



A CONCEPTUAL FRAMEWORK TO LEVERAGE TECHNOLOGY ACCEPTANCE MODELS FOR DIGITAL TWIN ACCEPTANCE AND ADOPTION IN THE CONSTRUCTION INDUSTRY

Guncel Vara¹, Guzide Atasoy¹, and Sevgi Ozkan Yildirim²

¹Department of Civil Engineering, Middle East Technical University, Ankara, Türkiye

²Graduate School of Informatics, Middle East Technical University, Ankara, Türkiye

Abstract

Digital twins offer solutions to efficiency and decision-making problems of the construction industry by expanding the capabilities of current technologies. However, their acceptance and adoption have not been thoroughly examined, creating barriers to their implementation. This study proposes a conceptual framework in the context of leveraging Technology Acceptance Model (TAM) for digital twins in construction through a systematic review of existing literature. The framework includes a modified TAM enhanced by constructs from the Innovation Diffusion Theory (IDT) to tailor TAM for digital twin technology. The framework also outlines the model constructs, scale item and target audience selection procedures.

Introduction

Construction companies are undertaking construction projects on larger scales compared to the past, in order to address the growing needs for built environment and infrastructure. When the unique nature of construction projects is combined with large-scale implementation, complexity of these projects becomes the instigator of significant challenges in terms of budget, time and quality requirements. The construction industry has been in search of solutions to these challenges, and robust technologies and methodologies to tackle these challenges can unlock the potential of the industry to increase time and cost efficiency, in addition to improved quality.

Digital twin is a data-driven information technology that might remedy these problems, as the data-driven concepts such as Internet of Things (IoT) and big data (Ammar et al., 2022), in addition to artificial intelligence (AI) and machine learning (ML) are becoming prominent in the construction industry. Digital twins can leverage these technological developments (Sacks et al., 2020) in order to collect real-time data during the course of construction projects to create virtual digital replicas or copies of the physical assets; then, these copies can be used for informed decision-making via planning, simulations, forecasts, predictions and performance optimizations (Opoku et al., 2021; Khajavi et al., 2019; Boje et al., 2020).

Digital twins can also open new pathways in the construction industry by integrating novel methods and tools with the ones already in use, at different stages in the life cycle of a construction project. For example, Building Information Modeling (BIM) implementations can be integrated with digital twins to achieve more efficient construction management practices, since the capabilities of BIM models can be expanded by real-time data exchange, and predictive analyses and simulations introduced by creating corresponding digital twins (Khajavi et al., 2019). Waste and energy consumption can also be optimized with digital twins by streamlining workflows and improving resource use (Pan and Zhang, 2021) through the utilization of accurate real-time data.

Digital twin is a promising technology to improve construction practices throughout all life cycle stages, yet they have not reached the state of widespread use by the companies operating within the construction industry (Zhu et al., 2024; Madubuike et al., 2022). The conceptual confusion among the concepts of digital model, digital shadow and digital twin often emerges as the first barrier to digital twin adoption in the construction industry, affecting user perception towards this technology (Jahangir et al., 2024). Several other key challenges resulting in a cumbersome adoption of digital twins are also scrutinized in the literature, yet a number of these challenges obstructs digital twin adoption in all life cycle stages of construction practices. Data interoperability challenges that arise due to incompatible data formats between the employed digital technologies and tools, and digital twin tools constitute a group of internal challenges of this nature for construction companies, resulting in hindered representations of building progress and performance (Boje et al., 2020; Sacks et al., 2020). Organizational resistance stemming from problems caused by digital twin integration into established workflows and legacy systems emerges as another prominent internal challenge to be tackled (Opoku et al., 2023). Finally, shortage of skilled professionals is another internal challenge which limits the ability to create complex models, hence reducing the quality of work done by using digital twin technology (Opoku et al., 2023).

Among the significant external challenges, regulatory constraints related to data privacy, security and compliance create bottlenecks due to challenging

navigation in the legal landscape regarding the use of digital twins (Hoeft and Trask, 2022). Cybersecurity challenges are another group of external challenges impeding digital twin adoption, which result in distrust towards the real-time data exchange mechanisms of digital twin technology (Fuller et al., 2020).

Within this landscape of a wide variety of challenges, the acceptance and adoption of digital twins as a novel information technology in the construction industry should be studied in depth to identify barriers and potential pain points to analyze these for devising mitigation methodologies. The barriers to digital twin acceptance and adoption have been a long-discussed topic in the literature; however, holding such discussions within the broader context of information technologies, where established and systematic models and methods can provide significant insights to technology acceptance and adoption, has seldom been the case.

Information technology use can be considered a demonstration of the acceptance of a technology by its prospective users, and proves to be a basis for research towards investigating the determinants of information technology acceptance and use. Building on these features, many models and approaches have been developed in the information technology literature. These models incorporate elements, known as constructs, which are intended to explain and predict why individuals or organizations adopt and use a given technology. Each construct in a model is measured by using scale items, which are designed to evaluate user responses to predefined scenarios categorized under these constructs. Technology Acceptance Model (TAM) was introduced by Davis (1989), which is now regarded a prominent example of such efforts, and adapts the Theory of Reasoned Action (TRA) by Ajzen (1985) and the Theory of Planned Behavior (TPB) also by Ajzen (1991) intended to model user-level acceptance of information systems or technologies. By definition, TAM is aimed at providing a theoretically justified explanation of the determinants of information technology acceptance, which can also account for user behavior for different end-user technologies among diverse user populations. TAM suggests that the behavioral intention of a user is influenced by two key constructs: Perceived Usefulness, which reflects the belief that using a technology will improve job performance, and Perceived Ease of Use, which represents the belief that the technology will be easy to use. Subsequent models, such as the Unified Theory of Acceptance and Use of Technology (UTAUT) by Venkatesh et al. (2003), expanded on TAM by incorporating additional constructs, including social influences, facilitating conditions, attitudes toward technology use, self-efficacy, anxiety, and behavioral intention. Communication theories, such as Innovation Diffusion Theory (IDT) by Rogers (2003), are also integrated into information technology acceptance research to develop comprehensive models and methodologies, since such theories can introduce the

organizational dimension of technology acceptance into existing acceptance models (Tornatzky and Klein, 1982). These models are typically applied by collecting data through user surveys with carefully designed scale items corresponding to the selected constructs. Information technology acceptance frameworks have been applied across various industries to evaluate the adoption of numerous technologies, and thus can similarly be adapted for use in the construction industry.

This study aims to propose a novel technology acceptance model for digital twin acceptance and adoption in the construction industry by modifying TAM with additional constructs taken from IDT. Thus, it is intended to assess the understanding of the barriers to the adoption of digital twins among the researchers and practitioners in the construction industry through a mapping of these barriers to user- and organizational-level constructs of these models to explore more efficient methodologies to adopt digital twin technology. The developed conceptual framework enables a foundation for future empirical application to unveil the possible pain points associated with the use of digital twins in construction companies.

Methodology

This study adopts the “Preferred Reporting Items for Systematic Reviews and Meta-Analyses” (PRISMA) guidelines to review the literature, in order to ensure accuracy, reliability and clarity in the reporting process (Moher et al., 2009). In the identification phase of the literature review for digital twin adoption and acceptance, the literature search was conducted on Scopus and Web of Science (WoS) databases using the search terms and operators in Table 1 and Table 2.

The searches on Scopus and WoS databases included journal articles, conference proceedings, and reviews written in English, which are related to the construction industry. In addition, papers including the information technology acceptance models and theories that are more common in the literature, namely Technology Acceptance Model (TAM), Diffusion of Information Theory (DOI) also known as Information Diffusion Theory (IDT), Theory of Planned Behavior (TPB), Theory of Reasoned Action (TRA), Task-Technology Fit Model (TTF), and the Unified Theory of Acceptance and Use of Technology (UTAUT) are sought by including them as keywords in the search (Taherdoost, 2018). Following the identification phase, the results retrieved from the searches on both databases are combined and duplicates are removed at the beginning of the screening phase. The texts in which digital twin technology was not the main topic or in which DT adoption and acceptance was not discussed were eliminated in the following steps. In the eligibility phase, a total of 62 papers was selected to be included in this study. However, only 8 out of 62 papers were found to be discussing DT adoption and acceptance within the scope of information technology acceptance models and theories, marking the scarcity of studies to this end (see Figure 1).

Table 1: Structure of the query string used in Scopus database for DT-related papers.

Descriptions and Fields	Operators and Keywords Used
Search elements	TITLE-ABS-KEY
Digital Twin	("digital twin" OR "digital twins")
Operator	AND
Construction Industry	("construction" OR "building" OR "built environment" OR "AEC" OR "AECO" OR "AECOFM" OR "asset management" OR "facility management" OR "operation and maintenance" OR "management" OR "construction management")
Operator	AND
Technology Acceptance and Adoption	("acceptance" OR "adoption" OR "technology acceptance" OR "TAM" OR "diffusion of innovation theory" OR "DOI" OR "innovation diffusion theory" OR "IDT" OR "task-technology fit" OR "TTF" OR "theory of planned behavior" OR "TPB" OR "theory of reasoned action" OR "TRA" OR "unified theory of acceptance and use of technology" OR "UTAUT")

Table 2: Structure of the query string used in Web of Science database for DT-related papers

Descriptions and Fields	Operators and Keywords Used
Search elements	TI (title) OR AB (abstract) OR AK (author keywords)
Digital Twin	("digital twin" OR "digital twins")
Operator	AND
Construction Industry	("construction" OR "building" OR "built environment" OR "AEC" OR "AECO" OR "AECOFM" OR "asset management" OR "facility management" OR "operation and maintenance" OR "management" OR "construction management")
Operator	AND
Technology Acceptance and Adoption	("acceptance" OR "adoption" OR "technology acceptance" OR "TAM" OR "diffusion of innovation theory" OR "DOI" OR "innovation diffusion theory" OR "IDT" OR "task-technology fit" OR "TTF" OR "theory of planned behavior" OR "TPB" OR "theory of reasoned action" OR "TRA" OR "unified theory of acceptance and use of technology" OR "UTAUT")

A detailed examination of the results of the literature review efforts led to the observation that digital twins are increasingly considered to be the natural successor of building information modelling (BIM), which is another information technology extensively used in the construction industry for end-to-end project management (Honghong et al., 2023; Deng et al., 2021). The similarities between their capabilities, the challenges they strive to address and suffer in their organization-wide implementations are extensive, and there exists several acceptance and adoption studies related to BIM within the context of IT acceptance. It is suggested, therefore, that searching the literature for technology acceptance models intended for BIM may prove beneficial for devising a similar model for digital twins.

In a second literature search for finding texts to serve this purpose, Scopus and Web of Science (WoS) databases are used with the same search terms as the ones used for the previous cycle of literature search, after changing the keywords related to digital twins with those related to BIM, and by removing the separate keywords of "acceptance" and "adoption", since these terms resulted in query returns not related to information technology acceptance models. At the end of the screening and eligibility processes (see Figure 2), 100 papers related to BIM adoption and acceptance within the scope of IT acceptance theories were found. Upon the examination of the 100 papers received at the end of the PRISMA flow, it was observed that studies employing TAM and DOI (or IDT) make up the majority of these papers (see Table 3), but other models and methods such as TTF and UTAUT, in addition to hybrid models, also have been utilized by researchers to investigate BIM adoption and acceptance.

Findings

Among the eight studies selected by the first round of literature review on digital twins, which are listed in Table 4, TAM and TTF are the prominent choices to investigate DT technology adoption in the construction industry, but the number of available studies is not sufficient to be able to observe the empirically tested and proven methodologies in model construction, involving the selection of constructs, scale items, and statistical analysis methods to evaluate the collected responses from potential users. In addition, it is deemed evident, therefore, that the research efforts towards digital twin acceptance and adoption in the industry can benefit from an expansive selection of implementation examples.

Results of the literature review on DT adoption also reveal that the constructs utilized to form the acceptance models in the selected papers do not consider company-level interactions with the technology. This observation is supported by the construct definitions of the models used in these studies, since TAM and TTF use user-concentrated constructs (Davis, 1989; Goodhue and Thompson, 1995), and UTAUT only has social influence constructs, which are mostly limited to peer interactions (Venkatesh et al., 2003).

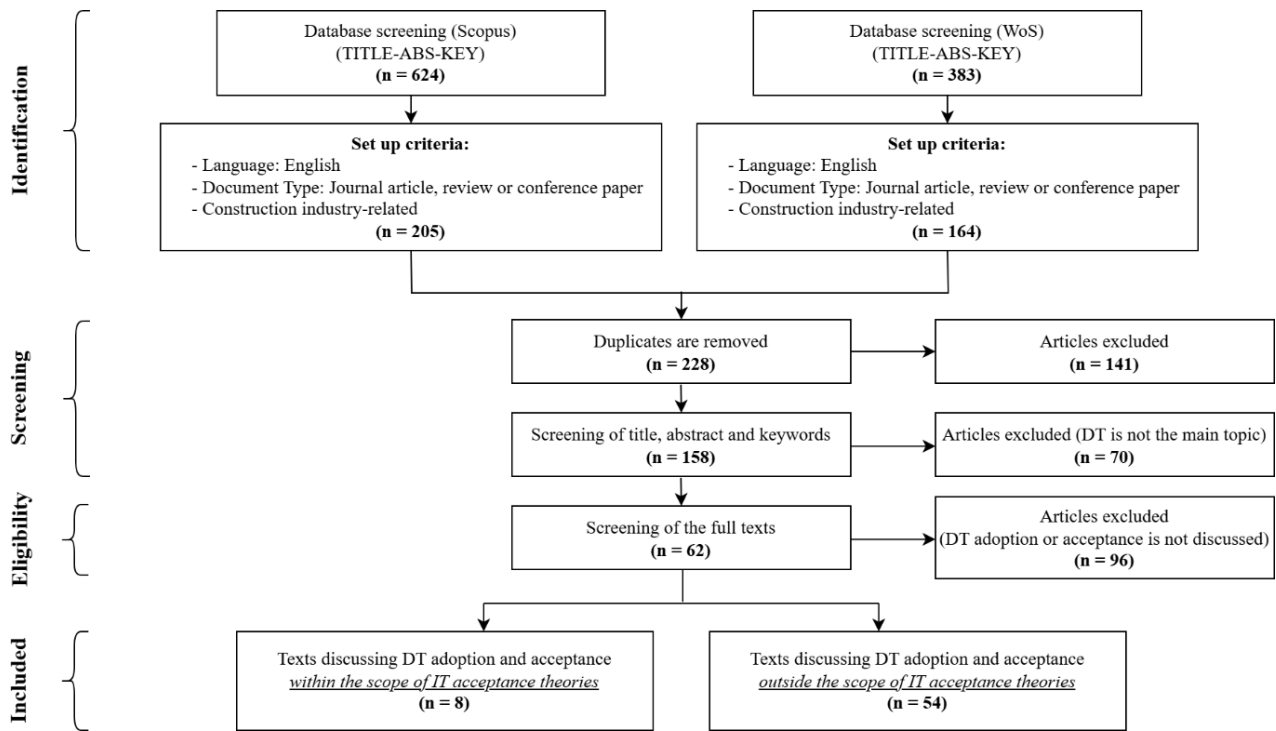


Figure 1: The PRISMA flow diagram for DT adoption and acceptance literature review

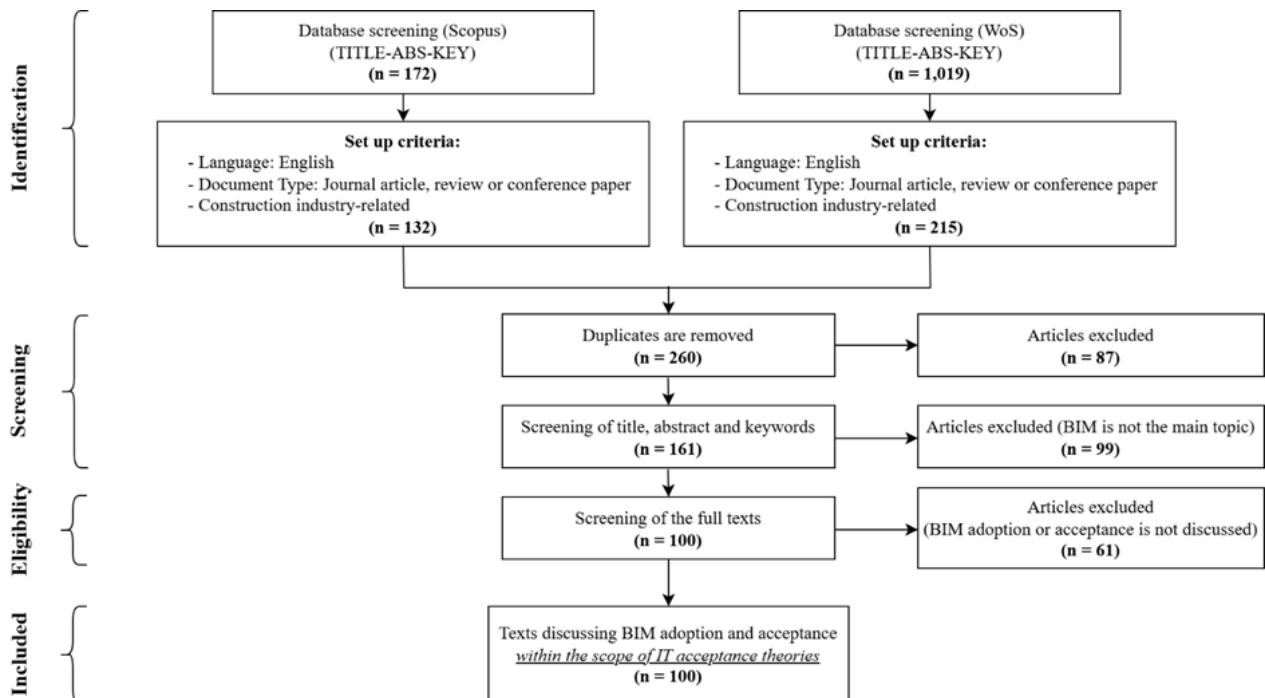


Figure 2: The PRISMA flow diagram for BIM adoption and acceptance literature review

Table 3: Adoption frequencies of BIM adoption models among the papers selected by the literature review

BIM Acceptance Model Structure	Number of Papers Adopting the Model
TAM	44
IDT (DOI)	24
UTAUT	9
TAM + IDT (DOI)	8
UTAUT + TTF	4
UTAUT + TAM	2
TAM + IDT (DOI) + UTAUT	1
TAM + TPB	1
TAM + TTF	1
TPB	1
TRA	1
TTF	1

TAM is defined as a model capable of explaining user-level behavior across a wide range of information technologies and user groups (Davis et al., 1989), and a number of studies on BIM acceptance and adoption focusing on the use of TAM has explored its empirically tested and proven capabilities in reflecting technology acceptance behavior at user-level to the extent that specialized TAM hybrids are created for this purpose (Lee et al., 2015). Therefore, it is suggested that this model can also be utilized for investigating DT acceptance and adoption. However, it is important to pinpoint that TAM, in its lean form, is a user-level model, utilizing constructs and scale items focusing on the interaction between the technology under examination and its potential users. In this regard, the scope of a proposed DT acceptance and adoption model should also incorporate measuring items to reflect the interaction of the technology both with the users within and the structure of a given construction company.

To this end, it is proposed that a hybrid TAM can be devised by introducing suitable constructs from other technology acceptance models and theories, which can account for the interactions at the organizational level.

The second literature review on BIM acceptance and adoption revealed that the Innovation Diffusion Theory (IDT or DOI) was among the mostly used technology acceptance methodologies (see Table 3), since it was found to be validating TAM with its similar constructs, and complementing the model with the new constructs. Grounded in sociology, IDT was devised by Rogers (1995) in order to study a variety of innovations and technologies. Moore and Benbasat (1991) adapted the characteristics of innovations presented by Rogers to technology acceptance. Constructs such as Relative Advantage and Ease of Use have similarities with the constructs of TAM, but the construct of Compatibility, which is defined as the degree to which a technology is perceived as compatible with the existing values, needs,

and experiences of the adopting party (user or organization), differs from TAM constructs in the sense that it can be adapted to involve organization-level interactions by creating a set of scale items designed to evaluate these interactions. In addition, it is suggested and demonstrated in several studies that Compatibility is one of the most utilized IDT constructs, and combining TAM and IDT by using the Compatibility construct of IDT complements TAM with social influence factors, which could be used for discussing acceptance and adoption at the company level (Gillenson and Sherrell, 2002; Tung et al., 2008). Thus, incorporating the Compatibility construct from IDT into the TAM model would enhance its performance.

Table 4: Selected studies on DT acceptance and adoption from the literature review

Reference	Acceptance Model or Theory Used for Digital Twin Implementation
Bello <i>et al.</i> (2024)	Problem statement includes two constructs from TAM (Perceived Usefulness & Perceived Ease of Use), but the model is not implemented.
Bruno <i>et al.</i> (2022)	TTF model is used to evaluate the proposed DT-based tool.
Ning <i>et al.</i> (2024)	Focusing on DT implementation in education, UTAUT2 and TTF models are used.
Sepasgozar <i>et al.</i> (2021)	An extended TAM is used for mixed reality and digital twin (MRDT) adoption.
Shan <i>et al.</i> (2024)	IDT is used for investigating the relationship between DT and construction project management performance.
Wong <i>et al.</i> (2022)	TTF model is used to determine the relationship between the characteristics of DT technology and building maintenance tasks.
Zech <i>et al.</i> (2025)	A workflow is proposed, and its functionality is tested with TAM, but details of the test are not provided.
Zech <i>et al.</i> (2024)	TAM is used to demonstrate the feasibility of the proposed model-based auto-commissioning solution.

Building up on the literature review findings, this study proposes an integrated TAM-IDT model for studying DT acceptance and adoption in the construction industry, which incorporates the constructs listed in Table 5. Based on the commonly used connections between the constructs in similar acceptance models, a number of hypotheses are proposed to explain the connections among these constructs. The constructs derived from TAM are expected to help assess the first-hand user experience related to internal challenges. On the other hand, the Compatibility construct from IDT is expected to

reflect the impact of external challenges on construction companies through user responses.

Table 5: Definitions of the constructs included in the proposed DT technology acceptance model

Construct	Definition
Attitude Towards Behavior	An individual's positive or negative feelings (evaluative affect) about performing the usage behavior (Fishbein and Ajzen, 1975).
Behavioral Intention to Use	The degree to which an individual has devised conscious plans to perform or not perform usage behavior in the future (Fishbein and Ajzen, 1975).
Compatibility	The degree to which an innovation is regarded consistent with the existing values, needs, and past experiences of potential adopters (Moore and Benbasat, 1991).
Perceived Ease of Use	The degree to which an individual believes that using a particular system would require no effort (Davis, 1989).
Perceived Usefulness	The degree to which an individual believes that using a particular system would improve their job performance (Davis, 1989).

Perceived Ease of Use has been defined as a direct determinant of Perceived Usefulness (Davis et al., 1989), since systems perceived as easier to use are judged to be more useful due to reduced cognitive effort (Venkatesh, 1999). Similarly, Perceived Ease of Use directly shapes positive attitudes by reducing perceived effort and anxiety (Davis, 1989), leading to the following two hypotheses to test the proposed model:

- H1: Perceived Ease of Use positively influences Perceived Usefulness.
- H2: Perceived Ease of Use positively influences Attitude Towards Behavior.

Perceived Usefulness was found to be significantly correlated to Attitude Towards Behavior and Behavioral Intention to Use again by the research of Davis (1989), and Venkatesh and Davis (2000) points out that Perceived Usefulness has consistently been a strong determinant of usage intentions and attitudes towards use, in addition to verifying relevant hypotheses. It can also be stated that Perceived Usefulness enhances attitudes by reinforcing performance benefits, and encourages users to prioritize systems that improve efficiency. Hence, the following two hypotheses are devised to reveal the relationships among Perceived Usefulness, Behavioral Intention to Use, and Attitude Towards Behavior within the context of our study:

- H3: Perceived Usefulness positively influences Attitude Towards Behavior.
- H4: Perceived Usefulness positively influences Behavioral Intention to Use.

Ajzen (1991) puts forth as a general rule that a more favorable attitude with respect to behavior should result in stronger intention in an individual to perform the behavior under consideration. Since this rule has also been followed by various studies on technology acceptance literature, the following hypothesis is formed to test the proposed model:

- H5: Attitude Towards Behavior positively influences Behavioral Intention to Use.

While Tornatzky and Klein (1982) testifies that compatibility positively influences adoption behavior in individuals, studies by Karahanna et al. (1999) and Moore and Benbasat (1991) lead to the observation that compatibility, in an organizational context, is a key construct affecting individuals' perception of a technology and subsequent adoption behavior. Hence, the following three hypotheses are suggested to test the impact of compatibility on user adoption behavior:

- H6: Compatibility positively influences Perceived Usefulness.
- H7: Compatibility positively influences Perceived Ease of Use.
- H8: Compatibility positively influences Attitude Towards Behavior.

Finally, the following hypothesis between Behavioral Intention to Use and Actual System Use is formed, which can be regarded a logical connection between the two constructs:

- H9: Behavioral Intention to Use positively influences Actual System Use.

The hypotheses listed here are also found in the BIM acceptance and adoption studies returned by the literature review loops outlined previously in this study, and they have been empirically tested and verified in these studies. In the implementation of this framework, these hypotheses are planned to be empirically tested and verified for digital twin acceptance and adoption.

The relationships among the constructs explained by the hypotheses listed above are depicted in the model diagram in Figure 3. The outward arrows on the constructs indicate the direction of influence.

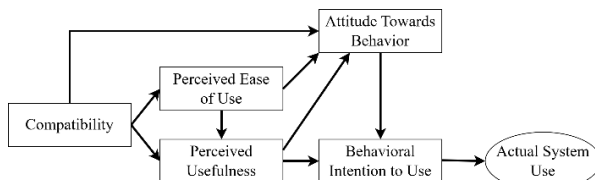


Figure 3: Proposed DT technology acceptance model

Conclusion and Future Work

This study proposes a novel digital twin technology acceptance model for the construction industry by

combining TAM and IDT, which facilitates the investigation of DT acceptance and adoption on both the user- and the organization-level, thereby leveraging the strengths of both TAM and IDT. Two separate rounds of literature reviews of DT acceptance and BIM acceptance models and theories for the construction industry presented in this body of work unfolded research trends to be used for devising the proposed model.

While the framework is not empirically tested in this study, it is grounded in a structured synthesis of relevant literature on digital twin, BIM, and information technology acceptance domains. This conceptual model is designed to guide future empirical research to address the acceptance and adoption dynamics for digital twins across all life cycle stages of construction practices, and this function could be achieved by customizing the hypotheses and the scale items used for assessing each construct.

Although this study is limited in presenting the scale items for the model constructs, commonly-used, empirically-tested and proven scale items from the DT and BIM technology acceptance and adoption literature will be used for verification and validation.

Implementation of the model requires the dissemination of the scale items in the form of a questionnaire among a diverse group of professionals from within the construction industry, which could be determined depending on the implementation case of the proposed model. For most cases, these groups are expected to include end users such as engineers and coordinators, BIM managers, site supervisors, facility managers, company executives, and top brass members. The framework is designed to provide a foundation for targeted questionnaire development that can be modified to suit the needs of different use cases.

The proposed model will be implemented in the next phase of this research to examine the interplay of the constructs and scale items by conducting statistical analyses of the results obtained from surveys conducted with the participation of industry professionals, and to further unveil potential barriers to the adoption of digital twin technology in the construction industry. Depending on the results obtained from implementations of this nature might provide clues to improve the proposed framework with enhancements or additions of constructs, hypotheses, scale items and test group demographics.

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References

Ajzen, I. (1985). From intentions to actions: A theory of planned behavior. In *Action control: From cognition to behavior* (pp. 11-39). Berlin, Heidelberg: Springer Berlin Heidelberg.

- Ajzen, I. (1991). The theory of planned behavior. *Organizational behavior and human decision processes*, 50(2), 179-211.
- Ammar, A., Nassereddine, H., AbdulBaky, N., AbouKansour, A., Tannoury, J., Urban, H., & Schranz, C. (2022). Digital twins in the construction industry: a perspective of practitioners and building authority. *Frontiers in Built Environment*, 8, 834671.
- Bello, A. O., Olanrewaju, O. I., Gbenga, P. O., Khan, A. A., & Isa, R. B. (2024). Exploring the barriers to digital twin adoption in the Nigerian construction industry: a structural equation modelling approach. *Journal of Engineering, Design and Technology*.
- Boje, C., Guerriero, A., Kubicki, S., & Rezgui, Y. (2020). Towards a semantic Construction Digital Twin: Directions for future research. *Automation in construction*, 114, 103179.
- Bruno, S., Sciotti, A., Pierucci, A., Rubino, R., Di Noia, T., & Fatiguso, F. (2022). Verbum--Virtual Enhanced Reality for Building Modelling (Virtual Technical Tour in Digital Twins for Building Conservation). *Journal of Information Technology in Construction*, 27.
- Davis, F. D. (1989). Perceived usefulness, perceived ease of use, and user acceptance of information technology. *MIS quarterly*, 319-340.
- Davis, F. D., Bagozzi, R. P., & Warshaw, P. R. (1989). User acceptance of computer technology: A comparison of two theoretical models. *Management science*, 35(8), 982-1003.
- Deng, M., Menassa, C. C., & Kamat, V. R. (2021). From BIM to digital twins: A systematic review of the evolution of intelligent building representations in the AEC-FM industry. *Journal of Information Technology in Construction*, 26.
- Fuller, A., Fan, Z., Day, C., & Barlow, C. (2020). Digital twin: Enabling technologies, challenges and open research. *IEEE access*, 8, 108952-108971.
- Gillenson, M. L., & Sherrell, D. L. (2002). Enticing online consumers: an extended technology acceptance perspective. *Information & management*, 39(8), 705-719.
- Goodhue, D. L., & Thompson, R. L. (1995). Task-technology fit and individual performance. *MIS quarterly*, 213-236.
- Hoefl, M., & Trask, C. (2022). Safety built right in: exploring the occupational health and safety potential of BIM-based platforms throughout the building lifecycle. *Sustainability*, 14(10), 6104.
- Honghong, S., Gang, Y., Haijiang, L., Tian, Z., & Annan, J. (2023). Digital twin enhanced BIM to shape full life cycle digital transformation for bridge engineering. *Automation in Construction*, 147, 104736.

- Jahangir, M. F., Leslie Schultz, C. P., & Kamari, A. (2024). A review of drivers and barriers of Digital Twin adoption in building project development processes. *Journal of Information Technology in Construction*, 29.
- Karahanna, E., Straub, D. W., & Chervany, N. L. (1999). Information technology adoption across time: A cross-sectional comparison of pre-adoption and post-adoption beliefs. *MIS quarterly*, 183-213.
- Khajavi, S. H., Motlagh, N. H., Jaribion, A., Werner, L. C., & Holmström, J. (2019). Digital twin: vision, benefits, boundaries, and creation for buildings. *IEEE access*, 7, 147406-147419.
- Lee, S., Yu, J., & Jeong, D. (2015). BIM acceptance model in construction organizations. *Journal of management in engineering*, 31(3), 04014048.
- Madubuike, O. C., Anumba, C. J., & Khallaf, R. (2022). A review of digital twin applications in construction. *Journal of Information Technology in Construction*, 27.
- Moher, D., Liberati, A., Tetzlaff, J., Altman, D. G., & PRISMA Group*, T. (2009). Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *Annals of internal medicine*, 151(4), 264-269.
- Moore, G. C., & Benbasat, I. (1991). Development of an instrument to measure the perceptions of adopting an information technology innovation. *Information systems research*, 2(3), 192-222.
- Ning, G., Luo, H., Yin, W., & Zhang, Y. (2024). Exploration of the Application and Practice of Digital Twin Technology in Teaching Driven by Smart City Construction. *Sustainability* (2071-1050), 16(23).
- Opoku, D. G. J., Perera, S., Osei-Kyei, R., Rashidi, M., Bamdad, K., & Famakinwa, T. (2023, January). Barriers to the adoption of digital twin in the construction industry: A literature review. In *Informatics* (Vol. 10, No. 1, p. 14). MDPI.
- Opoku, D. G. J., Perera, S., Osei-Kyei, R., & Rashidi, M. (2021). Digital twin application in the construction industry: A literature review. *Journal of Building Engineering*, 40, 102726.
- Pan, Y., & Zhang, L. (2021). Roles of artificial intelligence in construction engineering and management: A critical review and future trends. *Automation in Construction*, 122, 103517.
- Rogers, E. M. (2003). *Diffusion of Innovations*, 5th ed. New York: Free Press
- Sacks, R., Brilakis, I., Pikas, E., Xie, H. S., & Girolami, M. (2020). Construction with digital twin information systems. *Data-Centric Engineering*, 1, e14.
- Sepasgozar, S. M., Ghobadi, M., Shirowzhan, S., Edwards, D. J., & Delzendeh, E. (2021). Metrics development and modelling the mixed reality and digital twin adoption in the context of Industry 4.0. *Engineering, Construction and Architectural Management*, 28(5), 1355-1376.
- Shan, J., Chai, C. S., Lim, B. C. Y., & Palaneeswaran, E. Unveiling the digital horizon: Bridging the realms of digital twinning and construction project management performance. *Journal of Infrastructure, Policy and Development*, 8(9).
- Taherdoost, H. (2018). A review of technology acceptance and adoption models and theories. *Procedia manufacturing*, 22, 960-967.
- Tornatzky, L. G., & Klein, K. J. (1982). Innovation characteristics and innovation adoption-implementation: A meta-analysis of findings. *IEEE Transactions on engineering management*, (1), 28-45.
- Tung, F. C., Chang, S. C., & Chou, C. M. (2008). An extension of trust and TAM model with IDT in the adoption of the electronic logistics information system in HIS in the medical industry. *International journal of medical informatics*, 77(5), 324-335.
- Venkatesh, V. (1999). Creation of favorable user perceptions: Exploring the role of intrinsic motivation. *MIS quarterly*, 239-260.
- Venkatesh, V., & Davis, F. D. (2000). A theoretical extension of the technology acceptance model: Four longitudinal field studies. *Management science*, 46(2), 186-204.
- Venkatesh, V., Morris, M. G., Davis, G. B., & Davis, F. D. (2003). User acceptance of information technology: Toward a unified view. *MIS quarterly*, 425-478.
- Wong, J., Hoong, P., Teo, E., & Lin, A. (2022, November). Digital twin: a conceptualization of the task-technology fit for individual users in the building maintenance sector. In *IOP Conference Series: Earth and Environmental Science* (Vol. 1101, No. 9, p. 092041). IOP Publishing.
- Zech, P., Hammes, S., Goldin, E., Geisler-Moroder, D., Breu, R., & Pfluger, R. (2025). From BIM to Digital Twin: A transformation process through advanced control modeling and automated commissioning using daylight and artificial lighting as examples. *Energy and Buildings*, 329, 115184.
- Zech, P., Goldin, E., Hammes, S., Geisler-Moroder, D., Pfluger, R., & Breu, R. (2024). Model-based auto-commissioning of building control systems. In *Proceedings of the 26th International Conference on Enterprise Information Systems (ICEIS 2024)* (pp. 121-128).
- Zhu, H., Hwang, B. G., Tan, Y. Z., & Wei, F. (2024). Building on Digital Twin: Overcoming Barriers and Unlocking Success in the Construction Industry. *Journal of Construction Engineering and Management*, 150(10), 04024