

Field work gaps: digital twin modeling intervention – a moderated-mediation model

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Abstract

Purpose – This article investigates the moderated-mediation roles of perceived usefulness and perceived ease of use, as well as, digital competency between digital twin modeling experience and continuous use among built environment students in Ghanaian technical universities.

Design/methodology/approach – 788 students in the faculty of built environment were deployed through stratification from six technical universities in Ghana. Regression analysis was used to examine the conjectured paths.

Findings – The study outcome shows that digital competency moderates the mediated link between perceived usefulness and students' continuous use; however, the moderated mediation role of perceived ease of use was not supported.

Research limitations/implications – Generalizability of the study outcomes was methodologically delimited as the survey was restricted to only students in built environment faculties in Ghanaian technical universities.

Originality/value – Uniqueness of the research is entrenched as it is one of the first studies to explore digital twin modeling experiences of built environment students in technical universities in sub-Saharan Africa.

Keywords Digital twin modeling experience, Digital competency, Perceived usefulness, Perceived ease of use, Continuous use, Ghana

Paper type Research article

Introduction

Across the globe, there is growing research interest among learners, educators and practitioners on the integration of digital twin (DT) technologies into built environment curricula in institutions of higher learning (IHL). This development may be explained by rapid growth of digital replicas of physical systems and virtual laboratories to enrich students' active learning experiences (Errabo *et al.*, 2024). Virtual laboratories offer “hands-on” approaches to

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experiential learning. Thus, DT technologies possess affordances that deliver suitable responses to the pedagogical needs of students (du Preez *et al.*, 2023). Nonetheless, capacity to efficiently incorporate DT technologies into built environment curriculum is premised on instructor-learner psychological readiness (Shambare and Jita, 2025). According to technology acceptance model (TAM) (Davis, 1989), users' opinion (psyche) of effortlessness and productive gains of digital applications enhances psychological readiness and increases adoption rate. Also, situated expectancy value theory (SEVT) (Eccles and Wigfield, 2020) accentuates that users' desire for achievement and personal task ideals are the utmost proximal psychological elements that influence productive choices and outcomes. Touted as a necessity for students in IHL, DT technologies are seen as a major driver of experiential learning (Omran *et al.*, 2025). Evidence-based practical prowess of DT technologies has led to their increasing use by IHL to enrich students' technical and conceptual understanding of real-world construction situations (Damaševičius and Zailskaitė-Jakštė, 2024).

Despite the benefits of integrating digital technologies into IHL's curricula, there have been enormous implementation hiccups. First, evidence abounds that contemporary higher education system incorporates the use of enhanced digital pedagogical techniques. Nonetheless, these techniques are limited in capacity to stimulate students' inquisitiveness, leading to lack of initiative (Liu *et al.*, 2024). Second, while this study acknowledges some attempts by prior studies to investigate technology user experience in IHL (Hevi *et al.*, 2024; Sedrakan *et al.*, 2025). Scanty empirical evidence exists on the adoption of DT technologies within technical universities in sub-Saharan Africa, particularly on moderated-mediation models. The current study contends that contemporary literature on industry 4.0 and 5.0 digital evolution have not adequately addressed field-specific demands of DT technologies. Premised on this assumption, this study explores the moderated-mediation roles of digital competency, perceived "usefulness" and "ease of use" between DT modeling experience and continuous use among built environment students in Ghanaian IHL.

The study makes two distinct contributions. First, the academic piece adds to the growing body of knowledge on human behavior in built environment literature by moving beyond technology adoption among professionals. The study enhances knowledge through the exploration of holistic integration of DT technologies into built environment curriculum in IHL. Thus, the study espouses the significance of DT modeling in optimizing learning outcomes among engineering students (Ebekozen *et al.*, 2024). Second, the study is in response to the need for IHL to lead digital transformation within the built environment industry. This assertion is strongly rooted in the UN Sustainable Development Goal 9 (UNDP, 2024), which, among other things, seeks to build smart communities through experiential learning and application of innovative technologies.

Literature review

Digital twin modeling experience and continuous use

DT technologies bridge gaps that exist between real and digital worlds via real time engagements (Yao *et al.*, 2023). DT tools are interactive platforms that mitigate limitations posed by real situational elements. Fuller *et al.* (2020) note that DT technology is an emerging concept that continues to attract attention from both industry and academia. DT technologies rely on virtual techniques and digital learning models such as 3D simulation and system modeling for error reduction and overall system efficiency (Jones *et al.*, 2020). Context-wise, DT technologies offer virtual affordances that demonstrate practical construction scenarios (Lin and Cheung, 2020). The scholars note that decision-making, detection of anomalies, estimation of cost, and time resources are optimized through DT affordances. Additionally, these technology-aided learning tools equip students with structural integrity evaluation competences (Damaševičius and Zailskaitė-Jakštė, 2024). This study asserts that continuous use of DT technologies may lead to skills manifestation in real-life situations. Despite

reasonable benefits gained by construction firms over the years, hostility toward digitalization remains a major characteristic of the industry. The current study argues that IHL could play a significant role in promoting attitudinal change toward digitalization within the built environment industry.

The article argues that DT modeling experience may influence students' professional attitudes toward technology adoption. The study draws on SEVT to explain links between DT modeling experience and students' continuous use. SEVT has been commonly used to explain links between a person's degree of ambition and goal-setting behaviors. SEVT is a description of how specific environmental factors influence a person's desire for future goal attainment (Eccles and Wigfield, 2020). The theory is viewed as an efficient means of understanding elements within an environment that helps in shaping behaviors for success. SEVT is made up of four key elements. The first element relates to the relevance of achieving success within a specific domain (attainment value). The second element makes reference to how individuals enjoy activities that lead to success (intrinsic value). The third element highlights the usefulness of engagements that lead to success (utility value). The fourth element relates to the forgone opportunities an individual suffers as a consequence of pursuing a particular goal. These four value-based assumptions are shaped (strengthened or weakened) by students' digital competency levels. Thus, students' digital competency delivers the enabling environment that promotes adoption and continuous use of DT technologies.

Based on the assertions made, this article argues that DT modeling experience enhances the continuous use of DT tools. This assertion is backed by an empirical work conducted by Boettcher *et al.* (2023). The study establishes a positive link between virtual reality experience and continuous use of laboratory learning among students. The study adds that despite initial unfamiliarity concerns with the learning methodology, students found the experience intriguing and pragmatic in solving challenges. In a related study, Olowa *et al.* (2023) demonstrate that learning methods that integrate BIM deliver hands-on in-service training that trigger engineering students' future goal attainment. Henceforth, the study conjectures that.

H1. Digital Twin Modeling Experience positively predicts Continuous Use.

Mediating effect of PUS and PEU of DT tools

Although perceived usefulness (PUS) and perceived ease of use (PEU) have received some fairly considerable research attention in higher education literature (Boettcher *et al.* (2023); Olowa *et al.*, 2023), their role as mediators between DT modeling experience and students' outcomes has not been satisfactorily investigated. Significance of PUS stems from users' belief that deployment of technological tools may lead to performance efficiency (Saputra *et al.*, 2023). It relates to the degree to which a person feels embracing a specific approach may lead to enhanced output (Baidoun and Salem, 2024). Context-wise, PUS relates to students' perspicacity toward benefits that are likely to accrue from using DT tools. In other words, a user's mindset that a piece of technological tool requires the exertion of minimal effort to attain optimum performance (Ayanwale and Ndlovu, 2024). On the other hand, this article describes PEU as students' effortlessness to understand and operate DT tools.

The article draws on the cognitive assumptions of TAM (Davis, 1989) to explain the parallel indirect roles of PUS and PEU between experience and continuous use of DT tools. Grounded in the theory of reasoned action (TRA), TAM is seen as an improved cognitive version of explaining human behavioral intentions toward technology adoption (Baidoun and Salem, 2024; Davis, 1989). The scholars allude to the conjoint roles of PUS and PEU as the principal determinants of acceptance of any given technology. The article argues that PUS and PEU serve as parallel mediators between DT modeling experience and students' continuous use of DT tools. This assertion is strongly rooted in quite a number of extant works that established an indirect effect of PUS and PEU between digital experience and continuous use (Alam *et al.*, 2023; Kumari and Biswas, 2023; Ebadi and Raygan, 2023; Saputra *et al.*, 2023).

Digital competency as a moderator variable

In harnessing benefits of digitalization within the built environment industry, it is incumbent on firms and institutions to build conceptual and digital capacities of key actors. Digital competency refers to structural conditions that promote knowledge upgrade for well-tailored applications (Steens *et al.*, 2024). The scholars stress that competency development is reengineered through aspirations and inclinations of both instructors and learners. In the study, competency refers to learning activities that vary from intelligence gathering, know-how optimization, precision and mastery (Odusami, 2002). This article argues that the SEVT delivers a good reasoning ground to explain the role of skills acquisition as a prerequisite for knowledge application in real-life situations. The article relies on four key elements of SEVT (Eccles and Wigfield, 2020). These values include attainment, enjoyment, satisfaction and opportunity cost, which the scholars' describe as crucial in the determination of favorable behavioral changes.

The article conjectures that the development of DT competencies may harness tailor-made technical know-hows that is vital for digital evolution in the built environment sector. As a result, higher levels of digital competencies connote continual use of DT technologies among students (Ezeudoka and Fan, 2024; Yang and Jang, 2024). The aforementioned arguments point to the viability of digital competency to moderate between DT modeling experience and students' continuous use. Thus, the study theorizes that.

H3. Digital Competency moderates between digital twin modeling experience and continuous use.

Methodology*Participants and procedure*

The study was built on the ideals of positivism. Positivist's philosophy is "characterised by the use of quantitative methodological approach which emphasizes the need to generalize about the world and the need for accurate measurement" (Mukherji and Albion, 2015, p. 24). Ensuing, the study relied on a cross-sectional quantitative research design to empirically investigate the hypothesized paths. The study's statistical model measures links between DT modeling experience and continuous use. Further, the model explores parallel mediating roles PUS and PEU, as well as digital competency among engineering students in Ghanaian technical universities. The choice of technical universities was deemed most appropriate because they are primarily tasked to use applied research to equip students with technical and vocational skills for industry purposes (Graphic Online, 2022). In addition, the government of Ghana enacted an all-encompassing policy to promote digital transformation, termed "ICT for Accelerated Development" (ICT4AD) (Republic of Ghana, 2003). This policy has led to the adoption of digital technologies such as machine learning algorithms to enhance teaching and learning experiences among students in technical universities (Kuadey *et al.*, 2023).

After securing Institutional Review Board (IRB) approval, engineering students in the "Faculty of Built Environment" across six technical universities were sampled between the months of November 2024 and January 2025. A stratified sampling techniques was used in distributing 1088 questionnaires, with 788 valid responses retrieved, indicating 72.4% response rate. Accordingly, six technical universities were categorized into three STRATAs with each group (constituting 300 students) led by one of the authors. The authors were supported by ten well-trained enumerators for the purposes of data gathering. The enumerators were trained in contemporary dilemmas in conducting behavioral research, such as adherence to respondents' anonymity, data confidentiality and voluntary participation. An average time of 25 min was spent by the respondents in providing answers to the questions.

To address any possible problems that may accrue from the survey, some robust preliminary evaluations were performed. First, pre-testing the instrument, 31 undergraduate students from 2 private universities were engaged to provide responses to the itemized questions, a procedure

that was established by [Preneger et al. \(2014\)](#). The scholars state that responses from 30 participants are good enough to deliver 80% precision in an instrument. The pre-test outcomes reveal reliability appropriateness (α -value >0.70). Second, a very pronounced problem of cross-sectional surveys is common method bias. This potential challenge was addressed through the Harman single factor analysis (all factors <0.5) ([Podsakoff et al., 2003](#)).

Measures

A five-point Likert-type scale with anchors (1) strongly disagree to (5) strongly agree was used in the collection of responses. The scales are described.

DT modeling experience. A 10-item scale adapted from [Ellis and Goodyear \(2016\)](#) was deployed. Context-wise, DTME is defined as engineering students' experience with virtual replica models integrated into lessons. Example of questions asked: "digital twin modelling enhances my understanding of engineering concepts."

Perceived usefulness. A 6-item scale adapted from ([Davis, 1989](#)) was deployed. Context-wise, PUS is defined as digital resources that are beneficial to students' outcomes. Example of questions asked: "In my view, digital twin modelling supports core aspects of topics covered in our course outlines."

Perceived ease of use. A 6-item scale adapted from ([Davis, 1989](#)) was deployed. Context-wise, PEU is defined as digital resources that are beneficial to students' outcomes. Example of questions asked: "In my opinion, navigating through virtual replicas to under smart modelling is easy."

Digital competency (DCP). 3-item self-efficacy scale adapted from [Tierney and Farmer \(2002\)](#) was used. In this article, DCP describes a student's cognitive and technical skills in understanding and applying DT tools. Example of questions asked: "Digital twin applications allow me to evaluate structural integrity of building projects virtually."

Students' continuous use of DT tools. A 3-item questionnaire adapted from [Wu and Chen \(2017\)](#) was deployed. Context-wise, CUDT is defined as students' fulfilment and its concomitant benefits accrued from DT modeling experience. Example of questions asked: "I prefer lessons delivered with integrated virtual replicas."

Demographic characteristics and test of Normality

The study's demographic characteristics include gender, age, type of DT tool deployed by respondent's university and strata classification. Stratas constitute groupings that are homogenous in character and non-overlapping. Henceforth, the technical universities were categorized into three STRATAs based on geographical locations (Northern, Middle and Southern belts). Each STRATA was led by an author of the study, and four well-trained supporting enumerators for the purposes of data gathering. Specifically, males had a higher representation for gender, accounting for 65.7%. Age range "18–27" was the most dominant, with 62.8% share of total responses. Third, with regards to DT tools deployed by university, 88.2% of the respondents selected building information modeling/computer-aided designs. Finally, with strata classifications, Group 1 recorded the highest respondents to the study (35%) (see [Table 3](#)). Mean scores and standard deviations were measured (see [Table 2](#)). In satisfying a key assumption of undertaking a regression analysis, the normal distribution of the survey data was assessed via Kolmogorov–Smirnov and Shapiro–Wilk's tests. The outcome shows that p -values for all study constructs surpassed the benchmark α -value of 0.05 ([Pallant, 2007](#)); signifying a normal distribution curve. Lastly, multicollinearity challenges were deemed as resolved as correction coefficients were set at ($\alpha < 0.80$) ([Hair et al., 2010](#)).

Results

Psychometric properties of measures

Through an explanatory factor analysis (EFA), a predetermined standard eigenvalue set above 1 was used to extract adequately loaded items on the study's scales. The EFA scores for all

items of DTME, PUS, PEU, DCP and students' CUDT met the data threshold score of 0.07 (Hair *et al.*, 2017). Specifically, DTME, PUS, PEU, DCP and students' CUDT had 23 out of 28 items loading acceptably. The dataset was further subjected to robustness examination to establish goodness-of-fit (Hair *et al.*, 2010) (see Table 1). The EFA statistical procedure was undertaken to address contextual differences that could influence credibility of the scales.

Sampling Adequacy tests

KMO scores for principal estimation of the dataset are as follows: DTME, CUDT, PUS, PEU and DCP = 0.866; and explained 68.861% of variance in the model ($0 > \alpha < 1$), hence deemed suitable. Regarding sampling correctness, all the study variables' *p-values* of Bartlett's test of sphericity ($\alpha < 0.05$) were significant (see Table 1).

Reliability, validity and correlation analysis

Internal consistency of the study's instrument was tested to establish reliability. The result is outlined as follows; DTME = (α 0.814, CR 0.948); PUS = (α 0.778, CR 0.941); PEU (α 0.862, CR 0.935), DCP (α 0.781, CR 0.918) and CUDT (α 0.907, CR 0.910). Tested results exceed the minimum reliability passable mark of ($\alpha > 0.7$) as recommended by Ringle *et al.* (2018). In addition, convergent validity was confirmed owing to each construct's AVE obtaining a passable α -value > 0.5 . Further, square root of each construct's AVE was higher

Table 1. Factor analysis, reliability and composite reliability of constructs

Factor measurement	Loadings	Variance Exp. (%)	R	CR
Digital twin modeling experience ($\alpha = 0.814$)		21.237		0.948
DTME9	0.888		0.812	
DTME2	0.887		0.798	
DTME1	0.754		0.901	
DTME7	0.731		0.742	
DTME5	0.724		0.804	
DTME3	0.721		0.722	
DTME4	0.704		0.832	
Continuous use of DT tools ($\alpha = 0.907$)		15.003		0.910
CUDT2	0.897		0.799	
CUDT1	0.801		0.932	
CUDT3	0.723		0.835	
Perceived usefulness ($\alpha = 0.778$)		12.958		0.941
PUS6	0.872		0.832	
PUS1	0.869		0.804	
PUS5	0.801		0.899	
PUS2	0.737		0.906	
PUS4	0.719		0.848	
Perceived ease of use ($\alpha = 0.862$)		10.482		0.935
PEU2	0.863		0.873	
PEU3	0.824		0.855	
PEU5	0.823		0.784	
PEU1	0.711		0.892	
PEU4	0.709		0.811	
Digital competency ($\alpha = 0.781$)		9.181		0.918
DCP3	0.841		0.896	
DCP1	0.838		0.911	
DCP2	0.779		0.880	

Note(s): KMO = 0.866, Bartlett's test of sphericity: $\chi^2 = 8253.439$, $p < 0.000$

Source(s): Field survey by authors (2025)

Table 2. Mean, SD, reliability measures and intercorrelation for constructs

Items	CR	AVE	1	2	3	4	5
Digital twin modeling Exp	0.948	0.603	<i>0.776</i>				
Perceived usefulness	0.941	0.643	0.623**	<i>0.802</i>			
Perceived ease of use	0.935	0.622	0.175**	0.235**	<i>0.789</i>		
Digital competency	0.918	0.672	0.118**	0.162**	0.169**	<i>0.825</i>	
Continuous use	0.910	0.656	0.428**	0.460**	0.504**	0.266**	<i>0.810</i>
Mean			3.727	3.600	3.995	2.680	3.433
SD			0.729	0.573	0.689	1.209	0.705

Note(s): SD = Standard Deviation, AVE = Average Variance Explained and CR = Composite Reliability. All intercorrelation coefficients are significant at * $p < 0.05$ and ** $p < 0.01$. Italics Diagonal figures represent the square root of the AVE; sub-diagonal figures are the latent construct for intercorrelations

Source(s): Field survey by authors (2025)

Table 3. Demographic profile of respondents

Items	Categories	Frequency	%
Gender	Male	518	65.7
	Female	270	34.3
Age (In years)	18–27	495	62.8
	28–37	287	36.4
	38+	6	0.8
Digital tool deployed in institution	Building Intelligence Modeling – Computer-Aided Designs	695	88.2
	Simulation Software	93	11.8
STRATA types	Group 1	276	35.0
	Group 2	252	33.0
	Group 3	260	32.0

Source(s): Field survey by authors (2025)

than the correlation coefficients among the constructs, consequently confirming discriminant validity (Fornell and Larcker, 1981) (see Table 2).

Measurement and structural model

The statistics evaluation model indices detail the following ($\chi^2 = 534.921$, $df = 284$, $p = 0.001$); RMSEA = 0.003; CFI = 0.997; TLI = 0.996 and SRMR = 0.004, revealing a good model fit.

Parallel moderated-mediation model

Mediation analysis is a common statistical process for examining hypothesized path in a study's model to establish causal effects. The study joins the steadily growing phenomenon of mediation models that jointly explore mediator and moderator variables. These complex interactions are termed conditional process modeling (Hayes, 2013). The article deploys a Haye's PROCESS model 14 to test whether DT modeling experience was related to students' continuous use through PUS and PEU (via parallel mediation). Parallel mediation affords researchers the opportunity to evaluate non-chained indirect effects of mediator variables separately. The statistical application helps explore PUS and PEU simultaneously via two separate hypothetical paths in a single model. The following outcomes were revealed, first, the article's findings unearth that DT modeling experience significantly predicts PUS ($b = 0.553$, $SE = 0.020$, $t(788) = 27.684$, $p < 0.001$), PEU ($b = 0.127$, $SE = 0.030$, $t(788) = 4.185$,

$p < 0.001$) and students' continuous use ($b = 0.185$, $SE = 0.032$, $t(788) = 5.696$, $p < 0.001$) thus, the article confirms H2a, H3a and H1 respectively. In addition, PUS positively predicts students' continuous use ($b = 0.330$, $SE = 0.074$, $t(788) = 4.478$, $p < 0.01$), confirming H2b. However, PEU was not significant in predicting students' continuous use ($b = 0.150$, $SE = 0.084$, $t(788) = 1.797$, $p > 0.05$), consequently, H3b was not confirmed (see Table 3).

Second, the article assesses the mediating effect of PUS and PEU between DT modeling experience and students' continuous use. Mean estimate of the indirect effect of DT modeling experience on students' continuous use via PUS and PEU were (H2: $b = 0.007$, $SE = 0.004$) with [95%: *LL 0.001, UL 0.016*]; and (H3: $b = -0.006$, $SE = 0.013$) with [95%: *LL -0.032, UL 0.018*] respectively. Accordingly, H2 was confirmed; however, H3 was not confirmed.

Third, the article explores moderating effect of digital competency (DCP). Precisely, the assessment was done to establish linear and interaction effects of PUS and DCP as well as PEU and DCP. In accordance, the interaction term PUS*DCP positively predicts students' continuous use ($b = 0.058$, $SE = 0.026$, $t(788) = 2.225$, $p < 0.01$), confirming H4. Conversely, the interaction term PEU*DCP was not significant in predicting students' continuous use ($b = -0.011$, $SE = 0.026$, $t(788) = -0.418$, $p > 0.05$); hence, H5 was not confirmed. In furtherance, the conditional and total effects from PUS to students' continuous use were assessed against specific moderator values of digital competency (DCP). Study results illustrate that all indirect effects were significant within $\pm 1 SD$. This indicates that prediction of students' continuous use by PUS is probable within the DCP range of $M \pm 1 SD$. Additionally, the indirect effect from PUS to students' continuous use is higher for students with higher digital competency values compared to students with lower digital competency values. In testing conditional and total effects from PEU to students' continuous use. Study result shows that 2 out of 3 indirect effects met the acceptable threshold. Indicating that prediction of students' continuous use by PEU is likely within the DCP range of $M \pm 1 SD$. Further, the indirect effect from PEU to students' continuous use is higher for students with higher digital competency but not significant for students with lower digital competency (see Figure 1 and Table 4).

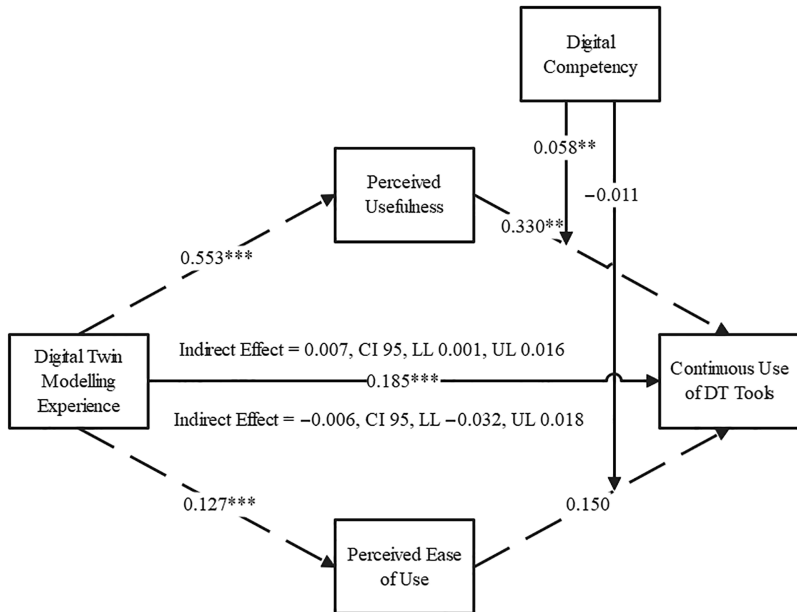


Figure 1. Tested research model. Source(s): Authors' tested (hypothesized paths) framework (2025)

Table 4. Hypotheses testing

Hypotheses	Beta coefficients	Proposed effects	Results
<i>Direct effect</i>			
DT modelling → Experience continuous use (H1)	0.182***	+	Supported
DT modeling experience → Perceived usefulness (H2a)	0.553***	+	Supported
Perceived usefulness → Continuous use (H2b)	0.330***	+	Supported
DT modeling experience → Perceived ease of use (H3a)	0.127***	+	Supported
Perceived ease of use → Continuous use (H3b)	0.150	+	Not Supported
Mediating effect of perceived usefulness (H2)	0.007	+	Supported
Mediating effect of perceived ease of use (H3)	-0.006	+	Not Supported
<i>Moderating effect</i>			
PUS*DCP → Continuous use (H4)	0.058**	+	Supported
PEU*DCP → Continuous use (H5)	-0.011	+	Not Supported
Note(s): *** $p \leq 0.001$, ** $p \leq 0.01$, * $p \leq 0.05$			

Indirect effects of digital twin modeling experience on students' continuous use via perceived usefulness and perceived ease of use at ± 1 SD of digital competency ($N = 788$)

	b	BootSE	BootLLCI	BootULCI
<i>Perceived usefulness</i>				
-1 SD	0.050	0.015	0.022	0.081
M	0.064	0.018	0.031	0.103
+1 SD	0.072	0.021	0.033	0.116
<i>Perceived ease of use</i>				
-1 SD	0.077	0.033	0.013	0.141
M	0.065	0.027	0.012	0.117
+1 SD	0.060	0.033	-0.005	0.122

Note(s): BootLLCI and BootULCI = Lower level and upper level of the bias-corrected and accelerated bootstrapped confidence interval for = 95%; bootstrapping resamples $N = 5,000$

Source(s): Field survey by authors (2025)

Discussion of findings

In exploring the direct and indirect effects of the study variables, it was revealed that DT modeling experience positively predicts students' continuous use. The study infers that integration of virtual replicas for experiential learning is a major building block for rapid adoption of DT tools. This result corroborates findings of empirical works of [Boettcher et al. \(2023\)](#), and [Olowa et al. \(2023\)](#). The studies assert that if DT modeling experience delivers optimum understanding of physical assets, then built environment students are likely to embrace its continuous use.

The first mediation hypothesis shows that PUS was proven as a mediator between DT modeling experience and students' continuous use. This cognitive assertion is borne out of the idea that conceptual modeling optimizes opportunities for technological competency development among students. The outcome validates empirical works conducted by [Alam et al. \(2023\)](#) and [Kumari and Biswas \(2023\)](#). In both studies, PUS was proven as a mediator between technology user experience and continuous use. Separately, these empirical works amplify values derived from technological affordances for task performance. Thus, a user's insight on benefits accruing from the use of a given technological tool may ignite continuous use. Therefore, the study infers that students with positive experiences with DT modeling are likely to sustain their continuous use. The capacity of PUS to mediate between DT modeling experience and students' continuous use in the article is grounded in the TAM ([Davis, 1989](#)).

The second mediation hypothesis shows that PEU did not satisfactorily explain relations between DT modeling experience and students' continuous use. Contrariwise, this result fails to corroborate existing related works conducted by [Ebadi and Raygan \(2023\)](#), and [Saputra *et al.* \(2023\)](#). These extant works posit that users' capacity to easily perform a task with technological tools is a good starting point for technology adoption and continuous use. Notwithstanding these outcomes, PEU fails to mediate between DT modeling experience and students' continuous use. The probable reason that may account for this deviation is linked to the overly simplistic explanation of technology acceptance in literature ([Salovaara and Tamminen, 2009](#)). In addition, contextual dynamics and pedagogical factors evident among IHL in sub-Saharan Africa could explain DT technologies navigation difficulties among students. The study argues that due to digital evolution, seismic pressures, instructor-learner interactive approaches have shifted from rote-learning to simulation-based and critical thinking methods ([McCowan *et al.*, 2022](#)). Although this development has been generally progressive, students in the region have to grapple with a technology-hostile mindset renewal. Further, deployment of DT technologies may cause additional learning burden leading to cognitive overload and technostress among students ([Daud, 2025](#); [Veletsianos and Houlden, 2019](#)). In summary, DT technologies are multifaceted in nature and may require continuous learning and consistent practical engagements to get accustomed ([Zheng *et al.*, 2022](#)).

As regards the moderation effect, the result unearthed that interaction term "PUS*DCP" moderates between PUS and students' continuous use of DT tools. This result upholds outcomes of related empirical works, where DCP was proven as a moderator on students' perceived behavioral intentions with technology usage ([Ezeudoka and Fan, 2024](#); [Yang and Jang, 2024](#)). Consequently, it is logical to state that the ability of PUS*DCP to moderate between PUS and students' continuous use could be explained by DT tools' desirability, value and efficiency in explaining physical asset concepts ([Shin and Kwak, 2024](#)).

Contrarily, it was unearthed that interaction term "PEU*DCP" did not moderate students' continuous use of DT tools. This result deviates from findings recorded in extant empirical literature ([Ezeudoka and Fan, 2024](#); [Yang and Jang, 2024](#)). In the aforementioned studies, DCP was proven as a moderator on students' behavioral intentions with regards to technology adoption. The study argues that inability of PEU*DCP to substantively moderate students' continuous use of DT tools could be given meaning by technology navigation complexities. The article proposes that some determinants may account for the slow assimilation of DT modeling among students in Ghanaian IHL. These determinants include: preference for traditional methods due to challenges of new knowledge acquisition, off-site user challenges and digital fatigue ([Wiitavaara and Widar, 2025](#)).

Conclusion

Can integration of DT technologies in built environment curriculum be a good starting point for building smart cities in sub-Saharan Africa? Does the adoption of DT technologies within fields of engineering feed into the wider intellectual discourse on ecological conservation? These questions constitute motivation for this scientific inquiry. The study offers relational insights into how IHL are developing students' cognitive and analytical capabilities for field-specific transformation in Industry 5.0 digital era. Henceforth, the study explores DT technologies adoption and continuous use among built environment students in Ghana. Based on the study outcomes, hypothesized paths "H1, H2a, H2b, H3a and H4" were confirmed. However, hypothesized paths H3b and H5 were not significant. Although mediating effect of "perceived ease of use" was not established in the study, the relevance of DT technologies adoption among IHL was strengthened.

Theoretical and practical implications

The research makes several academic and real-world recommendations. First, this article theoretically highlights the importance of DTME, PUS, PEU, digital competency and students'

continuous use through both the TAM and SEVT cognitive lenses. Second, the article makes a noteworthy contribution to curriculum re-design in higher education literature by conjointly investigating digital applications and students' attitudinal change in preparedness for future career endeavors. Relying on the assumptions of TAM and SEVT, this article extends literature on technology integration into built environment curriculum in higher education.

In practice, the study results are projected to be deployed as an outline for analyses of factors that determine students' use of DT technologies in sub-Saharan Africa. The study's practical implications are classified into three key categories, namely policy, curriculum design and digital training. For policymakers, the study projects a need for strong collaborations among industry experts, educational leaders, lecturers and students in Ghanaian IHL. These collaborative efforts have the propensity to bridge university-industry knowledge and competency gaps. In effect, government agencies, leaders of IHL, lecturers and students must jointly design roadmaps for effective transformation of acquired skills into overt manifestations. For curriculum development, the study emphasizes the relevance of team efforts in upgrading knowledge reservoirs in IHL. Curriculum crafting involves an integrated approach that finds an equilibrium between novelty, discursive frames and indigenous knowledge. Leaders of IHL should challenge indigenous systems and structures of knowledge creation to reflect contemporary exigencies. Thus, efficient curriculum reengineering could be achieved through deep engagements with key industry players, information technology experts and educational administrators. Finally, digital training constitutes a major determinant of technology adoption. DT affordances deliver functional properties that require personalization. Optimum use of these affordances is commonly attributable to a student's level of digital competencies. The study recommends that higher education administrators design capacity-building programs for students in quest to harness potential benefits of DT technologies in the built environment industry.

Limitations and areas for future study

Notwithstanding several remarkable inferences made in this article, some key methodological restrictions were identified for future exploration. First, this article was conducted among only built environment students in technical universities in Ghana, with reference to DT modeling experiences. Based on this assertion, generalization of the study's results is restricted to the sampling scope. Investigation of the phenomenon in future empirical works could explore students in other faculties, as segmentations could yield varying outcomes. Second, this investigation was undertaken from the philosophical standpoint of positivism. Consequently, the article examines its objectives through the deployment of inferential statistics. The article suggests that future explorations could investigate the phenomenon from an interpretivist's standpoint. Further, the study proposes that future studies could investigate comparative cross-country dynamics regarding DT technologies adoption in IHL. The results may serve as an outline to assess country-specific indices of digital transformation among IHL across the globe.

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