Modeling the Organizational Attributes and Strategies for Developing Accurate Digital Twins
The Case of Constructed Facilities

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Modeling the organizational attributes and strategies for developing accurate digital twins: the case of constructed facilities

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Abstract

Purpose – This study aims to establish relationships between organizational attributes and strategies for developing accurate digital twins (DTs) of constructed facilities. To achieve this aim, the study objectives are: (1) identify the key organizational attributes and strategies, (2) develop underlying constructs among the organizational attributes and strategies, and (3) model the relationships between the underlying constructs of organizational attributes and strategies.

Design/methodology/approach – A systematic literature review and semi-structured interviews with architecture, engineering, construction, and operation (AECO) industry professionals identified twenty-one organizational attributes and thirty organizational strategies. Through a survey, 129 AECO industry professionals evaluated the criticality of the organizational attributes and strategies. The collected data were analyzed using normalized mean analysis, exploratory factor analysis, and partial least-squares structural equation modeling.

Findings – The analyses identified eleven and twenty key organizational attributes and strategies. Furthermore, the organizational attributes and strategies can be categorized into two (organizational DT capabilities and technological capabilities requirements) and three (organizational competitiveness and investments, organizational workforce management and training, and organizational management capabilities) underlying constructs. Finally, organizational DT capabilities significantly impact the need for all three underlying constructs of organizational strategies, whereas technological capabilities requirements do not. These findings indicate that strategic initiatives should be driven by organizational and human-centric attributes, including leadership, strategic planning, and talent development, rather than on technological readiness alone, challenging assumptions that technological readiness is the catalyst for strategy deployment in DT development.

Originality/value – This is the first study that models the relationships between organizational attributes and strategies for developing accurate DTs of constructed facilities.

Keywords Construction projects, Digital twin, Organizational attributes, Organizational strategies

Paper type Research paper

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Introduction

In the operation and maintenance (O&M) phase of a constructed facility, inaccurate digital twins (DTs) pose challenges that undermine facility performance and compromise safety. DTs are designed to provide precise virtual representations of physical assets (Grieves, 2015), enabling facility managers to monitor system performance and proactively predict maintenance needs (Zhang *et al.*, 2022; Batty, 2018; Grieves and Vickers, 2017). However, when these digital models contain errors or rely on outdated information, misinformed decision-making becomes inevitable. This can lead to premature equipment failures, overlooked maintenance issues, and escalating operational costs, all of which jeopardize occupant safety and comfort. Moreover, the reliability of DTs is paramount for efficient resource allocation. Inaccurate representations may cause maintenance teams to divert efforts toward non-critical issues while neglecting urgent repairs, resulting in prolonged system downtime and financial losses (Weber-Lewerenz, 2021). Additionally, flawed DTs hinder the ability to conduct reliable simulations and scenario analyses, which are essential for planning renovations, enhancing energy efficiency, and ensuring robust emergency preparedness (Turner *et al.*, 2021), thereby impeding long-term sustainability and resilience. In other words, ensuring that digital models accurately reflect the physical state of constructed facilities is imperative for harnessing the full potential of DT in O&M practices.

The development of accurate DTs for the O&M phase remains underemphasized partly because both researchers and practitioners have focused on factors other than organizational capabilities. One barrier is the lack of a value proposition for DTs within the architecture, engineering, construction, and operation (AECO) industry. Many stakeholders remain uncertain about the tangible benefits and return on investment, which dampens their enthusiasm for investing in the development of accurate DTs (Shahzad *et al.*, 2022; Rajabi *et al.*, 2022). Moreover, the AECO industry's low level of technology acceptance and entrenched reliance on conventional methods contribute to cultural resistance to accurate DT development. This resistance is further compounded by the reliance on datasets that fail to capture real-time changes in facility conditions (Qi *et al.*, 2021), thereby hindering the development of accurate DTs. Additionally, the inherent complexity and uniqueness of construction projects complicate standardization and scalability (Cecconi *et al.*, 2017), leading to hesitancy in allocating necessary resources for accurate DT development. Overcoming these barriers requires a coordinated effort to clarify the value proposition, promote technological adoption, integrate real-time data, and manage project intricacies.

By optimizing the organizational attributes and strategies, AECO organizations can bridge the gaps that have hindered accurate DT development. Identifying and implementing optimal organizational strategies for developing accurate DTs is critical for enhancing project performance and securing a competitive advantage in the AECO industry. Strategic investments in state-of-the-art technologies and specialized personnel training ensure that DT development is effectively supported throughout its lifecycle, reducing redundancy and yielding cost savings. Aligning DT development with broader organizational strategies facilitates smooth transformation, fostering a culture of continuous improvement and technological adaptability. The establishment of rigorous validation frameworks and best practice guidelines enhances the reliability of DTs, thereby bolstering stakeholder confidence. Ultimately, bridging the gap between research and practice application enhances cross-departmental collaboration and positions organizations as leaders in DT development, thereby driving safety, performance, and sustainability across constructed facilities. With the optimal organizational strategies in place, the AECO industry can move beyond fear and hesitations in embracing DT as a catalyst for innovation, efficiency, and long-term success.

This study aims to establish relationships between organizational attributes and strategies for developing accurate DTs of constructed facilities. To achieve this aim, three study objectives were set out: (1) identify the key organizational attributes and strategies, (2) develop underlying constructs among the organizational attributes and strategies, and (3) model the relationships between the underlying constructs of organizational attributes and strategies. In pursuit of those objectives, a systematic literature review (SLR) was conducted alongside semi-structured interviews with AECO professionals, which together revealed organizational attributes and strategies for developing accurate DTs. Subsequently, a questionnaire survey was administered to evaluate the organizational attributes and strategies. The collected data were analyzed using the two-standard deviation (SD) technique, normalized mean analysis (NMA), exploratory Factor Analysis (EFA), and Partial Least-squares Structural Equation Modeling (PLS-SEM). Establishing the relationships strengthens the development of accurate DTs of constructed facilities by providing practitioners with recommendations for optimizing resource allocation. Accurate DTs of constructed facilities enable precise simulation of urban systems, supporting safe and sustainable cities. Furthermore, they can facilitate real-time monitoring of occupational hazards and indoor environment quality, reducing workplace injuries and enhancing well-being. Finally, accurate DTs of constructed facilities improve the early detection of infrastructure degradation, enabling predictive maintenance workflows and supporting resilient infrastructure development. Nevertheless, this is the first study that models the relationships between organizational attributes and strategies for developing accurate DTs of constructed facilities, thus it is unique and different from previous research within the subject matter.

Background

Organizational attributes to develop accurate digital twins of constructed facilities

Organizational attributes refer to the fundamental characteristics, structures, and operational frameworks that impact an organization's capability to develop accurate DTs. These attributes include leadership commitment, strategic financial investment, workforce competencies, and organizational culture towards innovation (Song and Chen, 2014). As Hodgson (2004) highlighted, such attributes act as constraints and catalysts, sharpening organizational actions and safeguarding organizational knowledge. In practical terms, these attributes establish the groundwork for developing accurate DTs by creating an environment that supports systematic data integration, cross-functional collaboration, and data-driven decision-making. The alignment of strategic vision with operational workflows ensures that DTs are not treated merely as technological upgrades but as integral components of an organization's overall strategy. This integration facilitates continuous improvement and responsiveness to emerging challenges. Moreover, robust organizational attributes help mitigate risks associated with DT development, ensuring that the resulting models accurately reflect the constructed facilities, thus leading to more reliable outcomes during the O&M phase.

Illustrative examples underscore the role of organizational attributes in developing accurate DTs of constructed facilities. Singapore's Smart Nation Initiative, for instance, demonstrates how strong leadership and a clear strategic vision can develop more accurate DTs by aligning project stakeholders and standardizing data integration. Such organizational attributes have enabled the test-bedding of innovative solutions, promoting smooth interdisciplinary collaboration and enhanced data-driven processes for developing DTs in Singapore (Smart Nation 2.0, 2024). Similarly, the Hong Kong-Zhuhai-Macau Bridge (HZMB) project showcases the benefits of having adequate inter-organizational collaboration maturity among project stakeholders. By integrating diverse datasets and emphasizing data-driven decision-making, the HZMB project enhanced DT accuracy, optimized design and construction processes, and improved asset lifecycle management (Cao *et al*., 2023; Ma *et al*., 2023). As Agrawal *et al.* (2022) note, the development of accurate DTs is linked to how well organizations embed DT within their strategic visions, operational workflows, and decision-making processes, affirming that DT development is an organizational endeavor rather than a mere technological upgrade.

Organizational strategies to develop accurate digital twins of constructed facilities

The development of accurate DTs for constructed facilities transcends mere technical execution. It represents an endeavor that demands a rethink among AECO organizations. As

Weber-Lewerenz (2021) highlighted, the successful development of accurate DTs requires the integration of cutting-edge technologies, the active engagement of skilled personnel, proactive discussions on emerging trends, and the identification of relevant application domains. These factors collectively compel project stakeholders to re-examine their organizational strategies in light of technical innovation, ensuring that DT development is linked with broader organizational goals. Weber-Lewerenz (2021) also emphasized that fundamental organizational strategies, including continuous skill development, cross-learning through professional institutions, interdisciplinary collaborations, and strategic leadership, are critical to fostering the organizational capabilities necessary for developing accurate DTs. In other words, aligning human capital, governance, and innovative practices can create an organizational environment conducive to the development of accurate DTs.

Evidence from real-world projects underscores the impact of organizational strategies on the accuracy of developed DTs. For example, the Siemens Amberg Electronics Plant in Germany demonstrates how continuous workforce upskilling, organizational readiness, and organization-wide system integration can develop DTs with higher accuracy. Similarly, Virtual Singapore, a flagship project under Singapore’s Smart Nation Initiative, leverages strong organizational leadership, open data policies, and public-private partnerships to enable the development of DTs with higher accuracy (Smart Nation 2.0, 2024). Additionally, the HZMB project highlights the benefits of providing a framework that enables cross-regional collaboration, comprehensive data integration, and stringent data governance protocols in enhancing the development of accurate DTs. Consequently, it is imperative for AECO organizations to adopt strategies that merge technological innovation with organizational development to develop accurate DTs of constructed facilities.

Research gap and study positioning

Previous research in developed countries has examined the diverse applications of DT across industries (e.g. Batty, 2018; Qi *et al.*, 2021; Cecconi *et al.*, 2017; Weber-Lewerenz, 2021). Additionally, previous research has advanced technological innovations and provided economic feasibility assessments for DT developments. However, although the technical and economic aspects of DT development have been analyzed, the role of organizational attributes and strategies in developing accurate DTs remains neglected. This oversight is evident within the AECO industry, where investigations into organizational elements remain scarce. The absence of a clear understanding of how organizational attributes and strategies, including leadership, strategic planning, workforce competencies, and collaborative frameworks, impact DT accuracy has resulted in digital models that are fragmented and underutilized. This gap in the body of knowledge limits the potential benefits of DT and poses risks to operational efficiency and asset management of constructed facilities. Therefore, this study aims to investigate the organizational attributes and strategies for developing accurate DTs of constructed facilities. Addressing the research gap and achieving the study aim is imperative to harness the full capabilities of DTs, ensuring that technological advancements are integrated with organizational practices.

Methodology

A questionnaire survey was employed as a systematic instrument for collecting randomized data and is widely used in construction project management research to capture expert insights. The survey was designed and implemented as the primary data collection instrument to evaluate the criticality of the organizational attributes and strategies for developing accurate DTs of constructed facilities. This approach enables the collection of structured data that reflect real-world perceptions and experiences within the AECO industry. The subsequent subsections detail the survey development, data collection, and data analysis processes. Figure 1 provides an overview of the methodology.

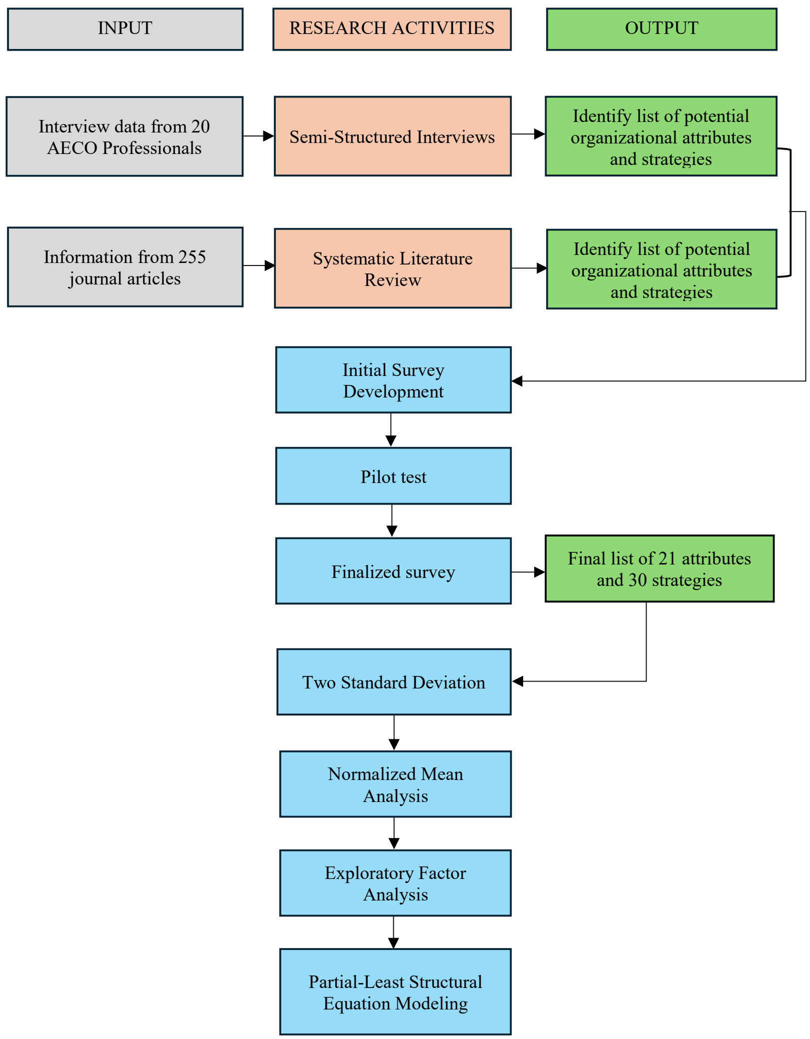

Figure 1. Overview of study methodology. Source: Authors' own work

Survey development

To systematically identify potential organizational attributes and strategies for developing accurate DTs of constructed facilities, a two-stage methodology was employed. This approach integrated qualitative insights from semi-structured interviews with an SLR, thereby establishing a basis for survey development. By combining these methods, the survey development captures a holistic and contextually relevant understanding of organizational attributes and strategies that underpin the successful development of DTs. This methodology enhances the validity and reliability of the findings and ensures that both industry practices and scholarly perspectives are represented.

The initial stage of the survey development focused on identifying organizational attributes and strategies through semi-structured interviews. A purposeful sampling technique was employed to ensure that interviewees possessed expertise and understanding of DT. Participants were selected based on criteria that included a minimum of two years of industry experience and representation from key stakeholder groups, such as contractors, consultants, and government officials from various regions across Malaysia. A sample size of twenty participants was deemed sufficient to achieve data saturation, as additional interviews were unlikely to yield new insights (Hagaman and Wutich, 2017). This qualitative phase was necessary for uncovering the organizational attributes and strategies associated with DT development that are currently missing from the existing body of knowledge. The insights gathered provided a foundation for the survey, ensuring that the identified organizational attributes and strategies are current. The recruitment process for the interviewees was executed through professional networks, industry associations and referrals. Prospective candidates received an introductory email that outlined the study objectives, assured them of data confidentiality, and the expected duration of the interviews. Following this, a telephone screening was conducted to verify eligibility, assess professional experiences, and confirm willingness to participate. The final selection ensured a balanced mix of industry professionals with varied roles and geographic representation. The interview questions were designed to explore organizational attributes and strategies for developing accurate DTs. The main questions were, “What are the organizational attributes required for developing accurate DT of constructed facilities?” and “What strategies can organizations implement for developing accurate DT of constructed facilities?”. Each interview, lasting approximately 45–60 min, was recorded, transcribed, and subsequently analyzed using thematic analysis. This analytical process involved coding and identification of recurring themes, ensuring the resulting data were both methodologically robust and aligned with industry practices.

In the subsequent stage, to generate a list of potential organizational attributes and strategies for the questionnaire survey, an SLR was conducted to examine existing literature. The SLR begins with a search using a combination of keywords relevant to the study scope (Senivongse *et al*., 2017). Scopus was selected as the primary database due to its extensive coverage and its inclusion of a larger number of peer-reviewed journals compared to other search engines (Falagas *et al*., 2008). Using Scopus’s “title/abstract/keyword” feature, the SLR implemented the following search string: “digital twin” AND “organization*” OR “organisation*” OR “compan*” AND (LIMIT-TO) (SRCTYPE, “j”) AND (LIMIT-TO (LANGUAGE, “English”)). The search retrieved 255 unique articles, with all articles originating from reputable peer-reviewed journals. Conference papers and theses were excluded to focus on journal articles, which undergo a more stringent peer-review process (Zamani *et al*., 2024). After reviewing the abstracts, eight articles that aligned with the study scope were selected for in-depth analysis. Organizational attributes and strategies extracted from these articles were synthesized with the interview findings, and synonymous variables were consolidated, resulting in a final list of 21 attributes and 30 strategies as detailed in Table 1. Figure 1 illustrates the SLR process, adapted from Qiao *et al*. (2021) and Zamani *et al*. (2024).

The survey instrument was structured into three sections to ensure a comprehensive evaluation of the organizational attributes and strategies. The first section focused on collecting demographic information, including respondents’ individual and professional backgrounds, as well as their organizational affiliations. This data was critical for assessing the respondents in ensuring that they were representative of project stakeholders in the AECO industry. The second and third sections presented the list of organizational attributes and strategies. Respondents were asked to evaluate the criticality of each organizational attribute and strategy using a five-point Likert scale (1 = not critical, 2 = slightly critical, 3 = moderately critical, 4 = critical, and 5 = very critical). This scale was adopted as it is widely recognized in construction project management research for its precision and reliability (Zhang *et al*., 2011). The evaluation facilitated a comparison of organizational attributes and strategies, allowing for the derivation of weightings and the prioritization of key variables. Such quantitative evaluations are essential for constructing a multivariate model that accurately represents the causal relationships between organizational attributes and strategies. To further enhance the survey’s robustness, open-ended questions were incorporated at the end

Table 1. List of organizational attributes and strategies for developing accurate DT of constructed facilities

Codes	Organizational attribute/strategy	Source
Organizational attribute		
ADT1	Technological capabilities among employees on DT	Agrawal *et al.* (2022)
ADT2	Strategic mindset among employees on DT	Agrawal *et al.* (2022), Abusohyon *et al.* (2021), Shahzad *et al.* (2022), Interview
ADT3	Coordination among employees on DT	Interview
ADT4	Employee awareness of the business value of DT	Agrawal *et al.* (2022), Abusohyon *et al.* (2021), Interview
ADT5	Employee understanding of the value of DT data	Agrawal *et al.* (2022), Abusohyon *et al.* (2021), Interview
ADT6	DT technological on infrastructure	Shahzad *et al.* (2022), Interview
ADT7	Mechanisms for DT data operationalization	Broo *et al.* (2022)
ADT8	Internal strategic digitalization framework on DT	Agrawal *et al.* (2022)
ADT9	Data compatibility plan for DT	Agrawal *et al.* (2022), Broo *et al.* (2022), Lu *et al.* (2020), Interview
ADT10	Shared data environment for DT	Broo *et al.* (2022), Aghimien *et al.* (2020), Interview
ADT11	On-going improvement processes for DT deployment	Abusohyon *et al.* (2021), Interview
ADT12	Internal guidelines for developing DT	Shahzad *et al.* (2022), Broo *et al.* (2022), Interview
ADT13	Organizational standardized procedures for developing DT	Agrawal *et al.* (2022), Broo *et al.* (2022), Lu *et al.* (2020), Interview
ADT14	Data security procedures on DT	Shahzad *et al.* (2022), Interview
ADT15	Organizational strategic plan on DT	Interview
ADT16	Strategic working processes on DT	Interview
ADT17	Well-defined organizational objective(s) on DT	Abusohyon *et al.* (2021), Lu *et al.* (2020), Interview
ADT18	Organizational work culture transformation plan for DT	Shahzad *et al.* (2022), Broo *et al.* (2022), Interview
ADT19	Top-down management involvement in the DT concept	Shahzad *et al.* (2022), Broo *et al.* (2022), Interview
ADT20	Financial capability of the organization for developing DT	Interview
ADT21	Organizational business development approach in relation to DT	Pilot study
Organizational strategy		
SDT1	Determine the right level of complexity when developing DT	Agrawal *et al.* (2022), *Interview*
SDT2	Determine strategies for organizational cultural transformation on DT	Shahzad *et al.* (2022), Broo *et al.* (2022), *Interview*
SDT3	Determine the organization's transformation goals for DT	Broo *et al.* (2022), Interview
SDT4	Determine the best method to achieve the expected level of data transmission quality for DT	Abusohyon *et al.* (2021), Shahzad *et al.* (2022), *Interview*
SDT5	Provide external training on DT	Interview
SDT6	Provide internal training on DT	Abusohyon *et al.* (2021), Shahzad *et al.* (2022), Broo *et al.* (2022), *Interview*
SDT7	Provide opportunities for learning and experimentation without restrictions on time or cost	Broo *et al.* (2022), *Interview*
SDT8	Provide employees with opportunities to explore DT data	Abusohyon *et al.* (2021), Shahzad *et al.* (2022), Broo *et al.* (2022), *Interview*
SDT9	Provide effective tools for communicating information on DT	Shahzad *et al.* (2022), *Interview*
SDT10	Provide DT awareness to all management levels	Shahzad *et al.* (2022), *Interview*

(*continued*)

Table 1. Continued

Codes	Organizational attribute/strategy	Source
SDT11	Increase investments in aligning top employees and digital transformation	Broo *et al.* (2022)
SDT12	Enhance the organization's attractiveness to attract talented employees	Broo *et al.* (2022)
SDT13	Enhance the organization's attractiveness to attract DT experts	Broo *et al.* (2022)
SDT14	Recognize the necessity of having DT as part of the business	Interview
SDT15	Use digital currency as the organization's payment method	Interview
SDT16	Develop a strategic vision among all management levels to implement DT	Agrawal *et al.* (2022), *Interview*
SDT17	Transform conventional working practices into digitalized working platforms	Shahzad *et al.* (2022)
SDT18	Implement initiatives to manage cultural risk on DT	Broo *et al.* (2022)
SDT19	Implement digitalization framework as a project planning diagnostic tool throughout the organization	Agrawal *et al.* (2022), Abusohyon *et al.* (2021)
SDT20	Implement a digitalization framework to assist in a long-term vision of achievable levels	Agrawal *et al.* (2022)
SDT21	Implement a digitalization framework to assist in a strategic roadmap	Agrawal *et al.* (2022)
SDT22	Implement a comprehensive assessment framework on DT	Wei *et al.* (2022), Agrawal *et al.* (2022), *Interview*
SDT23	Create innovative workspaces using new technologies	Broo *et al.* (2022)
SDT24	Ensure employees have basic knowledge of DT	Broo *et al.* (2022)
SDT25	Ensure compatibility between new and previous versions of available software related to DT	Abusohyon *et al.* (2021)
SDT26	Emphasize transparency and accountability among employees on DT	Broo *et al.* (2022), *Interview*
SDT27	Incorporate existing data to generate information to improve insights for operations management in sustaining infrastructure assets	Broo *et al.* (2022)
SDT28	Arrange digital experts as external partners	Abusohyon *et al.* (2021), Aghimien *et al.* (2020)
SDT29	Build up a good organizational financial support system on DT	Interview
SDT30	Investment in creating custom technology to suit local market needs	Pilot study

Source(s): Authors' own work

of the second and third sections, allowing respondents to propose and evaluate additional organizational attributes or strategies they deemed critical. This component ensured that the instrument remained adaptive to industry insights beyond the predefined list, thereby reinforcing its validity and comprehensiveness.

Ensuring the validity and reliability of the survey was accomplished through a multi-step process designed to evaluate and refine the instrument for capturing the intended constructs. Initially, face and content validity were assessed by a panel of experts comprising three academic scholars and five industry professionals, each with over a decade of experience in related research and practices. These panels critically reviewed the survey for its alignment with the study scope, the comprehensiveness of its content, and the precision of its terminology. Their feedback led to refinements that enhanced clarity and ensured that the survey addressed all relevant aspects of organizational attributes and strategies for DT development. Subsequently, a pilot test was conducted with a subset of respondents representative of the target population, serving as a critical step in establishing construct validity. During this phase, the survey was tested to identify and rectify any ambiguous or biased questions to ensure that each item effectively measured the intended variable. The data obtained from the pilot study informed further modifications, resulting in an instrument that is methodologically sound and contextually appropriate.

Data collection

The finalized survey was disseminated to the target population, compromising a diverse range of stakeholders with knowledge of DTs from varied organizations, including government agencies, clients, contractors, and consultants. By targeting professionals with knowledge of DT, the collected data captures industry perspectives on the organizational attributes and strategies critical to DT development. Moreover, integrating insights from diverse stakeholders is vital for capturing the dynamics of DT development. Finally, the delineation of the target population enhances the credibility and relevance of the data, thereby forming a foundation for statistical analyses and model development.

Given the absence of a sampling frame, a non-probability sampling approach was adopted (Zhao *et al*., 2015). This approach allows for the selection of participants based on their expertise and willingness to contribute insights (Berndt, 2020). Such an approach is advantageous when random sampling is not feasible (Ma *et al*., 2018; Hair *et al*., 2009). To further enhance the sampling process, a snowball sampling approach was employed to expand the respondent pool. Initially, a group of respondents was recruited through professional networks and industry associations. These participants were then encouraged to refer to their colleagues and other stakeholders, thereby broadening the reach of the survey (Noy, 2008; Al-Mohammad *et al*., 2023). This multifaceted recruitment strategy ensured a representative sample and enriched the overall data quality.

A total of 129 valid responses were collected through a survey dissemination process that involved multiple reminders and targeted interactions with potential participants. This sample size was determined to meet the requirements of the statistical analysis techniques employed, including NMA, EFA, and PLS-SEM. The selection of an appropriate sample size is critical as each analysis technique requires a minimum sample to ensure the reliability and validity of results. A minimum sample size of 30 is needed for NMA (Ott and Longnecker, 2015; Dahalan *et al*., 2023), 100 for EFA (Hair *et al*., 1995) and 100 to 120 for PLS-SEM (Ding *et al*., 1995). These benchmarks collectively justify the sample size of this study, ensuring that the analyses are statistically robust and that the conclusions are valid. Furthermore, the final sample size aligns with precedent research in the field. For example, Al-Mohammad *et al*. (2023) used a sample of 115 participants, Munianday *et al*. (2022) employed 121, while Sompolgrunk *et al*. (2022) and Zhao *et al*. (2018) worked with 92 and 95 participants. These comparable sample sizes provide external validation for this study's sample size, thereby reinforcing confidence in the findings.

Table 2 presents the demographic profile of the survey respondents, providing insight into their professional roles, industry experience, and familiarity with DT. Most respondents represent the consultants (44.2%). Of the respondents, 31.8% have more than 10 years of working experience in the AECO industry. The remaining respondents have less than 10 years of experience, with those having less than 2 years having the lowest percentage. Regarding knowledge about DT, 47.3% of respondents have less than 2 years of experience, 38.8% have 2–5 years of experience, 12.4% with 6–10 years, while 1.6% have more than 10 years of experience. This distribution indicates that DT in Malaysia is still in its nascent stages, with most professionals being relatively new to it. Overall, the varied backgrounds and extensive experience of the respondents enhance the reliability of the collected data, thereby providing a robust foundation for analyzing the organizational attributes and strategies for developing accurate DTs of constructed facilities in Malaysia's AECO industry.

Table 2. Respondent profile

Profiles	Categories	Number of respondents	Percentage (%)
Types of organization	Client (Government/Private Developer)	24	18.6
	Consultant	57	44.2
	Contractor	38	29.5
	Supplier	1	0.8
	Manufacturer	5	3.9
	Others	4	3.1
Years of experience in construction industry	Less than 2 years	20	15.5
	2–5 years	38	29.5
	6–9 years	30	23.3
	More than 10 years	41	31.8
Working experience related to DT	Less than 2 years	61	47.3
	2–5 years	50	38.8
	6–10 years	16	12.4
	More than 10 years	2	1.6
Types of construction projects involved	Non-residential (e.g. Hotel, shop houses, business complex, office)	68	
*Multiple answers	Residential (e.g. Terrace, bungalow, flat, condominium)	73	
	Social amenities (e.g. Hospital, youth centre, community centre)	48	
	Infrastructure (e.g. Airport, railway or train station, bus station)	62	
	Others	10	

Source(s): Authors’ own work

Analysis and results

For analysis of the data collected, the data analysis techniques used were carefully selected to align with the research objectives. First is the two-SD technique. This technique was employed to detect and address potential outliers that could skew the results. Next is the NMA, which is used to rank identify the key organizational attributes and strategies. Additionally, EFA was employed to develop underlying constructs among the organizational attributes and strategies. Finally, PLS-SEM was used to model the relationships between the underlying constructs of organizational attributes and strategies. The upcoming subsection details the analysis techniques and their outputs.

Two-standard deviation technique

The two-SD technique was employed to detect and address potential outliers that could skew the results. This technique involves computing the mean and SD for each variable and flagging variables that fall outside the interval defined by the overall mean plus or minus two times SD of the means (Omer *et al*., 2025). Such observations, deemed atypical, are likely to influence statistical estimates, thereby compromising the robustness of the results. Upon applying this technique, the attribute coded as “ADT8” and the strategy coded as “SDT15” were identified as outliers and subsequently excluded from further analysis. These exclusions were deemed necessary to maintain the accuracy of the study findings.

Normalized mean analysis

NMA was used to identify the key organizational attributes and strategies. This technique, as previously used by Dahalan *et al*. (2023), facilitates the conversion of the minimum mean values to normalized mean values of 0, the maximum mean values to normalized mean values of 1 and those between to normalized mean values between 0 and 1. The normalization formula, presented in Equation (1), standardizes the dataset and enables direct comparisons across variables. By ensuring that each variable is evaluated equally, NMA provides clarity in determining the relative criticality of each organizational attribute and strategy. The results of the NMA are detailed in Table 3, which presents the normalized mean values for each organizational attribute and strategy. Variables that attained normalized mean values of at least 0.50 were designated as key variables. Through this analysis, 11 organizational attributes and 20 key organizational strategies were identified as key for developing accurate DTs of constructed facilities.

$$\text{Normalized mean value} = \frac{\text{Mean} - \text{Minimum mean value}}{\text{Maximum mean value} - \text{Minimum mean value}} \quad (1)$$

Exploratory factor analysis

EFA was employed to develop underlying constructs among the organizational attributes and strategies. This technique examines interrelationships among variables to reveal latent structures, thereby enhancing data interpretability (Norusis, 2008). The adequacy of sample size for EFA was evaluated by examining the ratio of participants to variables, with Gorsuch (1983) recommending a minimum ratio of 5:1. In this study, the ratios were 11.73 and 6.45 for organizational attributes and strategies, exceeding the minimum requirements. Further, data suitability was confirmed via the Kaiser-Meyer-Olkin (KMO) test, which yielded a value of 0.959, and Bartlett's test of sphericity, with a *p*-value less than 0.001, indicating that the correlation matrix was sufficiently interrelated for EFA. During the analysis, two variables (ADT8 and SDT15) with low factor loadings (below 0.40) were removed as the values suggest insufficient correlation with other variables. This step ensured that only the most relevant variables were included in the final underlying constructs.

Table 4 shows the EFA results. The results indicated that organizational attributes could be categorized into two underlying constructs: (1) organizational DT capabilities, which explained 66.927% of the variance and reflects an organization's proficiency in developing DTs; and (2) technological capabilities requirements, which explained 3.949% of the variance and encompass the necessary technological infrastructure and tools. Similarly, three underlying constructs emerged from the analysis of organizational strategies: (1) organizational competitiveness and investments (63.881% variance explained); (2) organizational workforce management and training (3.524% variance explained); and (3) organizational management capabilities (2.843% variance explained). These underlying constructs are then used as a basis for the modeling of the relationship between organizational attributes and strategies in the next stage of data analysis (i.e. PLS-SEM).

Partial least-squares structural equation modelling

SEM, and specifically PLS-SEM was employed to model the relationships between underlying constructs and strategies. PLS-SEM is particularly well-suited for exploratory research involving complex models and undefined theoretical frameworks, non-normal data distributions, and relatively smaller sample sizes (Joreskog and Wold, 1982; Hair *et al.*, 2019; Hair *et al.*, 2021; Pesämaa *et al.*, 2021). This technique facilitates the measurement of latent variables and examination of structural relationships (Hulland, 1999; Ringle *et al.*, 2014), making it an effective tool for modeling the interrelationships between organizational attributes and strategies. Its flexibility allows researchers to evaluate the reliability and validity of the measurement model and the hypothesized structural paths, thereby yielding insights into how organizational capabilities and strategies contribute to developing accurate DTs of constructed facilities.

The evaluation process in PLS-SEM is divided into two primary steps – evaluation of the (1) measurement model and (2) structural model. In the measurement model

Table 3. Normalized mean analysis results

Code	Organizational attribute/strategy	Mean	SD	NV
ADT3	Coordination among employees on DT	4.023	1.114	1.000
ADT10	Shared data environment for DT	4.016	1.031	0.964
ADT13	Organizational standardized procedures for developing DT	4.008	1.066	0.929
ADT20	Financial capability of the organization for developing DT	3.954	1.152	0.679
ADT12	Internal guidelines for developing DT	3.946	1.018	0.643
ADT18	Organizational work culture transformation plan for DT	3.946	1.026	0.643
ADT19	Top-down management involvement in the DT concept	3.946	1.041	0.643
ADT17	Well-defined organizational objective(s) on DT	3.923	1.043	0.536
ADT15	Organizational strategic plan on DT	3.915	1.054	0.500
ADT9	Data compatibility plan for DT	3.915	1.083	0.500
ADT11	On-going improvement processes for DT deployment	3.915	1.031	0.500
ADT4	Employee awareness of the business value of DT	3.907	1.162	0.464
ADT16	Strategic working processes on DT	3.868	1.056	0.286
ADT14	Data security procedures on DT	3.861	1.066	0.250
ADT21	Organizational business development approach in relation to DT	3.853	1.133	0.214
ADT5	Employee understanding of the value of DT data	3.837	1.184	0.143
ADT1	Technological capabilities among employees on DT	3.830	1.069	0.107
ADT2	Strategic mindset among employees on DT	3.822	1.079	0.071
ADT6	DT technological on infrastructure	3.814	1.164	0.036
ADT7	Mechanisms for DT data operationalization	3.806	1.061	0.000
SDT4	Determine the best method to achieve the expected level of data transmission quality for DT	4.124	0.875	1.000
SDT11	Increase investments in aligning top employees and digital transformation	4.116	0.965	0.973
SDT12	Enhance the organization’s attractiveness to attract talented employees	4.109	0.903	0.946
SDT10	Provide DT awareness to all management levels	4.109	1.055	0.946
SDT25	Ensure compatibility between new and previous versions of available software related to DT	4.093	0.905	0.892
SDT13	Enhance the organization’s attractiveness to attract DT experts	4.085	0.944	0.865
SDT24	Ensure employees have basic knowledge of DT	4.085	1.008	0.865
SDT5	Provide external training on DT	4.070	1.032	0.811
SDT9	Provide effective tools for communicating information on DT	4.062	0.990	0.784
SDT8	Provide employees with opportunities to explore DT data	4.054	1.063	0.757
SDT1	Determine the right level of complexity when developing DT	4.047	0.926	0.730
SDT26	Emphasize transparency and accountability among employees on DT	4.039	0.987	0.703
SDT14	Recognize the necessity of having DT as part of the business			
SDT6	Provide internal training on DT	4.031	0.960	0.676
SDT27	Incorporate existing data to generate information to improve insights for operations management in sustaining infrastructure assets	4.023	1.100	0.649
SDT20	Implement a digitalization framework to assist in a long-term vision of achievable levels	4.023	0.923	0.649
SDT22	Implement a comprehensive assessment framework on DT			
SDT29	Build up a good organizational financial support system on DT	4.008	0.948	0.595
SDT2	Determine strategies for organizational cultural transformation on DT	3.992	0.923	0.541
SDT7	Provide opportunities for learning and experimentation without restrictions on time or cost	3.992	0.964	0.541
SDT17	Transform conventional working practices into digitalized working platforms	3.985	0.893	0.514
SDT23	Create innovative workspaces using new technologies	3.985	1.075	0.514
SDT3	Determine the organization’s transformation goals for DT	3.977	0.964	0.486
SDT19	Implement digitalization framework as a project planning diagnostic tool throughout the organization	3.961	0.905	0.432
SDT16	Develop a strategic vision among all management levels to implement DT	3.946	0.987	0.378
SDT30	Investment in creating custom technology to suit local market needs	3.938	0.933	0.351
SDT21	Implement a digitalization framework to assist in a strategic roadmap	3.938	0.958	0.351
SDT18	Implement initiatives to manage cultural risk on DT	3.930	0.920	0.324
SDT28	Arrange digital experts as external partners	3.892	0.921	0.189

Source(s): Authors’ own work

Table 4. Exploratory factor analysis results

Codes	Organizational attributes/organizational strategies	Factor 1	2	3
Organizational attribute				
ADT10	Shared data environment for DT	0.637	–	–
ADT11	On-going improvement processes for DT deployment	0.687	–	–
ADT12	Internal guidelines for developing DT	0.707	–	–
ADT13	Organizational standardized procedures for developing DT	0.644	–	–
ADT14	Data security procedures on DT	0.707	–	–
ADT15	Organizational strategic plan on DT	0.792	–	–
ADT16	Strategic working processes on DT	0.767	–	–
ADT17	Well-defined organizational objective(s) on DT	0.713	–	–
ADT18	Organizational work culture transformation plan for DT	0.669	–	–
ADT19	Top-down management involvement in the DT concept	0.744	–	–
ADT20	Financial capability of the organization for developing DT	0.678	–	–
ADT21	Organizational business development approach in relation to DT	0.728	–	–
ADT1	Technological capabilities among employees on DT	–	0.730	–
ADT2	Strategic mindset among employees on DT	–	0.800	–
ADT3	Coordination among employees on DT	–	0.728	–
ADT4	Employee awareness of the business value of DT	–	0.656	–
ADT5	Employee understanding of the value of DT data	–	0.653	–
ADT6	DT technological on infrastructure	–	0.800	–
ADT7	Mechanisms for DT data operationalization	–	0.751	–
ADT9	Data compatibility plan for DT	–	0.592	–
Eigenvalue		13.673	1.067	
Variance (%)		66.927	3.949	–
Cumulative variance (%)		66.927	70.876	–
Organizational strategy				
SDT 11	Increase investments in aligning top employees and digital transformation	0.633	–	–
SDT 12	Enhance the organization's attractiveness to attract talented employees	0.657	–	–
SDT 13	Enhance the organization's attractiveness to attract DT experts	0.689	–	–
SDT 16	Develop a strategic vision among all management levels to implement DT	0.667	–	–
SDT 17	Transform conventional working practices into digitalized working platforms	0.657	–	–
SDT 19	Implement digitalization framework as a project planning diagnostic tool throughout the organization	0.741	–	–
SDT 20	Implement a digitalization framework to assist in a long-term vision of achievable levels	0.686	–	–
SDT 21	Implement a digitalization framework to assist in a strategic roadmap	0.687	–	–
SDT 23	Create innovative workspaces using new technologies	0.551	–	–
SDT 27	Incorporate existing data to generate information to improve insights for operations management in sustaining infrastructure assets	0.595	–	–
SDT 28	Arrange digital experts as external partners	0.587	–	–
SDT 30	Investment in creating custom technology to suit local market needs	0.581	–	–
SDT 5	Provide external training on DT	–	0.665	–
SDT 6	Provide internal training on DT	–	0.640	–
SDT 7	Provide opportunities for learning and experimentation without restrictions on time or cost	–	0.663	–
SDT 8	Provide employees with opportunities to explore DT data	–	0.685	–
SDT 9	Provide effective tools for communicating information on DT	–	0.627	–
SDT 10	Provide DT awareness to all management levels	–	0.628	–
SDT 14	Recognize the necessity of having DT as part of the business	–	0.540	–
SDT 24	Ensure employees have basic knowledge of DT	–	0.525	–

(*continued*)

Table 4. Continued

Codes	Organizational attributes/organizational strategies	Factor 1	2	3
SDT 25	Ensure compatibility between new and previous versions of available software related to DT	–	0.495	–
SDT 26	Emphasize transparency and accountability among employees on DT	–	0.528	–
SDT 29	Build up a good organizational financial support system on DT	–	0.533	–
SDT1	Determine the right level of complexity when developing DT	–	–	0.697
SDT 2	Determine strategies for organizational cultural transformation on DT	–	–	0.736
SDT 3	Determine the organization's transformation goals for DT	–	–	0.658
SDT 4	Determine the best method to achieve the expected level of data transmission quality for DT	–	–	0.752
SDT 18	Implement initiatives to manage cultural risk on DT	–	–	0.635
SDT 22	Implement a comprehensive assessment framework on DT	–	–	0.581
Eigenvalue		18.819	1.326	1.118
Variance (%)		63.881	3.524	2.843
Cumulative variance (%)		63.881	67.405	70.248

Note(s): Extraction method: principal axis factoring; Rotation method: Varimax with Kaiser Normalization
Source(s): Authors' own work

evaluation, internal consistency and reliability are examined using composite reliability and Cronbach's alpha, with values exceeding 0.7 indicating satisfactory consistency and reliability (Hair *et al.*, 2011). Indicator reliability is evaluated by examining outer loadings, where values above 0.70 are deemed acceptable, though loadings between 0.40 and 0.70 may be tolerated if overall reliability is maintained (Hair *et al.*, 2011). Convergent reliability was confirmed via the average variance extracted (AVE), with values above 0.50 demonstrating that a construct explains more than half of its indicators (Hair *et al.*, 2011). Discriminant validity is evaluated using the Fornell-Larcker criterion and the Heterotrait-Monotrait (HTMT), with HTMT values below 1.00 suggesting adequate discriminant validity (Fornell and Larcker, 1981; Hulland, 1999; Hair *et al.*, 2011; Henseler *et al.*, 2009). Following the validation of the measurement model as shown in Figure 2, the structural model was evaluated by examining path coefficients through bootstrapping procedures. Together, these analyses provide the steps for understanding the interrelationships that underpin the organizational attributes and strategies for developing accurate DTs of constructed facilities.

Hypotheses for structural models

Using the EFA results outlined in the preceding section, the subsequent six hypotheses were formulated to model the relationship between the underlying constructs of organizational attributes and strategies:

H1. Organizational DT capabilities (ATC1) positively impact the need for organizational competitiveness and investments (STC1).

H2. Organizational DT capabilities (ATC1) positively impact the need for organizational workforce management and training (STC2).

H3. Organizational DT capabilities (ATC1) positively impact the need for organizational management capabilities (STC3).

H4. Technological capabilities requirements (ATC2) impact the need for influence organizational competitiveness and investments (STC1).

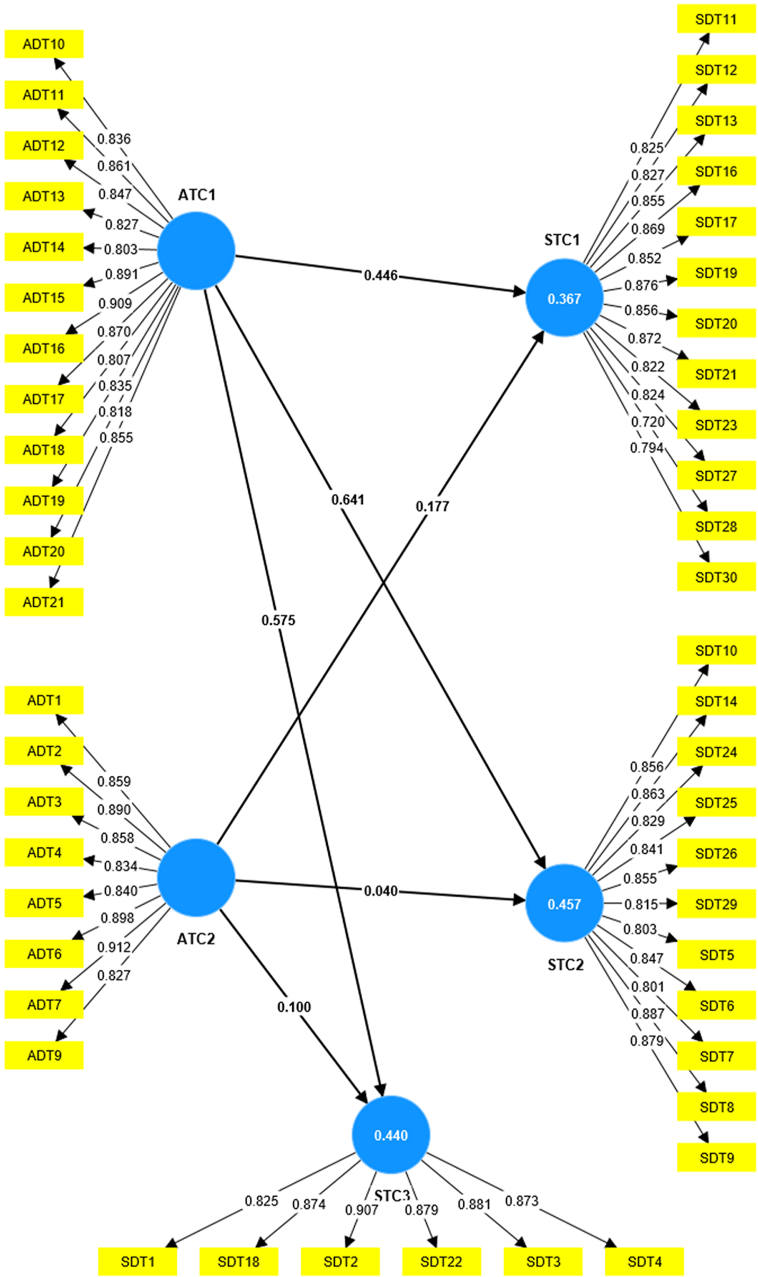

Figure 2. Measurement model evaluation. Source: Authors' own work

H5. Technological capabilities requirements (ATC2) positively impact the need for organizational workforce management and training (STC2).

H6. Technological capabilities requirements (ATC2) positively impact the need for organizational management capabilities (STC3).

Measurement model evaluation: convergent validity

Evaluating the dependability and reliability of the measurement models is a critical prerequisite for conducting structural model testing. This step evaluated the measurement model to ensure that all constructs and indicators reliably captured the intended phenomena. As demonstrated in Figure 2, the factor loadings of all variables exceeded the recommended threshold of 0.40, while the AVE values surpassed the threshold of 0.50, thereby confirming satisfactory convergent validity for the indicators and constructs under investigation (Hair *et al*., 2011). This indicates that each latent variable explains more than half of the variance in its observed indicators, a requirement for valid measurement of the construct. Furthermore, an internal consistency and reliability of the constructs were confirmed through the calculation of composite reliability and Cronbach's alpha, both of which exceeded the minimum threshold of 0.7 as suggested by Hair *et al*. (2011). These reliability indices demonstrate that the indicators within each construct are coherent and consistently reflect the underlying constructs.

Measurement model evaluation: discriminant validity

The results indicate that the square-rooted AVE values for the constructs, displayed on the diagonal correlation matrix, exceeded the correlation coefficients between any two latent constructs in the respective rows and columns, thereby confirming satisfactory discriminant validity for most latent constructs (Fornell and Larcker, 1981). However, an exception was observed for construct ATC1. Its square-rooted AVE value (0.847) was lower than its correlation with ATC2 (0.873). To further evaluate discriminant validity, the HTMT ratio was computed, revealing values of 0.911 for ATC1-ATC2, 0.911 for STC1-STC2, and 0.902 for STC3-STC3, all of which remained below the threshold of 1.0, therefore satisfying the criterion established by Henseler *et al*. (2009). Additionally, a cross-loading analysis, as proposed by Chin (1998), demonstrated that each variable had a stronger association with its intended construct than with other constructs in the model. This evaluation provides evidence that, overall, the constructs possess discriminant validity.

Structural model evaluation

Following the step outlined by Hair *et al*. (2011), a bootstrapping procedure with 5,000 samples was employed to evaluate the path coefficients within the PLS-SEM model. This sampling technique facilitates hypothesis testing under non-normal data distribution conditions. For a two-tailed test at the 0.05 significance level, a value of 1.96 was used as the threshold for determining statistical significance. Table 5 presents the structural model evaluation results, which reveal that all hypotheses exhibit positive and statistically significant path coefficients. Specifically, Hypotheses 1, 2, and 3 are supported at the 0.05 level. However, Hypotheses 4, 5, and 6 are not supported. The subsequent section discusses these results further.

Discussion

Relationship between organizational DT capabilities and organizational competitiveness and investments

The results demonstrate that organizational DT capabilities impact the need for organizational competitiveness and investments. Thiyagarajan *et al*. (2022) emphasize that developing accurate DTs necessitates the integration of multiple business systems and supply chain solutions, which require substantial financial investment. This finding demonstrates the need for organizations to align strategic decisions with the development of technological infrastructures tailored to market demands. Investment in state-of-the-art technologies and skilled personnel is essential to foster

Table 5. Partial-least squares structural equation modeling results

Hypothesis	Path	*t*-value	*p*-values	Decision
H1	Organizational DT capabilities → Organizational competitiveness and investments	2.614	0.009	Supported
H2	Organizational DT capabilities → Organizational workforce management and training	4.622	0.000	Supported
H3	Organizational DT capabilities → Organizational management capabilities	4.008	0.000	Supported
H4	Technological capabilities requirements → Organizational capabilities management	0.965	0.335	Not supported
H5	Technological capabilities requirements → Organizational competitiveness and investments	0.239	0.811	Not supported
H6	Technological capabilities requirements → Organizational workforce management and training	0.654	0.513	Not supported

Source(s): Authors' own work

organizational DT capabilities. Moreover, the experience of developing countries, as highlighted by Rani *et al*. (2023), demonstrates how structured policies, such as financial grants, mandatory usage in public projects, and standardized guidelines, can accelerate digitalization. In highly regulated markets, aligning organizational investments with national digitalization roadmaps is vital for optimizing returns and enhancing operational efficiency. Conversely, organizations in emerging markets must compensate for limited governmental support by focusing on internal strategic planning, workforce training, and work environments that attract DT experts. However, organizations must also identify the technologies required to develop organizational DT capabilities. Therefore, generating awareness and obtaining a firm understanding of DT are crucial to the success of the transformation. This must be counterbalanced by establishing an effective organizational financial support structure for DT development (Weber-Lewerenz, 2021). However, AECO industry professionals lack structured project pathways for DT development, as well as cultural and strategical resistance to change are the greatest obstacles to accurate DT development, indicating a lack of strategic vision among practitioners and organizations (Neto *et al*., 2020). Ultimately, the barriers to accurate DT development will most likely be overcome by an organization's DT capabilities, adaptability to change, and shared common values and goals. Implementing organizational strategies, such as enhancing the organization's attractiveness to attract talented employees, enhancing the organization's attractiveness to attract DT experts, and creating innovative workspaces using new technologies, which impact the DT capabilities of the organization, is a crucial strategy.

Relationship between organizational DT capabilities and organizational workforce management and training

The results also indicate that organizational DT capabilities impact the need for organizational workforce management and training. An organization's investments in human resources, including compensation, training, and communication, can impact its organizational capabilities (Ulrich and Smallwood, 2004). Therefore, top-down management participation in DT can facilitate this process by encouraging, supporting, and empowering project stakeholders through adequate human resources. These findings concur with Thiyagarajan *et al*. (2022) on the need for a business case on DT to gain the support of senior management in acquiring the necessary human resources for developing accurate DTs. In addition, the findings concur with Weber-Lewerenz's recommendation that all project stakeholders are responsible for ensuring the development of accurate DTs and shaping it proactively with competent personnel, open dialogue, and the allocation of supporting applications. With solid financial support, internal and external training for learning and experimentation can be provided with minimal cost or time constraints. In addition, the findings concur with Ulrich and Smallwood (2004), who asserted that organizational capabilities are intangible assets resulting from the talents and skills of an organization's personnel. This is further supported by Rajabi *et al.* (2022), who stated that organizational disparities in infrastructure, policy, and financial conditions impact organizational DT capabilities. Therefore, with appropriate training, employees have a foundational understanding of DTs and the means to develop them. As financial support relates to organizational integrity, it is essential to emphasize the importance of transparency and employee accountability regarding DT development. Consequently, organizations must be updated with the compatibility of available software and practical tools for communicating information on DTs, as they are essential for workforce management and training.

Relationship between organizational DT capabilities and organizational management capabilities

Finally, the results also show that organizational DT capabilities impact the need for organizational management capabilities. The capability of an organization is often connected to its identity and culture, which are defined by the organization's accumulated skills, abilities, and knowledge (Ulrich and Smallwood, 2004). When developing DTs, it is essential to determine the ideal level of maturity of the organization and complexity of the constructed facility (Bär *et al.*, 2018). Human resource management, technology maturity, and project procedures are essential organizational management capabilities that can impact organizational DT capabilities (Frederico *et al.*, 2019). By incorporating government policy frameworks into organizational strategies, AECO industry practitioners can accelerate DT development processes while mitigating external barriers. However, a one-size-fits-all strategy is ineffective, and organizations must align the organizational strategy with both internal organizational readiness and external regulatory conditions to achieve accurate DT development. Therefore, the finding indicates that optimal organizational management strategies are essential for developing accurate DTs.

Comparison with previous works

This section compares the findings of this study with existing literature to elucidate symmetries and asymmetries in the key organizational attributes and strategies for developing accurate DTs of constructed facilities. Table 6 and Table 7 summarizes the comparison results.

Table 6. Comparison of key organizational attributes for developing accurate DTs of constructed facilities

Organizational' attribute	This study	Source 1	2	3	4	5	6
Coordination among employees on digital twin	*						
Shared data environment for digital twin	*		*	*			
Organizational standardized procedures for developing digital twin	*	*		*	*		
Financial capability of the organization for developing digital twin	*						
Internal guidelines for developing digital twins	*			*		*	
Organizational work culture transformation plan for digital twin	*			*		*	
Top-down management involvement in the digital twin concept	*			*		*	
Well-defined organizational objective(s) on digital twin.	*				*		*
Organizational strategic plan on digital twin	*						
On-going improvement processes for digital twin deployment	*						*
Data compatibility plan for digital twin	*	*		*	*		

Note(s): Agrawal *et al.* (2022), Aghimien *et al.* (2020), Broo *et al.* (2022), Lu *et al.* (2020), Shahzad *et al.* (2022) and Abusohyon *et al.* (2021)
Source(s): Authors' own work

Table 7. Comparison of key organizational strategies for developing accurate DT of constructed facilities

Organizational strategy	This study	Source 1	2	3	4	5	6
Determine the best method to achieve the expected level of data transmission quality for digital twin	*					*	*
Increase investments in aligning top employees and digital transformation	*					*	
Enhance the organization's attractiveness to attract talented employees	*			*			
Provide digital twin awareness to all management levels.	*					*	
Ensure compatibility between new and previous versions of available software related to digital twin	*						*
Enhance the organization's attractiveness to attract digital twin experts	*			*			
Ensure employees have basic knowledge of digital twin	*			*			
Provide external training on digital twin	*						
Provide effective tools for communicating information on digital twins	*					*	
Provide employees with opportunities to explore digital twin data	*			*		*	*
Determine the right level of complexity when developing digital twin	*	*					
Emphasize transparency and accountability among employees on digital twin.	*			*			
Recognize the necessity of having digital twins as part of the business	*						
Provide internal training on digital twin	*			*		*	*
Incorporate existing data to generate information to improve insights for operations management in sustaining infrastructure assets.	*			*			
Implement a digitalization framework to assist in a long-term vision of achievable levels	*	*					
Implement a comprehensive assessment framework on digital twin	*	*					
Build up a good organizational financial support system on digital twin	*						
Determine strategies for organizational cultural transformation on digital twin	*			*		*	
Provide opportunities for learning and experimentation without restrictions on time or cost.	*			*			

Note(s): Agrawal *et al.* (2022), Aghimien *et al.* (2020), Broo *et al.* (2022), Lu *et al.* (2020), Shahzad *et al.* (2022) and Abusohyon *et al.* (2021)
Source(s): Authors' own work

Although the results largely align with prior research, several notable asymmetries were observed. In particular, three key organizational attributes emerged as distinct: coordination among employees on DT, financial capability of the organization for developing DT, and organizational strategic plan on DT. Effective collaboration is essential for developing accurate DTs. However, the results suggest that coordination among personnel is often suboptimal, potentially due to inadequate training or the absence of structured processes. This deficiency may hinder the development of accurate DTs. Furthermore, although prior research acknowledges financial constraints, the results indicate that many organizations face challenges in allocating sufficient funds for DT development, a challenge that has been less emphasized in earlier research. Similarly, the lack of a strategic plan for DT development is more pronounced in this study, thereby highlighting a gap in long-term vision and planning among organizations. These gaps underscore the need for organizations to prioritize investment in both technology and strategic human capital to foster accurate DT development.

Regarding organizational strategies, three key organizational strategies diverged from previous research: provide external training on DT, recognize the necessity of having DTs as part of the business, and build up a good organizational financial support system for DT. First, although prior research did not emphasized the role of external training, the results highlight that providing external training on DTs is essential for enhancing competencies and fostering an innovative mindset among project stakeholders. Second, the results reveal a gap in the recognition of DTs as an integral component of business strategy, thereby acknowledging that the necessity of DTs in business operations is vital for developing accurate DTs. Third, the results underscore the importance of building an organizational financial support system dedicated to DT, a strategy that is critical for securing the necessary investments and resources but has been underemphasized in prior research. These insights indicate that to develop accurate DTs, organizations must expand their focus beyond operational elements and invest in human capital development, strategic recognition, and financial planning.

Theoretical implications

Unlike previous research that focused on exploring attributes and strategies for developing accurate DTs of constructed facilities, this study models the underlying interrelationships between organizational attributes and strategies. The findings highlighted that investments in technologies may be supported by corresponding organizational readiness, which implies that the capability maturity models for accurate DT development must include competitiveness and investment dynamics as feedback mechanisms. Besides that, the findings indicated that workforce development is both an enabler and outcome of developing accurate DT, which implies that the risk of creating technological disconnects that lead to inaccurate DT development can be mitigated. Additionally, the findings can result in considering position management capabilities as a moderating factor that determines whether accurate DT is developed effectively. This result implies that organizational strategies for developing accurate DTs must consider management capacity as an external support function and as a central determinant. These findings are useful for researchers in developing frameworks of organizational strategies for developing accurate DTs at a global level. Additionally, the findings are crucial for providing future directions and identifying specific areas of shortfall that researchers should target when developing strategies to enhance development of accurate DTs.

Practical implications

For practical implications, the findings can help decision-makers take actions to overcome the shortcomings associated with developing accurate DTs of constructed facilities. These findings call for AECO organizations to treat organizational DT capabilities as a strategic investment, rather than merely a technological upgrade. These operational advantages translate into greater market credibility, which improves organizations in attracting project fundings, partnerships and digital infrastructure management. Besides that, the findings also emphasize the need for a competent workforce in developing accurate DT. AECO organizations are recommended to embed continuous training and reskilling programs to ensure the entire project team can effectively use and maintain accurate data of constructed facilities. Additionally, these findings also highlighted that strong management capabilities are essential for coordinating accurate DT development initiatives across multiple stakeholders, departments, and project phases. Therefore, AECO organizations must build leadership structures that support cross-functional coordination and data governance. In summary, these practical implications emphasize that accurate DT development is not merely a technological endeavor. Instead, it requires coordinated action across stakeholders, workforce, and investments. For AECO organizations to succeed in developing accurate DTs of constructed facilities, organizations should devote themselves to an organizationally integrated approach that is involved and supported by the right people, processes, and strategic structures.

Limitations and future recommendations

Despite these findings, several limitations exist that warrant further exploration. Firstly, this study employed a small sample size. Nonetheless, all the statistical analyses fulfilled the required sample size. While this sample provides meaningful insights into DT development, it is acknowledged that a more extensive and geographically diverse dataset could further enhance the generalizability of the findings. Future research should consider expanding its scope to include more international participants, thereby capturing regional variations in organizational strategies. Secondly, the *nonprobability sampling approach* was adopted due to the *absence of a defined sampling frame*, as constructing one proved challenging. Despite its inherent limitations, this approach remains effective in obtaining a *representative sample* (Omer *et al*., 2025; Suri, 2011). It is particularly suitable when respondents *are selected based on their willingness to participate*, rather than being randomly selected from the entire population (Omer *et al*., 2025; Wilkins, 2011). Thirdly, this study was conducted within a specific country and industry context, which may limit the generalizability of the findings. AECO industries in different countries may have varying regulatory frameworks, infrastructures, and levels of technological readiness, all which impact DT development differently. Future research should conduct cross-regional comparisons to examine how policy environments and market maturity shape DT development. Although there were limits, the study aims was successfully achieved.

Concluding remarks

In conclusion, this study achieved its aim of investigating the organizational attributes and strategies necessary for developing accurate DTs of constructed facilities. This study was structured around three objectives. First, through NMA, 11 key organizational attributes and 20 key organizational strategies were identified. Second, EFA was employed to develop underlying constructs among the organizational attributes and strategies. Organizational attributes were categorized into two underlying constructs: organizational DT capabilities and technological capability requirements. Conversely, organizational strategies were categorized into three underlying constructs: organizational competitiveness and investments, workforce management and training, and management capabilities. Finally, PLS-SEM was used to model the causal relationship among these underlying constructs. Out of the six formulated hypotheses, three are empirically supported: organizational DT capabilities impact the need for organizational competitiveness and investments, workforce management and training, and management capabilities.

For theoretical implications, the study findings suggest that investments in technology must be paired with organizational readiness, with capability maturity models incorporating competitiveness and investments as feedback mechanisms. Moreover, workforce development emerges as both a prerequisite and a product of accurate DT development, which highlights the need for continuous training and reskilling to prevent technological disconnects. The results also emphasize that management capabilities are not merely supportive but serve as a central determinant for developing accurate DTs. For practical implications, these findings provide AECO organizations with a framework that advocates for treating organizational strategies as strategic investments, fostering innovation, and strengthening internal management systems when ensuring the development of accurate DTs of constructed facilities.

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