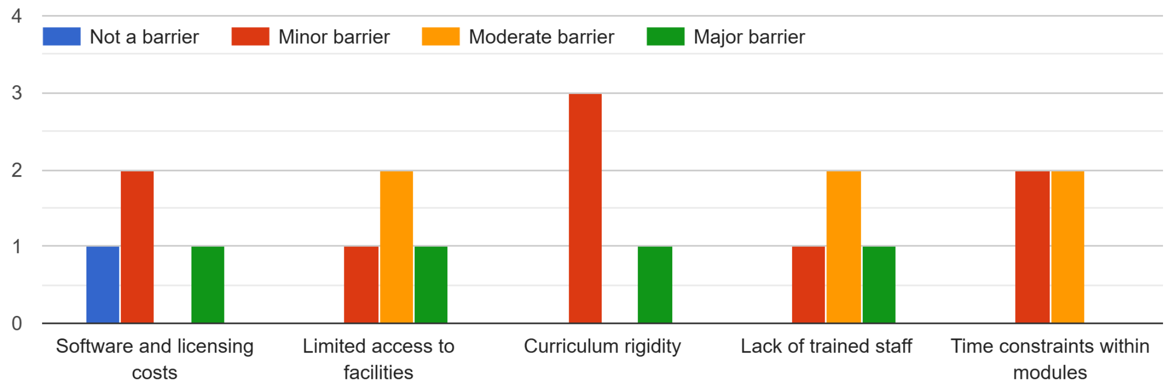

Fig. 3: Key barriers to BIM training

However, examples of good practice were identified. The University of Johannesburg Virtual Lab was highlighted as a valuable platform that provides students with remote access to BIM software and collaborative tools. This initiative demonstrates how targeted institutional investment can mitigate infrastructure constraints and enhance training quality. Participants further recommended dedicated BIM laboratories, structured lecturer upskilling programmes, stronger university and industry partnerships, and the development of national or regional BIM education standards. Such measures would align educational outcomes with industry expectations and strengthen digital transformation pathways.

6 DISCUSSION AND IMPLICATIONS

The findings confirm that BIM integration within BE curricula remains limited, uneven and insufficiently mature. This aligns with literature highlighting fragmented adoption and institutional resistance (Azhar, 2011; Volk et al., 2014; Schroeder et al., 2020). In the South African context, limited BIM integration has significant implications for graduate readiness and industry competitiveness. As infrastructure projects increasingly demand collaborative digital workflows, graduates lacking advanced BIM competencies may struggle to meet employer expectations. This perpetuates a skills gap and increases training burdens on industry.

Moreover, the dominance of software-centric training constrains deeper understanding of BIM as a process-driven digital transformation tool. Without interdisciplinary and project-based learning, students fail to develop competencies in coordination, data exchange and lifecycle management – all essential for higher maturity levels. Addressing these gaps requires systemic curriculum reform, sustained institutional investment and stronger alignment between academia and industry. By embedding BIM progressively across programmes, investing in digital infrastructure and enhancing educator capacity, higher education institutions can play a transformative role in advancing digital maturity within the South African Built Environment sector.

7 CONCLUSION

This study examined the role and effectiveness of Building Information Modelling (BIM) training within Built Environment (BE) programmes and identified significant gaps between current educational practices and the evolving demands of industry. The findings reveal that BIM integration within higher education remains limited, uneven and largely software-centric. Exposure is often delayed and insufficiently embedded within core curricula, while advanced competencies related to collaboration, coordination and lifecycle integration remain underdeveloped. Resource constraints, including high software licensing costs, inadequate digital infrastructure, and limited lecturer capacity, further inhibit progress. Collectively, these challenges weaken graduate readiness and constrain broader digital transformation efforts within the BE sector.

The study underscores the urgent need for policy reform and sustained institutional investment. Curriculum restructuring is required to embed BIM progressively across academic programmes, ensuring interdisciplinary and project-based learning that reflects real-world industry workflows. Institutions must prioritise investment in digital infrastructure, including dedicated BIM laboratories, cloud-based collaboration platforms, and updated software environments. Equally important is structured professional development for educators to ensure that teaching remains aligned with industry innovation. Strengthening industry–academia collaboration is critical to closing the identified gaps. Partnerships with professional councils, government departments, and private-sector firms can facilitate knowledge transfer, curriculum co-design, internship pipelines, and access to real-world project datasets. In addition, the development of national or regional BIM education standards would promote consistency in competency development, clarify expected graduate outcomes and align higher education outputs with industry benchmarks. Such standards could support coordinated digital transformation strategies at the sectoral level.

Future research should extend this work by exploring the effectiveness of university–industry partnership models in enhancing BIM competency development. Longitudinal studies tracking students from entry into higher education through to professional practice would provide valuable insights into how BIM skills mature over time and how curriculum interventions influence career readiness. Comparative studies across institutions or provinces could further illuminate structural inequalities and identify scalable best practices within the South African context. Ultimately, BIM training is not merely a technical curriculum component but a strategic enabler of digital transformation. Strengthening BIM education is essential to enhancing graduate competitiveness, improving infrastructure delivery, and supporting sustainable urban development. In the South African context, characterised by rapid urbanisation, infrastructure backlogs, and pressing sustainability challenges, robust and integrated BIM training will play a pivotal role in accelerating digital maturity and equipping the Built Environment workforce to meet the complex demands of the future.

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