

Article

A BIM Competency Framework for Hybrid AEC Education in Sub-Saharan Africa

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Abstract

This study examines how hybrid AEC education can foster BIM-enabled construction workflow competencies in Sub-Saharan Africa, where digital limitations impact graduate readiness. A quantitative survey of 120 students and graduates yielded 81 valid responses (68% response rate). Data were analysed using descriptive statistics and Principal Component Analysis (KMO = 0.943; Bartlett's test $p < 0.001$), revealing components that explained 77.65% of the variance. Respondents strongly supported hybrid learning, emphasising the importance of digital collaboration, curriculum reform, and equitable access to technology. However, institutional barriers such as limited digital readiness and inadequate BIM workflow training were also identified. These findings informed a competency-based framework linking hybrid delivery, digital infrastructure, curriculum modernisation, and learner capabilities to improved workflow proficiency. The study suggests that hybrid AEC education can help close digital skills gaps if supported by staff upskilling, accessible software, and workflow-focused pedagogy. Future work should validate the framework across contexts and track long-term learning outcomes.

Keywords: BIM competency; hybrid education; construction workflows; digital readiness; curriculum modernisation; AEC education

1. Introduction

The Architecture, Engineering, and Construction (AEC) industry is undergoing rapid digital transformation, driven largely by the global adoption of Building Information Modelling (BIM), which enhances project coordination, information accuracy, and data-driven decision-making across the construction lifecycle [1,2]. BIM-enabled workflows require graduates to demonstrate competence not only in software operation but also in digital processes, collaborative communication, and adherence to standards such as ISO 19650. As construction becomes more technology-dependent, higher education systems are expected to shift from traditional discipline-based learning toward competency-based models that prioritise workflow literacy, teamwork, and process-driven thinking aligned with modern industry expectations [3,4]. Hybrid learning has emerged as an adaptable approach for AEC education, blending online delivery with hands-on studio and site-based learning. This approach enables students to participate in digital simulations, virtual coordination tasks, and collaborative modelling environments that reflect real BIM processes [5–8]. Because BIM workflows demand advanced problem-solving and data integration skills, hybrid delivery offers an effective platform for assessing student competence in authentic digital project scenarios while maintaining flexibility and accessibility.



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Although the benefits of hybrid BIM education are well recognised globally, its implementation in Sub-Saharan Africa remains constrained by structural and systemic challenges. Studies in South Africa, Nigeria, and Kenya report persistent limitations such as unstable digital connectivity [9,10], restricted access to licensed BIM software [10,11], insufficient training in digital pedagogy [11,12], and weak curriculum integration of BIM workflow literacy [9]. These conditions reinforce a widening competency gap between AEC graduates and the digital coordination requirements that dominate contemporary construction practice. This raises a critical question: *Do current AEC programmes in Sub-Saharan Africa adequately prepare students for BIM-enabled workflows central to global industry practice?* While previous research has examined BIM awareness and adoption trends in the region [11,13], there is still limited evidence linking hybrid learning structures, institutional capacity, and competency-based curriculum design to measurable BIM workflow readiness. The lack of integrated frameworks connecting these factors highlights the need for a structured investigation into how hybrid AEC education can support BIM-centric skill development in Sub-Saharan African universities.

The novelty of this study lies in its development of a competency-based framework grounded in quantitative analysis to address workflow-oriented BIM skill deficits in the region. It is one of the first studies to synthesise hybrid pedagogy, institutional readiness, and BIM workflow literacy into a measurable structure tailored to Sub-Saharan Africa's digital construction context. Beyond regional relevance, this research provides insights that can inform digital education reform in other developing regions and the broader Global South, where similar infrastructural and pedagogical constraints are also present. Therefore, the study aims to develop a competency-based framework that supports BIM workflow readiness through hybrid AEC education in Sub-Saharan Africa. The objectives are to (1) identify key drivers influencing the adoption of hybrid AEC education, (2) assess the institutional and pedagogical conditions affecting BIM-centric competency development, and (3) conceptualise a framework aligning hybrid delivery, curriculum modernisation, and institutional capacity with learner digital competency and employability outcomes.

2. Literature Review

2.1. Global BIM-Enabled Workflows and Competency Development

Building Information Modelling is widely recognised as a driver of transformation in global construction workflows because it enables digital coordination, improves information accuracy, and supports lifecycle asset management [14,15]. Scholars argue that BIM shifts construction practice away from fragmented delivery models toward integrated workflows characterised by real-time information exchange, shared decision-making, and common data environments [7,16]. International frameworks such as ISO 19650 formalise these expectations by defining structured information management processes, collaborative responsibilities, and digital protocols that professionals must follow to ensure efficient project execution. Recent studies emphasise that BIM competence now extends far beyond software proficiency; it requires process literacy, knowledge of interoperability, and the ability to participate effectively in digitally mediated teamwork [14–16]. Akponeware and Adamu [17] note that graduates must understand model authoring, clash detection, information structuring, and data governance to contribute meaningfully to BIM workflows. Mahamadu et al. [18] note that BIM competence is multidimensional, encompassing technical, managerial, and collaborative skills that are aligned with workflow-driven delivery.

Despite growing industry expectations, evidence suggests that BIM education often lags behind global best practices. Several scholars report that universities frequently prioritise software instruction while neglecting workflow-based thinking, interdisciplinary problem-solving, and digital information governance [19,20]. This mismatch between

academic preparation and industry needs creates competency gaps that hinder digital transformation in the workforce [21,22]. In emerging contexts, including many parts of Sub-Saharan Africa, the gap is further widened by limited BIM teaching expertise, low institutional investment in digital infrastructure, and limited access to experiential learning environments [23,24]. Ramakrishnan et al. [25] therefore argue that curriculum reform must embed competency-based models integrating digital workflows, collaborative methodologies, and industry-aligned standards. Across the global literature, scholars consistently conclude that BIM readiness requires educational systems to adopt a holistic approach that aligns graduate capabilities with the collaborative and data-intensive processes shaping the future of construction [25–28]. This global shift forms the foundation for identifying gaps in regional BIM literacy and justifies the need for structured frameworks that enhance workflow competence within higher education.

2.2. Hybrid AEC Education and Competency-Based Learning in Sub-Saharan Africa

Hybrid learning has gained significant recognition as a suitable model for AEC education, as it combines digital delivery with hands-on studio and site-based experiences, providing flexibility for diverse learning needs [29,30]. Scholars highlight that hybrid formats are particularly effective in skill-intensive disciplines because they allow students to engage in virtual simulations, digital modelling, and collaborative design environments that reflect real construction workflows [29–32]. Cuyacot and Cuyacot [31] argue that combining hybrid delivery with competency-based assessment ensures that students progress based on demonstrated mastery rather than seat time. Research further supports that hybrid AEC learning enhances teamwork, problem-solving, and digital communication—all essential components of BIM-enabled project delivery [31–33]. Moreover, hybrid models facilitate authentic assessments, such as virtual coordination tasks, clash detection exercises, and interdisciplinary design reviews, which mirror real-world project conditions and develop workflow fluency.

However, successful hybrid implementation in Sub-Saharan Africa faces persistent obstacles. Studies report that digital inequality, inadequate infrastructure, and restricted access to licensed BIM technologies remain key barriers in the region [34,35]. Omodan [36] emphasise that many educators lack formal training in digital pedagogy, which limits their ability to manage collaborative virtual environments or assess complex, performance-based outcomes. Nahar and Machado [37] note that many universities in SSA rely on theory-based instruction with limited opportunities for experiential or practice-based digital learning. Research also reports a weak relationship between academia and industry, resulting in a misalignment between classroom experiences and professional BIM coordination expectations [24,38,39]. Despite these limitations, scholars agree that hybrid AEC education has significant potential to broaden access to digital learning and improve competency development if institutions invest in training, infrastructure, and curriculum redesign [5,6]. These insights strengthen the rationale for frameworks that integrate hybrid delivery and competency-based elements tailored to the SSA context.

2.3. BIM Adoption, Hybrid Learning, and Digital Capability Development in Sub-Saharan Africa

The construction sector in Sub-Saharan Africa is gradually adopting digital tools; however, the diffusion of BIM remains slower and less structured than in developed markets. Researchers attribute this lag to inconsistent institutional readiness, limited BIM training infrastructure, and curriculum designs that still prioritise traditional construction methods [23,40]. Many institutions continue to operate in disciplinary silos, hindering the development of interdisciplinary and collaborative workflows that reflect global BIM practice. High software costs and inadequate access to modern computing facilities fur-

ther restrict students' opportunities to engage with model authoring, clash detection, and data-rich coordination processes [41,42]. Scholars warn that without a shift toward workflow-oriented, competency-based BIM education, graduates may remain unprepared for emerging digital project environments and face reduced employability in both local and international markets [32,33].

Despite these challenges, there is growing interest in hybrid learning models as a pathway for developing digital capabilities across the region. Mulenga and Shilongo [6] and Rydzewski [35] report that hybrid education expands access to digital tools and collaborative platforms, allowing students to experience BIM processes beyond the constraints of physical laboratories. Several governments and industry bodies, particularly in South Africa, Nigeria, and Kenya, have initiated support for BIM literacy initiatives, academic–industry partnerships, and digital construction policies aimed at enhancing workforce readiness [24,43]. However, hybrid models are only effective when supported by adequately trained instructors and institutional systems capable of enabling BIM-driven pedagogy [44]. The literature increasingly emphasises the need for structured frameworks that guide universities in aligning hybrid delivery with the competency expectations of BIM-enabled workflows, including workflow literacy, interdisciplinary teamwork, and digital communication [45]. This recurring theme across regional and international studies confirms the need for a competency-based framework tailored to the unique constraints and opportunities of Sub-Saharan Africa.

2.4. Summary and Gaps

The construct–author matrix (Table 1) highlights clear disparities between global and regional literature across the major constructs reviewed in Sections 2–4. The strongest evidence appears for Industry Alignment and Workforce Readiness, as well as BIM Competency Development, reflecting extensive global scholarship on the technical and collaborative skills needed for BIM-enabled project environments. In contrast, Workflow Literacy and ISO 19650 alignment receive much weaker support, particularly from Sub-Saharan studies, revealing Gap 1: a limited curriculum focus on process-oriented BIM competencies. Institutional Readiness shows a similar divide: while global studies often assume adequate digital capability, regional evidence emphasises infra-structure constraints, gaps in staff expertise, and inconsistent access to hybrid learning resources. These issues form Gap 2: insufficient institutional capacity to support hybrid BIM learning and competency-based assessment. Figure 1 brings these gaps together visually by linking them to three core enablers, BIM workflow competency development, hybrid pedagogy enablement, and institutional capacity readiness, which then converge to shape industry alignment and, ultimately, graduate readiness for BIM-enabled construction workflows. This progression, from global expectations to regional limitations and into actionable framework constructs, reinforces the need for the competency-based model proposed in this study and positions it as a timely contribution to BIM-oriented AEC education in Sub-Saharan Africa.

Table 1. Construct–author matrix (Authors' summary).

Authors	BIM Competencies	Workflow Literacy & ISO 19650	Hybrid Learning Effectiveness	Institutional Readiness (Staff + Infrastructure)	Industry Alignment & Workforce Readiness
Klocko [14], Georgiadou [7]—[ISO 19650/BSI (2018–2021)]		*			*

Table 1. Cont.

Authors	BIM Competencies	Workflow Literacy & ISO 19650	Hybrid Learning Effectiveness	Institutional Readiness (Staff + Infrastructure)	Industry Alignment & Workforce Readiness
Mahamadu et al. [18], Nikolic et al. [15], Correa et al. [16]—(framework)	*	*			*
Abdirad and Dossick [41], Maina [42]—(capability/maturity)	*	*			*
Georgiadou [7], Alnaser et al. [26]—(BIM Handbook)	*	*	*		*
Pasi and Dhamak [27], Correa et al. [16]—(Common Data Environment (CDE))	*	*			*
Cuyacot and Cuyacot [31], Chandan et al. [33], Mulenga and Shilongo [6]—(Virtual Design Construction (VDC) pedagogy)	*	*	*		*
Sisttermans [32], Cuyacot and Cuyacot [31]—(competency-based engineering education)			*		*
Abbasnejad et al. [5], Ramadan et al. [28] (blended learning)			*		*
Ramadan et al. [28], Mulenga and Shilongo [6]—(hybrid design)			*		
Abbasnejad et al. [5], Mulenga and Shilongo [6]—(online/hybrid practice)		*	*	*	
Abbasnejad et al. [5], Mulenga and Shilongo [6]—(authentic assessment)		*	*		*
Bosch-Sijtsema et al. [34], Saliu et al. [11], Rydzewski [35]—(SSA digital learning)			*	*	
Abdirad and Dossick [41], Maina [42], Nahar and Machado [37]—(SSA higher-ed constraints)				*	

Table 1. Cont.

Authors	BIM Competencies	Workflow Literacy & ISO 19650	Hybrid Learning Effectiveness	Institutional Readiness (Staff + Infrastructure)	Industry Alignment & Workforce Readiness
Sisttermans [32], Saliu et al. [11], Chandan et al. [33], Stephen and Aigbavboa [24]—(SSA BIM adoption)	*			*	*
Abdirad and Dossick [41], Maina [42], Bosch-Sijtsema et al. [34], Rydzewski [35]—(BIM barriers)	*			*	*
Succar [39], Wang et al. [40], Ramakrishnan et al. [25], Saliu et al. [11]—(curriculum–industry)				*	*
Zeidan and Bishnoi [38], Alnaser et al. [26], Pasi and Dhamak [27], Stephen and Aigbavboa [24]—(regional readiness)	*	*	*		
Head et al. [19], Mendonca et al. [20]—(curriculum gaps)	*			*	*
Succar [29], Gu and London [30]—(BIM maturity + AEC readiness)	*	*		*	*
Castro [44]—(Blended learning systems)			*	*	
Gervais [45]—(Competency-based education)	*		*		*
TOTALS	11	10	11	9	15

Legend: Explanation of symbols and shorthand used in Table 1. * indicates that the author(s) substantially contributed to the construct based on thematic relevance in the literature. **ISO 19650/BSI (2018–2021)** refers to international standards governing information management throughout the building lifecycle. **Framework** indicates studies proposing structured BIM competency, maturity, or workflow models. **CDE** stands for Common Data Environment, a core element of BIM collaboration. **VDC pedagogy** refers to Virtual Design and Construction teaching methods used to support BIM-oriented learning. **Competency-based education** relates to models prioritising demonstrable mastery over time-based progression. **SSA** refers to Sub-Saharan Africa, highlighting region-specific constraints or readiness.

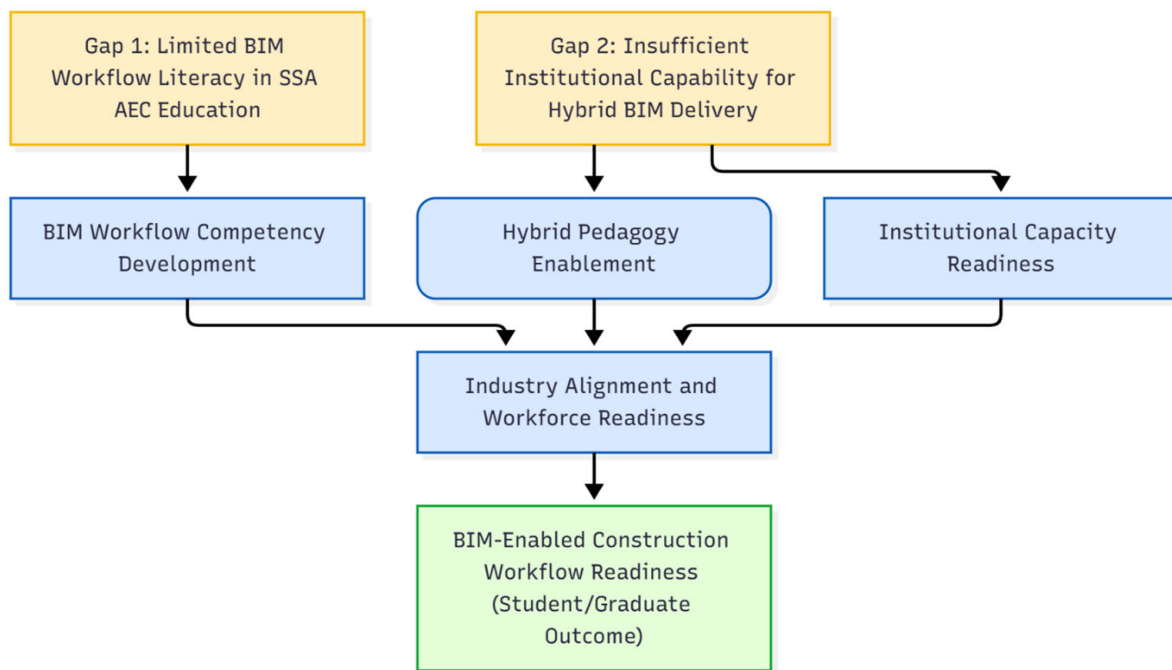


Figure 1. Study's gaps and construct-matrix alignment (Authors').

3. Methodology

This study adopted a deductive quantitative design grounded in a positivist research paradigm. In this context, positivism means that knowledge is generated through objective measurement, and that relationships between hybrid learning and BIM workflow competence can be tested statistically rather than interpreted subjectively [46]. A structured questionnaire was selected because it allows consistent collection of measurable data on learner perceptions, institutional readiness, and digital competency development across a defined sample [47]. The instrument was developed after reviewing BIM competency frameworks, hybrid learning literature, and digital pedagogy models, ensuring that items aligned with the skills required for BIM-enabled workflows. The final questionnaire consisted of 15 items, grouped into two sections: (1) demographic characteristics and (2) drivers of hybrid AEC education. Section 2 contained 12 measurable variables rated on a five-point Likert scale. A pilot test was conducted with six academics, following the recommendations of Wadood et al. [47], to assess clarity, wording, and content validity. Their feedback helped refine items related to digital collaboration, workflow literacy, and hybrid delivery. Ethical approval for the study was granted by the university's research ethics committee (Approval Code: UJ_FEBE_FEPC_00677). Participation was voluntary, and informed consent was obtained electronically. No personal identifiers were collected.

The target population consisted of AEC students and recent graduates in Johannesburg who had at least one year of hybrid learning experience. Although the intention was to reach participants broadly, the sampling technique aligns more closely with voluntary response sampling because the questionnaire link was shared through Google Forms via WhatsApp, LinkedIn, and Instagram groups. The estimated population size across the institutions ranges from 500 to 600 students. A total of 120 survey links were distributed, and 81 completed questionnaires were returned, representing a 68% response rate, which exceeds the minimum recommended threshold for online surveys in educational research [48,49]. Respondents included qualifications ranging from a diploma to a master's level. Professionally, the sample represented quantity surveyors (42.0%), construction managers (34.6%), civil engineers (12.3%), and architects (6.2%). Hybrid learning exposure ranged mainly between one and two years (74.1%), meeting the inclusion criteria for mean-

ingful experience. This demographic profile demonstrates adequate representation of the AEC disciplines relevant to BIM adoption.

Data were processed and analysed using SPSS version 26.0. Prior to analysis, responses were screened for completeness and inconsistent answering patterns; no cases were removed. Descriptive statistics, including frequencies, percentages, Mean Item Scores (MIS), and Standard Deviations (SD), were used to evaluate the drivers of hybrid learning and perceptions of competency. The reliability of the scales was assessed using Cronbach's alpha, with a common threshold of $\alpha \geq 0.70$ considered acceptable [50]. The suitability of the data for multivariate analysis was evaluated using the Kaiser–Meyer–Olkin (KMO) measure and Bartlett's Test of Sphericity, both required to justify factor analysis. The analysis returned a high KMO value and a significant Bartlett's test, indicating adequate correlations among variables. The study applied Principal Component Analysis (PCA) with Oblimin rotation to identify the main clusters of drivers influencing hybrid education. PCA was selected because the aim was to reduce items into interpretable components rather than model latent variables. Loadings of 0.40 and above were considered meaningful, and components contributing to cumulative variance of 60% or more were retained, following standard practice in educational measurement [50]. Objective 1 was addressed using descriptive statistics and PCA; Objective 2 was examined through reliability analysis, PCA interpretation, and demographic profiling; Objective 3 was addressed through a synthesis of factor results and literature to build the competency-based framework. In line with open-science practice, the full questionnaire will be provided as Supplementary Materials to support transparency and reproducibility.

4. Findings and Discussion

4.1. Findings

Table 2 shows that respondents consistently rated all twelve drivers of hybrid AEC education positively, with means above 3.9 and standard deviations below 1.20. The distribution was slightly left-skewed, and kurtosis values indicated moderate clustering around higher response categories, suggesting strong agreement across the sample. The highest-ranked items, "Utilise emerging technologies" (Mean = 4.37) and "Integrate digital technologies" (Mean = 4.31), highlight respondents' belief that hybrid learning is needed to support the digital transformation already reshaping global AEC practice [35]. Collaboration-oriented drivers, such as "Support university collaboration" (Mean = 4.27), and capability-building drivers, such as "Develop digital wisdom" (Mean = 4.26), also scored highly, showing alignment with wider arguments that BIM workflows depend on shared decision-making and digital maturity rather than isolated software proficiency [9,26]. Lower-ranked items, including "Promote real-world relevance" (Mean = 3.96), still received positive ratings, indicating broad support for hybrid learning, even where motivations are slightly weaker. Overall, the descriptive results indicate that students perceive hybrid learning as a credible approach to enhance the technological, collaborative, and competency-driven aspects of AEC education necessary for BIM-enabled construction workflows [26].

Table 3 presents the pattern matrix, and the diffuse loading structure shows that respondents did not differentiate strongly between the drivers. Most loading values were small and spread across components, and the rotation required fourteen iterations, indicating weak factor separation. This suggests that learners perceive the drivers of hybrid AEC adoption as interconnected rather than belonging to distinct categories. Table 4 confirms this interpretation: Component 1 explains 67.57% of the variance, while Components 2 and 3 contribute 5.14% and 4.95%, respectively. The large dominance of a single component suggests that a shared underlying construct, digital transformation, may be driving respondent perceptions. However, for conceptual clarity, three components were retained because the

content of the items aligns with themes identified in earlier sections of the literature review. Table 5 further validates the dataset: the KMO value of 0.943 and significant Bartlett's Test ($p < 0.001$) indicate strong correlations among variables, confirming the suitability of the dataset for PCA.

Table 2. Drivers influencing hybrid AEC education adoption.

Drivers	Mean	Std. Deviation	Rank
Utilise emerging technologies	4.37	0.955	1
Integrate digital technologies	4.31	0.944	2
Support university collaboration	4.27	1.025	3
Develop digital wisdom	4.26	0.972	4
Enable remote learning	4.22	0.987	5
Reform higher education	4.22	1.037	5
Build digital literacy	4.20	1.005	7
Improve knowledge transfer	4.10	1.044	8
Encourage educational innovation	4.05	1.011	9
Adapt to student growth	4.04	1.054	10
Address traditional learning gaps	4.02	1.072	11
Promote real-world relevance	3.96	1.167	12

Table 3. Pattern matrix.

Pattern Matrix ^a			
Drivers	Component		
	1	2	3
Reform higher education	−0.176		
Improve knowledge transfer	0.195		
Address traditional learning gaps	0.124		
Integrate digital technologies	0.106		
Enable remote learning		0.052	
Support university collaboration		0.247	
Utilise emerging technologies		−0.044	
Build digital literacy			0.133
Develop digital wisdom			−0.056
Promote real-world relevance			0.102
Encourage educational innovation			−0.052
Adapt to student growth			−0.144
Extraction Method: Principal Component Analysis.			
Rotation Method: Oblimin with Kaiser Normalisation ^a .			

^a Rotation converged in 14 iterations.

Table 4. Total variance explained by principal components.

Total Variance Explained				
Component	Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings ^a
	Total	% of Variance	Cumulative %	Total
1	8.109	67.573	67.573	7.256
2	0.616	5.136	72.709	7.089

Table 4. *Cont.*

Total Variance Explained				
Component	Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings ^a
	Total	% of Variance	Cumulative %	Total
3	0.593	4.945	77.654	2.833
Extraction Method: Principal Component Analysis.				
^a When components are correlated, sums of squared loadings cannot be added to obtain a total variance.				

Table 5. Reliability and validity test.

KMO and Bartlett's Test		
Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0.943
Bartlett's Test of Sphericity	Approx. Chi-Square	811.236
	df	66
	Sig.	<0.001

4.2. Discussion

4.2.1. Descriptive

The findings reflect strong learner agreement that hybrid AEC education is being driven by the increasing need for digital capability, consistent with broader studies on digitalisation in the construction sector [40]. High mean scores for technology-focused drivers, such as emerging technologies and digital integration, confirm that students see hybrid learning as a pathway to develop BIM-aligned digital skills and workflow literacy [9,26]. Collaboration drivers, such as inter-university cooperation, also relate to findings in the literature showing that BIM adoption depends on interdisciplinary, data-rich teamwork [7,40]. The moderate yet positive ratings for real-world relevance and knowledge transfer support arguments that hybrid models can address limitations in traditional delivery by offering simulations, virtual coordination tasks, and digitally enhanced studio environments [15,41]. Standard deviations remain low across the table, suggesting that opinions are largely consistent regardless of discipline or level of hybrid learning exposure [51,52]. Together, these results reinforce the view that hybrid AEC education aligns with global expectations for BIM-driven performance and provides a foundation for developing the digital competencies needed in Sub-Saharan Africa [26].

4.2.2. Factor Component (Cluster) Report

Although PCA produced three components, shown in Table 3, the weak loading values require interpreting the clusters conceptually rather than as strong empirical categories. This aligns with the literature, which also links these drivers to overlapping themes of digital transformation, collaboration, and learner capability development.

i. Cluster 1—Technology-Driven Modernisation

This cluster brings together curriculum reform, digital integration, knowledge transfer, and addressing traditional learning gaps. The grouping aligns with international scholarship, which shows that BIM competence depends on process literacy, information management, and ISO 19650-aligned workflows, rather than isolated software skills [7,14]. The literature further emphasises the need for curriculum modernisation to transition students from tool-centred tasks to workflow-based design and coordination [1,53,54]. Cluster 1, therefore, corresponds to Gap 1 identified earlier, limited BIM workflow literacy, and supports the construct of BIM Literacy and Curriculum Modernisation.

ii. Cluster 2—Collaboration and Access Enablers

Cluster 2 encompasses support for university collaboration, remote learning, and the utilisation of emerging technologies. These reflect the enablers required for hybrid AEC learning, especially in regions where digital inequality and infrastructure shortages impede participation [6,41,42]. Studies show that hybrid platforms allow shared design tasks, coordination reviews, and teamwork simulations that mirror BIM collaboration [55]. This cluster directly relates to Gap 2, insufficient institutional capability, and supports the construct of Hybrid Delivery Infrastructure and Institutional Preparedness.

iii. Cluster 3—Learner-Centred Digital Capability

Cluster 3 combines digital literacy, digital wisdom, innovation, real-world relevance, and adaptability. These elements align with competency-based education models where students demonstrate measurable mastery through authentic, workflow-related tasks [31–33]. Research on VDC/BIM pedagogy also shows gains in collaboration, problem-solving, and readiness when students engage in digital simulation and CDE-based work [6,56]. This cluster supports the construct of Learner Digital Competency and Employability, which is essential for addressing both identified gaps.

4.3. Framework Application and Other Conceptualised Frameworks

The proposed framework (Figure 2) integrates the PCA clusters with the literature-derived gaps to show how Sub-Saharan African institutions can strengthen BIM-related competencies through hybrid education. The framework explains that digital modernisation, collaboration enablers, and learner-centred capability development must be addressed simultaneously to support BIM workflow proficiency. It also shows how the four gaps, limited workflow literacy, weak institutional readiness, poor collaboration structures, and inadequate industry-aligned assessment, act as constraints that prevent learners from achieving digital fluency [23,24,41]. By linking these gaps to three core constructs, Institutional Digital Preparedness, BIM Literacy and Curriculum Modernisation, and Hybrid Delivery Infrastructure, the framework offers a structured pathway toward improving the region's AEC education.

A key addition to this framework is feasibility. Implementing the framework requires practical steps: staff upskilling [57], investment in digital infrastructure [58], staged curriculum reform [59], and partnerships with industry bodies [58,59], as literature suggested. These interventions are realistic when introduced incrementally, especially in resource-limited environments. Successful implementation requires alignment with BIM Capability Maturity Models [29,39], activity-centred blended-learning frameworks that support collaborative online tasks [30,58], and competency-based education principles that emphasise measurable mastery [44]. Technology Acceptance Theory further supports the model by explaining how perceived usefulness, accessibility, and institutional digital readiness influence the adoption of hybrid BIM learning [45,60].

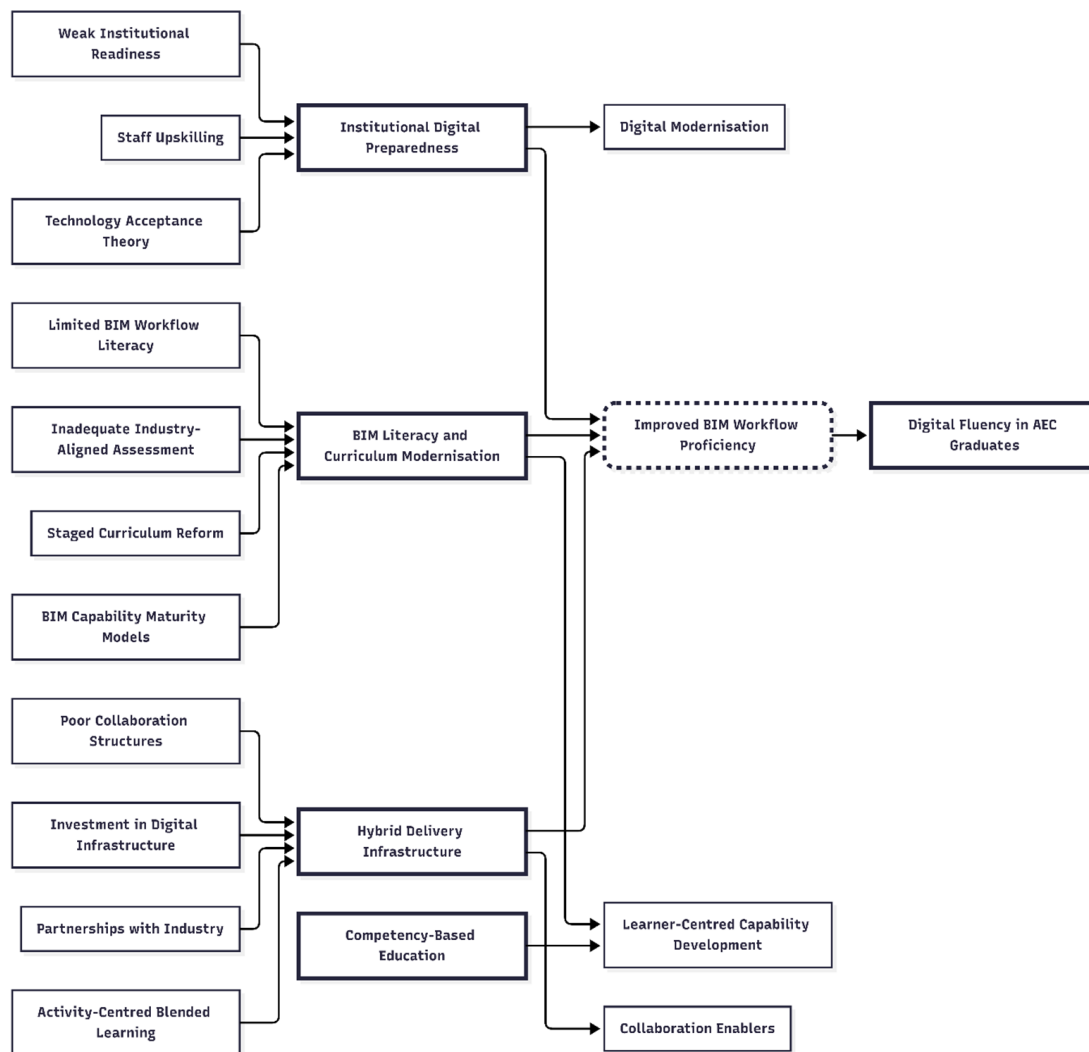


Figure 2. Competency-based framework for BIM-enabled construction workflows in Sub-Saharan African hybrid AEC education (Authors).

5. Conclusions and Recommendations

This study examined how hybrid AEC education can support the development of BIM workflow competencies in Sub-Saharan Africa and used these insights to propose a competency-based framework tailored to the region's educational realities. It integrates hybrid learning design with BIM workflow literacy, institutional readiness, and employability outcomes in a way that existing BIM competency or blended-learning models do not explicitly combine. The framework is grounded in both empirical patterns from the PCA results and the structural gaps identified in the literature, offering a practical way for institutions to align hybrid pedagogy with the process-driven nature of BIM-enabled construction.

The findings suggest that learners perceive hybrid education as a meaningful avenue for strengthening digital skills, improving collaboration, and supporting the workflow-oriented competencies associated with BIM. Technology integration, access to digital resources, and opportunities for collaborative learning emerged as strong collective drivers of hybrid learning adoption. At the same time, the results point to persistent challenges across Sub-Saharan AEC programmes, including limited institutional capacity, uneven digital infrastructure, and insufficient emphasis on BIM coordination processes within curricula. These insights shaped the proposed framework, which positions curriculum modernisation, hybrid delivery readiness, and learner capability development as mutually

reinforcing components. While the empirical base is modest and context-specific, the framework provides a structured approach for universities to scaffold BIM workflow literacy within hybrid environments, offering clearer links between educational delivery and workplace expectations.

Several actionable recommendations follow from the study. Universities should invest in digital teaching capacity by training instructors in workflow-focused BIM pedagogy and by improving access to licensed software and stable digital platforms. Curriculum restructuring could include interdisciplinary studio modules built around a Common Data Environment (CDE), workflow-based capstone projects that require clash detection and coordination reporting, or scaffolded hybrid learning sequences where students complete digital collaboration tasks before engaging in on-site or studio activities. Institutions should also establish industry partnerships to align assessment with real BIM practices and strengthen graduate employability. Despite these contributions, the study has limitations. It relies on self-reported perceptions, which may not fully reflect actual competency levels or institutional realities, and the voluntary online sampling approach introduces potential selection bias. Future research should test the framework in multiple countries, incorporate performance-based measures of BIM competence, and investigate hybrid learning outcomes over extended timeframes. This will help refine the model and support broader efforts to build digital capacity across AEC education in Sub-Saharan Africa.

Supplementary Materials: The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/buildings16091723/s1>, Questionnaire.

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Informed Consent Statement: Informed consent was obtained from all participants involved in the study.

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