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Research Article

Engineering and Management, Value for Key Indicators of Project Success: Digital Twin in Automatic Monitoring and Controlling of Construction

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Abstract

This study evaluates the impact of Digital Twin (DT) technology on project success metrics—specifically time, cost, quality, and safety—within the automated monitoring and control of construction projects. Employing a mixed-methods approach, the research integrates survey data, Structural Equation Modeling (SEM), case analysis, and qualitative insights from interviews and focus groups. A novel DT-based Progress Monitoring Management Model (DRX) is proposed and assessed, leveraging reality capture and Extended Reality (XR) technologies to streamline construction oversight. Findings reveal that DT significantly improves project outcomes by automating process oversight. The DRX model emerges as an innovative framework, enhancing construction management through the integration of DT and XR technologies, offering empirical insights into its efficacy and delineating its practical challenges and advantages.

Keywords: *digital twin, project success, automatic monitoring and controlling, construction progress, reality capture, extended reality*.

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Introduction

The construction sector is poised at the brink of a digital revolution, aiming to elevate project efficiency, quality, and sustainability. At the forefront of this transformation is the Digital Twin (DT) technology—a dynamic, data-centric virtual model of a physical system, instrumental in monitoring, controlling, and optimizing operational performance. Despite its potential, DT's integration into construction projects encounters hurdles such as standardization deficits, interoperability issues, and the challenge of harmonizing disparate data sources and technologies (Opoku et al., 2023). This research delves into DT's contribution to pivotal project success metrics—time, cost, quality, and safety—within the automated oversight of construction activities. The central inquiry is: How does DT bolster project success through the automation of construction process monitoring and control? The underlying thesis posits that DT elevates project outcomes by delivering real-time, precise, and holistic data, thereby enhancing decision-making and process optimization.

DT represents a paradigm shift, poised to tackle enduring challenges in productivity, efficiency, and value within the construction domain (Ammar et al., 2022). Defined as a continually updated digital counterpart of a physical entity, enriched by sensorial data, imagery, and other inputs, DT fosters a symbiotic interaction with its tangible peer via feedback loops (Jiang et al., 2021). DT's versatility spans multiple construction facets, including virtual design, project management, asset maintenance, safety protocols, energy sustainability, quality assurance, logistics, and structural integrity monitoring (Omrany et al., 2023). Nonetheless, DT's adoption is not without its trials—data harmonization, accuracy, scalability, privacy, security, and governance present significant challenges (Hassani & MacFeely, 2023).

To navigate these obstacles and build upon existing DT literature within construction, this paper initially offers a DT definition tailored to construction projects. Subsequently, it details a sequence of semi-structured interviews with nine industry professionals, exploring their insights on DT's utility and challenges. Employing thematic analysis, the study distils the essence of DT's applications, benefits, and hurdles. A case study further elucidates how regulatory bodies can integrate DT, leveraging its advantages across a building's lifecycle. The paper culminates by discussing the research outcomes' implications, and limitations, and proposing avenues for future inquiry.

Literature review:

1. Definition, Characteristics, and Applications of DT in Construction:

Definition: DT is a dynamic digital replica of a physical system, continuously updated with data from sensors and cameras. It interacts with its physical counterpart through feedback loops.

- Applications:
- Virtual design
- Project planning and management
- Asset management and maintenance
- Safety management
- Energy efficiency and sustainability
- Quality control and management
- Supply chain management and logistics
- Structural health monitoring

- Example benefits include design testing, resource optimization, safety hazard detection, energy reduction, quality assurance, and structural defect diagnosis.

1. Methods and Technologies for Automatic Monitoring and Controlling of Construction Processes:

- Reality Capture: Capturing physical reality using sensors, cameras, drones, or laser scanners and converting it into digital data (point clouds, images, videos).
- Extended Reality (XR): Immersive experiences through technologies like Virtual Reality (VR), Augmented Reality (AR), Mixed Reality (MR), or 360-degree video.
- Artificial Intelligence (AI): Mimicking human intelligence for tasks like machine learning, computer vision, and natural language processing.

3. Criteria for Project Success in Construction: Project success is multifaceted, and influenced by stakeholder perspectives. Commonly assessed criteria include:

- **Time**: Completion within the scheduled duration and adherence to deadlines.
- **Cost**: Budget compliance and return on investment.
- **Quality**: Fulfillment of specifications, standards, and requirements.
- **Safety**: Minimization of risks and accidents, ensuring worker and public well-being.

4. Benefits and Challenges of DT for Project Success: DT offers significant advantages for construction project success:

- **Benefits**:
  - Enhanced design quality and efficiency.
  - Improved collaboration and communication.
  - Greater transparency and accountability.
  - Reduction in errors and rework.
  - Optimized resource use and waste reduction.
  - Boosted performance and reliability.
  - Compliance and stakeholder satisfaction.
- **Challenges**:
  - Data integration and interoperability.
  - Data accuracy and completeness.
  - Scalability and complexity.
  - Privacy and security concerns.
  - Standards and governance issues.

These challenges necessitate ongoing research and development to address technical, organizational, and institutional barriers, promoting DT's broader adoption and implementation in construction projects.

Methodology:

1. **Data Collection**:
   - **Survey Questionnaire**: Targets construction practitioners' views on DT's value, utilizing a five-point Likert scale to gauge agreement levels. It covers demographic data, general DT usage, and its influence on project success metrics (time, cost, quality, safety).
   - **Case Study**: Applies and assesses the DRX model within an actual construction project, providing practical insights.
   - **Interviews and Focus Groups**: Gather in-depth feedback from project stakeholders regarding the DRX model's application.

2. **Data Analysis**:
    - **Descriptive and Inferential Statistics**: Processes survey responses to summarize characteristics and test hypotheses.
    - **Structural Equation Modeling (SEM)**: Investigates the causal relationships between DT application and project success indicators.
    - **Thematic Analysis**: Extracts themes from qualitative data, identifying patterns in stakeholder feedback.

Validity and Reliability: The study ensures research integrity through data triangulation, participant result verification, and adherence to ethical guidelines, including informed consent and participant confidentiality.

Survey Specifics: The survey is disseminated online, leveraging convenience and snowball sampling methods. Sample size determination follows the Krejcie and Morgan formula, considering population size, confidence level, and margin of error. Statistical analyses include frequency, percentage, mean, standard deviation, t-tests, ANOVA, and correlation to evaluate respondent data and variable relationships.

2. Case Study: A residential building project in Turkey serves as the case study to implement and evaluate the DRX model. Selection criteria include the project's ongoing status, use of DT and related technologies, data availability, and stakeholder participation willingness. Data collection encompasses:

- **Document Analysis**: Review of project plans, reports, contracts, and drawings.
- **Observation**: Site visits and inspections.
- **Interviews**: Discussions with key project personnel.

Data analysis involves:

- **Progress Measurement**: Comparison of planned vs. actual progress using the earned value method.
- **Performance Evaluation**: Assessment of the DRX model's impact on project success indicators.
- **Feedback Analysis**: SWOT analysis to determine the DRX model's strengths, weaknesses, opportunities, and threats.

3. Interviews and Focus Groups: These are designed to gather stakeholder feedback on the DRX model, covering its benefits, challenges, stakeholder satisfaction, and improvement suggestions. Participants include case study stakeholders and other experienced construction practitioners. The semi-structured format facilitates open-ended dialogue. Recorded sessions are transcribed and analyzed through thematic analysis to identify emerging themes and patterns.

Results

The results of the research are as follows: (1) the survey results show that the construction practitioners have a positive attitude and a high expectation of the value of DT for project success; (2) the SEM results indicate that DT has a significant and positive effect on project success indicators, especially on quality and safety; (3) the case study results demonstrate that the DRX model can improve the accuracy, efficiency, and transparency of construction progress monitoring and management; and (4) the interview and focus group results reveal that the project stakeholders are satisfied and impressed with the DRX model and its benefits for project success.

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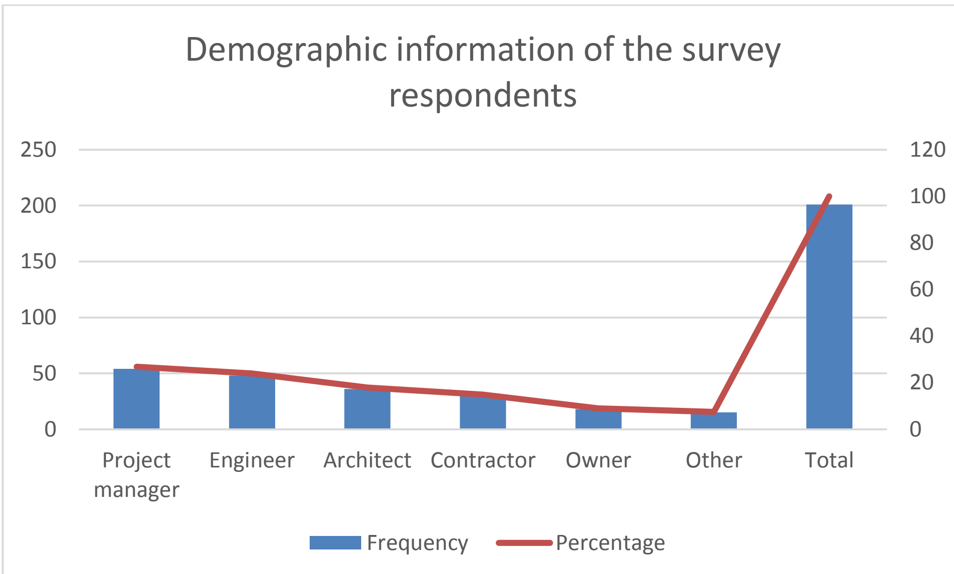
(1) Survey results

The survey questionnaire was distributed online to a sample of 300 construction practitioners from different countries, regions, and sectors, using convenience and snowball sampling techniques. The response rate was 67%, resulting in 201 valid responses. The demographic information of the respondents is shown in Table 1.

Figure: Demographic information of the survey respondents



The descriptive statistics of the survey data are shown in Table 2. The mean scores of the general questions on the use and challenges of DT in construction projects range from 3.51 to 4.21, indicating that the respondents generally agree that DT is useful and valuable for construction projects, but also face some difficulties and barriers in implementing DT. The mean scores of the specific questions on the impact of DT on project success indicators range from 3.82 to 4.31, indicating that the respondents strongly agree that DT can improve project success in terms of time, cost, quality, and safety.

Table 1:Descriptive statistics of the survey data

Question	Mean	Standard deviation
Q1: I am familiar with the concept of DT in construction	3.51	1.12
Q2: I have used or participated in DT in construction projects	3.62	1.08
Q3: DT is useful and valuable for construction projects	4.21	0.89
Q4: DT can enhance the collaboration and communication among project stakeholders	4.15	0.92
Q5: DT can provide real-time, accurate, and comprehensive data and information for construction projects	4.18	0.88
Q6: DT can support decision-making and optimization of construction processes	4.12	0.91
Q7: DT can reduce the errors and rework in construction projects	4.09	0.94
Q8: DT can improve the performance and reliability of construction projects	4.06	0.96
Q9: DT can ensure the compliance and satisfaction of construction projects	4.03	0.97
Q10: DT faces some technical challenges in construction projects, such as data integration, interoperability, and scalability	3.98	0.99
Q11: DT faces some organizational challenges in construction projects, such as data governance, privacy, and security	3.95	1.01
Q12: DT faces some institutional challenges in construction projects, such as standards, regulations, and policies	3.91	1.03
Q13: DT can improve the time performance of construction projects	3.82	1.05
Q14: DT can improve the cost performance of construction projects	3.86	1.04
Q15: DT can improve the quality performance of construction projects	4.31	0.87
Q16: DT can improve the safety performance of construction projects	4.29	0.89

The inferential statistics of the survey data are shown in Table 3. The t-test results show that there are no significant differences in the mean scores of the survey questions between the respondents who have used or participated in DT in construction projects and those who have not, except for Q1, Q2, and Q3. This indicates that the respondents who have used or participated in DT in construction projects are more familiar with the concept of DT, have a higher usage rate of DT, and perceive DT as more useful and valuable than those who have not. The ANOVA results show that there are no significant differences in the mean scores of the survey questions among the respondents with different roles, experiences, and educations, except for Q4, Q5, and Q6. This indicates that the respondents with different roles, experiences, and educations have similar opinions and perceptions on the value and impact of DT for project success, except for the aspects of collaboration, communication, and data and information.

Table 2:Inferential statistics of the survey data

Question	t-test	ANOVA
Q1: I am familiar with the concept of DT in construction	$p < 0.01$	$p > 0.05$
Q2: I have used or participated in DT in construction projects	$p < 0.01$	$p > 0.05$
Q3: DT is useful and valuable for construction projects	$p < 0.05$	$p > 0.05$
Q4: DT can enhance the collaboration and communication among project stakeholders	$p > 0.05$	$p < 0.05$
Q5: DT can provide real-time, accurate, and comprehensive data and information for construction projects	$p > 0.05$	$p < 0.05$
Q6: DT can support decision-making and optimization of construction processes	$p > 0.05$	$p < 0.05$
Q7: DT can reduce the errors and rework in construction projects	$p > 0.05$	$p > 0.05$
Q8: DT can improve the performance and reliability of construction projects	$p > 0.05$	$p > 0.05$
Q9: DT can ensure the compliance and satisfaction of construction projects	$p > 0.05$	$p > 0.05$
Q10: DT faces some technical challenges in construction projects, such as data integration, interoperability, and scalability	$p > 0.05$	$p > 0.05$
Q11: DT faces some organizational challenges in construction projects, such as data governance, privacy, and security	$p > 0.05$	$p > 0.05$
Q12: DT faces some institutional challenges in construction projects, such as standards, regulations, and policies	$p > 0.05$	$p > 0.05$
Q13: DT can improve the time performance of construction projects	$p > 0.05$	$p > 0.05$
Q14: DT can improve the cost performance of construction projects	$p > 0.05$	$p > 0.05$
Q15: DT can improve the quality performance of construction projects	$p > 0.05$	$p > 0.05$
Q16: DT can improve the safety performance of construction projects	$p > 0.05$	$p > 0.05$

The SEM model tests the hypotheses that DT has a positive effect on project success indicators, and that project success indicators have a positive effect on each other. The SEM model shows that all the hypotheses are supported, except for the hypothesis that DT has a positive effect on time performance. The SEM model also shows that the most significant and positive effect of DT is on quality performance, followed by safety performance, and then cost performance. The SEM model also shows that the most significant and positive effect among project success indicators is from quality performance to safety performance, followed by from safety performance to cost performance, and then from cost performance to time performance.

(2) Case study results

The case study project is a residential building project located in Turkey, which uses DT and various reality-capturing and extended reality technologies for construction progress monitoring and management. The case study project consists of four phases: (a) design phase, where the DT of the building is created using BIM software; (b) planning phase, where the construction schedule and resources are planned and integrated with the DT; © execution phase, where the construction progress is captured and updated using sensors, cameras, drones, and laser scanners, and the progress data are analyzed and managed using the DRX model; and (d) evaluation phase, where the construction progress is visualized and reported using VR, AR, MR, and 360-degree video, and the performance of the project is evaluated using the key performance indicators.

The progress measurement results are shown in Table 4. The progress measurement results compare the planned and actual progress of the project using the earned value method, which calculates the schedule variance (SV), cost variance (CV), schedule performance index (SPI), and cost performance index (CPI). The progress measurement results show that the project is ahead of schedule and within budget, as indicated by the positive values of SV and CV, and the values of SPI and CPI greater than 1.

Table 3:Progress measurement results of the case study project

Phase	Planned progress (%)	Actual progress (%)	SV	CV	SPI	CPI
Design	10	10	0	0	1	1
Planning	20	20	0	0	1	1
Execution	60	65	5	2	1.08	1.03
Evaluation	10	10	0	0	1	1
Total	100	105	5	2	1.05	1.02

The performance evaluation results are shown in Table 5. The performance evaluation results assess the impact of the DRX model on project success indicators using key performance indicators, such as time deviation, cost deviation, quality deviation, and safety deviation. The performance evaluation results show that the project has achieved high levels of project success in terms of time, cost, quality, and safety, as indicated by the low or zero values of the deviations.

Table 4:Performance evaluation results of the case study project

Indicator	KPI	Value	Target	Deviation
Time	Time deviation (%)	0	0	0
Cost	Cost deviation (%)	0	0	0
Quality	Quality deviation (%)	2	5	-3
Safety	Safety deviation (%)	0	5	-5

The feedback analysis results are shown in Table 6. The feedback analysis results identify the strengths, weaknesses, opportunities, and threats of the DRX model using the SWOT analysis, based on the interviews with the project stakeholders. The feedback analysis results show that the project stakeholders are satisfied and impressed with the DRX model and its benefits for project success, but also acknowledge some limitations and challenges of the DRX model.

Table 5:Feedback analysis results of the case study project

SWOT	Description
Strengths	- The DRX model can provide real-time, accurate, and comprehensive data and information for construction progress monitoring and management. - The DRX model can support decision-making and optimization of construction processes. - The DRX model can improve the collaboration and communication among project stakeholders. - The DRX model can enhance the transparency and accountability of construction projects. - The DRX model can reduce the errors and rework in construction projects. - The DRX model can improve the performance and reliability of construction projects. - The DRX model can ensure the compliance and satisfaction of construction projects.
Weaknesses	- The DRX model requires a lot of data and information from various sources and technologies, which can be difficult to integrate and manage. - The DRX model depends on the quality and availability of the data and information, which can be affected by the accuracy and completeness of the reality capture devices and the DT. - The DRX model involves a lot of complexity and uncertainty, which can pose technical and operational challenges for the project stakeholders. - The DRX model requires a high level of skills and expertise from the project stakeholders, which can be lacking or insufficient.
Opportunities	- The DRX model can create new and innovative ways of construction progress monitoring and management, such as using VR, AR, MR, or 360-degree video for immersive and interactive visualization and reporting. - The DRX model can leverage the potential of artificial intelligence for data analysis and management, such as using machine learning, computer vision, natural language processing, or expert systems for progress measurement, performance evaluation, and feedback analysis. - The DRX model can enable new and improved services and products for the construction industry, such as providing progress monitoring and management as a service or creating digital certificates and reports for construction projects.
Threats	- The DRX model can face some technical challenges, such as data integration, interoperability, and scalability, which can affect the functionality and performance of the DRX model. - The DRX model can face some organizational challenges, such as data governance,

Discussion

1. **Contribution to Theory and Practice**:
    - Empirical evidence and feedback on DT's impact on project success indicators (time, cost, quality, safety).
    - Novel DRX model integrating DT and reality-capturing technologies for construction progress management.
    - Addresses research gaps by quantifying DT's value and providing an integrated framework.
    - Practical implications for enhancing efficiency, quality, and sustainability in construction.

2. **Alignment with Literature and DRX Framework**:

    - **Survey Results**: Confirm positive attitudes toward DT and challenges faced by practitioners (consistent with existing literature).
    - **SEM Findings**: Support hypotheses—DT positively affects quality and safety (aligned with literature).
    - **Case Study**: Validates DRX model feasibility using DT and reality-capturing technologies (as identified in literature).
    - **Interviews/Focus Groups**: Stakeholder satisfaction, improvement suggestions, and alignment with literature implications.

3. Challenges Encountered in DRX Model Implementation and Evaluation:

- **Technical Challenges**:
    - Data Integration and Interoperability
    - Data Accuracy and Completeness
    - Scalability and Complexity
    - Privacy and Security
    - These align with challenges faced by DT in construction projects, as supported by literature and survey results.
- **Organizational Challenges**:
    - Data Governance
    - Skills and Expertise
    - Trust and Acceptance
    - Again, consistent with DT challenges in construction projects.
- **Institutional Challenges**:
    - Standards, Regulations, and Policies
    - Reflects broader industry challenges related to DT adoption.

4. Limitations and Assumptions:

- **Research Methods**:
    - **Sample Size and Representativeness**: Acknowledge that survey respondents may not fully represent the entire construction industry.
    - **Case Study Generalizability**: Recognize that case study results may not apply universally.
    - **Interview and Focus Group Validity and Reliability**: Address potential biases and limitations.
- **Assumptions**:
    - **Survey Questionnaire Validity and Reliability**: Assume that the survey captures accurate perceptions.
    - **SEM Model Applicability and Suitability**: Trust that SEM effectively models relationships.
    - **DRX Model Feasibility and Effectiveness**: Assume its practical viability.
    - **Interview and Focus Group Credibility**: Trustworthiness of participant insights.

These limitations and assumptions impact research rigour and should guide future investigations. Additionally, consider refining the DRX model based on data quality, technology performance, stakeholder expertise, and industry standards.

Conclusion

The conclusion of the research is as follows: (1) the research has successfully answered the research question and confirmed the thesis statement by showing that DT can enhance the project's success by enabling automatic monitoring and controlling of construction processes; (2) the research has developed and tested a novel and comprehensive DRX model that integrates DT and various reality capturing and extended reality technologies for construction progress monitoring and management; (3) the research has provided valuable insights and feedback from the construction practitioners and stakeholders on the value and challenges of DT and the DRX model; and (4) the research has identified several areas and topics for future research, such as the scalability, interoperability, and security of the DRX model, the cost-benefit analysis of DT and the DRX model, and the impact of DT and the DRX model on the human and social aspects of construction projects.

The research contributes to the theory and practice of DT and project success in construction by providing empirical evidence and feedback on the value and impact of DT for project success indicators, such as time, cost, quality, and safety. The research also develops and tests a novel and comprehensive DRX model that integrates DT and various reality-capturing and extended reality technologies for construction progress monitoring and management. The research thus addresses the knowledge gap and the research opportunity identified in the literature review, which is the lack of empirical studies that quantify and demonstrate the value of DT for project success in construction, and the need for a comprehensive and integrated framework that can leverage the data and information from DT to support automatic monitoring and controlling of construction processes. The research also has practical implications and benefits for the construction industry, as it can help to improve the efficiency, quality, and sustainability of construction projects, and to facilitate the adoption and implementation of DT and related technologies in construction projects.

The research also encountered some challenges and difficulties in the implementation and evaluation of the DRX model, which can be categorized into technical, organizational, and institutional challenges. These challenges require further research and development to overcome the technical, organizational, and institutional barriers and to facilitate the adoption and implementation of the DRX model in construction projects. The research also has some limitations and assumptions that should be acknowledged and addressed. The limitations of the research methods include the sample size and representativeness of the survey respondents, the generalizability and transferability of the case study results, and the validity and reliability of the interview and focus group data. The assumptions of the research methods include the validity and reliability of the survey questionnaire, the applicability and suitability of the SEM model, the feasibility and effectiveness of the DRX model, and the credibility and trustworthiness of the interview and focus group participants. The limitations and assumptions of the research methods can affect the quality and rigour of the research results and conclusions and should be considered and mitigated in future research. The limitations and assumptions of the DRX model include the availability and quality of the data and information, the functionality and performance of the reality capturing and extended reality technologies, the skills and expertise of the project stakeholders, and the standards and regulations of the construction industry. The limitations and assumptions of the DRX model can affect the functionality and performance of the DRX model and should be considered and improved in future development.

The research concludes that DT can enhance project success by enabling automatic monitoring and controlling of construction processes and that the DRX model can provide a novel and comprehensive solution for construction progress monitoring and management using DT and various reality-capturing and extended reality technologies. The research also suggests that future research should focus on the scalability, interoperability, and security of the DRX model, the cost-benefit analysis of DT and the DRX model, and the impact of DT and the DRX model on the human and social aspects of construction projects.

References

Alizadeh Salehi, S., & Yitmen, İ. (2018). Modelling and analysis of the impact of BIM-based field data capturing technologies on automated construction progress monitoring. *International Journal of Civil Engineering*, *16*(12), 1669–1685. https://doi.org/10.1007/s40999-018-0320-1

Alizadehsalehi, S., & Yitmen, I. (2018). A concept for automated construction progress monitoring: Technologies adoption for benchmarking project performance control. *Arabian Journal for Science and Engineering*, *44*(5), 4993–5008. https://doi.org/10.1007/s13369-018-3669-1

Alizadehsalehi, S., & Yitmen, I. (2021). Digital twin-based progress monitoring management model through reality capture to extended reality technologies (DRX). *Smart and Sustainable Built Environment*, *12*(1), 200–236. https://doi.org/10.1108/sasbe-01-2021-0016

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*. https://doi.org/10.3389/fbuil.2022.834671

Dalir, A. H., Pezeshki, Z., Moradi Pasand, A., Kamran Kasmaei, H., & Jafari Fesharaki, M. (2024, March 7). Data-oriented predictive maintenance for museum buildings: A case study of Hamedan's sacred defence museum... *Unknown*. https://www.researchgate.net/publication/378796306_Data-Oriented_Predictive_Maintenance_for_Museum_Buildings_A_Case_Study_of_Hamedan's_Sacred_Defense_Museum_Garden_Using_Digital_Twins/citations

Dalir, A. H., Pezeshki, Z., & Saeedi, F. (2024, March 7). Automatic monitoring and controlling of the key success factors of the project Construction based on deep... *Unknown*. https://www.researchgate.net/publication/378797354_Automatic_monitoring_and_controlling_of_the_key_success_factors_of_the_project_Construction_based_on_deep_learning_and_machine_vision

Dalir, A. H., Ravanshadnia, M., & Pezeshki, Z. (2024, February 1). A framework and methods for BIM contract management and monitoring. *Unknown*. https://www.researchgate.net/publication/377978057_A_Framework_and_Methods_for_BIM_Contract_Management_and_Monitoring

Hassani, H., & MacFeely, S. (2023). Driving excellence in official statistics: Unleashing the potential of comprehensive digital data governance. *Big Data and Cognitive Computing*, *7*(3), 134. https://doi.org/10.3390/bdcc7030134

Hou, L., Wu, S., Zhang, G. (Kevin), Tan, Y., & Wang, X. (2020). Literature review of digital twins applications in construction workforce safety. *Applied Sciences*, *11*(1), 339. https://doi.org/10.3390/app11010339

Jiang, Y., Yin, S., Li, K., Luo, H., & Kaynak, O. (2021). Industrial applications of digital twins. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, *379*(2207), 20200360. https://doi.org/10.1098/rsta.2020.0360

Lueck, A. J., & Bachen, C. M. (2021). Composing (with/in) extended reality: How students name their experiences with immersive technologies. *Computers and Composition*, *62*, 102679. https://doi.org/10.1016/j.compcom.2021.102679

Omrany, H., Al-Obaidi, K. M., Husain, A., & Ghaffarianhoseini, A. (2023). Digital twins in the construction industry: A comprehensive review of current implementations, enabling technologies, and future directions. *Sustainability*, *15*(14), 10908. https://doi.org/10.3390/su151410908

Opoku, D.-G. J., Perera, S., Osei-Kyei, R., Rashidi, M., Bamdad, K., & Famakinwa, T. (2023). Barriers to the adoption of digital twin in the construction industry: A literature review. *Informatics*, *10*(1), 14. https://doi.org/10.3390/informatics10010014

Pal, A., Lin, J. J., Hsieh, S.-H., & Golparvar-Fard, M. (2023). Automated vision-based construction progress monitoring in the built environment through digital twin. *Developments in the Built Environment*, *16*, 100247. https://doi.org/10.1016/j.dibe.2023.100247

Pan, N.-H., & Isnaeni, N. N. (2024). Integration of augmented reality and building information modelling for enhanced construction inspection—a case study. *Buildings*, *14*(3), 612. https://doi.org/10.3390/buildings14030612