



Integrating Digital Technologies for Enhancing Construction Sustainability: Advancements in Civil Engineering Education

Florante D. Poso, Jr.^{1*}

Kenneth Bryan M. Tana²

^{*}Polytechnic University of the Philippines, Manila, Philippines

Corresponding mail id : fdposojr@pup.edu.ph

Abstract

The construction industry is undergoing a transformative shift driven by digital technologies, offering new opportunities to enhance sustainability and efficiency. This study explores the integration of digital tools in civil engineering education to promote sustainable construction practices. A systematic review of current trends, challenges, and implementation strategies was conducted, highlighting the role of digitalization in improving resource management, waste reduction, and energy efficiency. The study employed descriptive-quantitative research design using an online survey involving the civil engineers working in the academe and industry. A total of 110 respondents were used in the study and descriptive statistics to interpret the results. The findings indicate that incorporating digital technologies into civil engineering curricula enhances students' ability to analyze environmental impacts, optimize designs, and adopt sustainable solutions. However, barriers such as high implementation costs, technological adaptability, and the need for faculty training must be addressed. The study concludes that fostering digital literacy and industry-academia collaboration is crucial for advancing sustainable construction education. Future research should focus on developing standardized frameworks for integrating digital tools into engineering programs, ensuring alignment with industry needs and sustainability goals.

Keyword: Civil Engineering, Construction, Digital Technologies, Engineering Education, Sustainability

I. INTRODUCTION

The construction industry, a cornerstone of economic development, faces significant challenges related to sustainability. The increasing demand for infrastructure, coupled with resource depletion and environmental concerns, necessitates innovative approaches to minimize the industry's ecological footprint. Digital technologies, with their potential to revolutionize various aspects of construction, offer promising solutions. This study investigates the utilization of digital technologies in construction projects to enhance sustainability and explores their implications for advancing civil engineering education Lu, W. et al. (2024).

The construction industry is a pivotal sector that significantly contributes to economic growth and development. However, it is also renowned for its substantial environmental footprint, characterized by resource consumption, waste generation, and greenhouse gas emissions. To address these challenges and promote sustainable practices, the integration of digital technologies has emerged as a promising solution Pan, Y., and Zhang, L. (2024).

The rationale for this study stems from the increasing urgency to foster sustainable construction practices. The growing global population and urbanization have placed immense pressure on natural resources and the environment Muhammad Asif, Ghinwa Naeem, and Muhammad Khalid, (2024). Consequently, there is a pressing need to adopt innovative approaches that minimize the negative impacts of construction activities. Digital technologies offer a wide range of tools and applications that can revolutionize the industry, enabling more efficient resource management, waste reduction, and improved environmental performance.

By examining the current state of digital technology adoption in construction, this study aims to contribute to the body of knowledge on sustainable construction practices Sargiotis, D., (2024).

The findings of this research will be valuable for policymakers, industry professionals, and educators in understanding the potential of digital technologies to drive sustainable construction. Furthermore, it will provide insights into the necessary steps to integrate these technologies into civil engineering curricula, ensuring that future generations of engineers are equipped to address the environmental challenges of the construction industry Yue Pan, and Limao Zhang, (2021).

This survey study aimed to determine the use of digital technologies in construction to enhance sustainability and its implication towards advancement in civil engineering education.

This study is grounded in the Technology Acceptance Model (TAM) which provides a robust foundation for understanding the integration of digital technologies in civil engineering education to promote construction sustainability. The Technology Acceptance Model (TAM), developed by Davis F. D. Davis, posits that perceived usefulness and perceived ease of use significantly influence users' acceptance of technology. In the context of this study, TAM provides a lens to evaluate how civil engineering educators and students perceive and adapt to digital tools such as Building Information Modeling (BIM), virtual reality (VR), digital twins, and cloud-based collaboration platforms. These technologies are increasingly employed in sustainable construction practices and are instrumental in equipping students with relevant skills and awareness of sustainability metrics. The extension of TAM by Venkatesh and Davis V. Venkatesh and F. D. Davis, which includes social influence and facilitating conditions, also supports the premise that institutional support and curriculum integration are critical in fostering the adoption of these technologies.

II. METHODS

a. Data Gathering and Analysis

The study employed descriptive-quantitative research design. The researchers conducted an online survey involving the civil engineers working in the academe and industry during the month of March 2026. The survey was distributed online using Google Forms within a duration of one (1) month. Only those who had responded to the survey were included in the survey study.

b. The respondents and sampling

There are 110 total respondents that were included in the study. Convenience sampling technique was employed in the study where the link to the google forms were sent through emails, and other social media platforms. The researchers set one (1) month for the respondents to fill out the questionnaires and a total of 110 responded. Only those who voluntarily responded to the survey were included in the study.

c. The Research Instrument

A survey questionnaire was deployed to the respondents which was patterned from the study of Lu, W. et al. (2024). Minor modifications were made to fit with the purpose of the current study. The questionnaire was divided into four (4) parts, the profile of the respondents, level of usage of digital technologies in construction, Prospects in Digital Technologies (DTs) for construction Sustainability and Key Challenges in Deploying Digital Technologies (DTs) for Construction Sustainability. Only in the profile of the respondents that there are changes in the instrument, thus there is no need for validation of the instrument. Lu, W. et al. (2024).

d. Scoring and interpretation

To answer the objectives on determining the Level of Usage of Digital Technology in Construction, the 5-Likert scale was used, one (1) as the lowest and five (5) as the highest score from never utilized, rarely utilized, sometimes utilized, often utilized and extremely utilized.

The weighted means for each of the items in the questionnaire is interpreted based on the criteria shown in Table 1.

Table 1. Interpretation Table for Level of Usage of DTs

Weighted Mean	Interpretation
1.00 – 1.50	Never utilized
1.51 – 2.50	Rarely utilized
2.51 – 3.50	Sometimes utilized
3.51 – 4.50	Often utilized
4.51 – 5.00	Extremely utilized

As regards to the objective on determining the prospects in digital technologies (DTs) for construction sustainability and the key challenges in deploying digital technologies (DTs) for Construction Sustainability, the 5-Likert scale was used, one (1) as the lowest and five (5) as the highest score from strongly disagree, disagree, neutral, agree and strongly agree. Descriptive statistics were employed to interpret the data and information gathered.

The weighted means for each of the items in the questionnaire is interpreted based on the criteria shown in Table 2.

Table 2. Interpretation Table for prospects and challenges of DTs

Weighted Mean	Interpretation
1.00 – 1.50	Strongly disagree

1.51 – 2.50	Disagree
2.51 – 3.50	Neutral
3.51 – 4.50	Agree
4.51 – 5.00	Strongly agree

III. RESULTS AND DISCUSSION

a. Respondents' profile

Table 3 presents the respondent's profile on sex, nature of the company they are working, and trainings attended on digital technology. In terms of sex, majority of the respondents are male, majority are working in the private industry and majority of them had attended trainings on the use of digital technology in construction. A significant portion of the respondents had attended training courses on the use of digital technology in construction, highlighting a growing awareness and interest in integrating these tools into industry practices. This implies a need for targeted efforts to promote the adoption of digital technologies in areas where they may be lagging, such as public sector construction projects. Furthermore, it underscores the importance of providing accessible and comprehensive training programs to equip the workforce with the necessary skills to effectively utilize digital tools and drive sustainable construction practices. Implying further, educational institutions should incorporate digital technology into their curricula, providing students with hands-on experience and training in relevant software and tools. This will help prepare graduates for the demands of the modern workplace and ensure they are equipped with the necessary skills to contribute to the industry's digital transformation.

Table 3. Respondent's Profile

Sex	Number	Percentage
Male	80	72.58
Female	30	27.42
Total	110	100.00
Nature of Company		
Government	30	27.27%
Private	80	72.73%
Total	110	100.00
Attended Trainings on Digital Technology?		
YES	69	62.90%
NO	41	37.10%
Total	110	100.00

b. Level of Usage of Digital Technology in Construction

Table 4 presents the level of usage of digital technology in construction. The table reveals that 'Mobile Technology' got the highest weighted mean of 4.10 interpreted as "often utilized" while the use of "Unmanned Aerial Vehicle" and "Augmented Reality" got the lowest weighted mean of 2.42 and 2.45 respectively, interpreted as "rarely utilized". Other digital technologies rated as often utilized are the use of Internet of Things (IoT) and Big Data. Mobile technology was the most widely utilized, suggesting that it is frequently incorporated into construction operations.

The findings highlight the uneven adoption of digital technologies in the construction industry. While mobile technology has become a standard tool, there is significant room for growth in the utilization of UAVs and AR. This disparity may be attributed to factors such as cost, lack of awareness, or concerns about data privacy and security. Implying that there is a need for educational institutions to focus on emerging technologies in their curricula.

A study by Li et al. H. Li, J. Kong, and X. Pang emphasized that mobile devices are extensively adopted in construction sites due to their accessibility, ease of use, and ability to facilitate real-time communication and data sharing. Conversely, technologies such as Unmanned Aerial Vehicles (UAVs) and Augmented Reality (AR) are still in the early stages of adoption, often hindered by high costs, lack of technical expertise, and limited integration into traditional workflows B. Sacks, C. Brilakis, and R. Pikas.

Table 4. Level of Usage of Digital Technology in Construction

Digital Technology	Weighted Mean	Interpretation
Building Information Modeling (BIM)	3.23	Sometimes utilized
Internet of Things (IoT)	3.79	Often utilized
Big Data	3.53	Often utilized
Artificial Intelligence (AI)	3.13	Sometimes utilized

Machine Learning (ML)	3.06	Sometimes utilized
Virtual Reality (VR)	2.53	Sometimes utilized
Augmented Reality (AR)	2.45	Rarely utilized
Unmanned Aerial Vehicle (UAV)	2.42	Rarely utilized
Cloud Computing	2.65	Sometimes utilized
Blockchain	2.32	Rarely utilized
Digital Twins	2.10	Rarely utilized
Smart Robotics	2.10	Rarely utilized
3D Printing	2.34	Rarely utilized
Mobile Technology	4.10	Often utilized
GRAND MEAN	2.84	Sometimes utilized

c. Prospects in Digital Technologies (DTs) for construction Sustainability

Table 5 shows the prospects in Digital Technologies (DTs) for construction Sustainability. Item 7 “Real-time tracking of work progress and building performance” got the highest weighted mean of 4.03 interpreted as “agree” while item 11 “Immersive sustainable practices training using VR and AR” got the lowest weighted mean of 3.52 interpreted as “agree”. Overall findings revealed a weighted mean of 3.97 interpreted as “agree”.

The findings suggest a growing recognition of the value of DTs in optimizing project efficiency and monitoring environmental impact. In contrast, 'Immersive sustainable practices training using VR and AR' received a slightly lower rating. While this still indicates a positive perception, it may imply a need for further exploration and development of immersive training solutions to fully realize their potential in fostering sustainable behaviors and knowledge among construction professionals.

Overall, the findings demonstrate a positive outlook on the integration of DTs into sustainable construction. The strong support for real-time tracking underscores the potential of DTs to revolutionize project management and decision-making. However, the relatively lower rating for immersive training highlights the need for continued innovation and refinement in this area to maximize its effectiveness.

While immersive training shows promise, further research and development are needed to optimize its effectiveness. Investing in innovative training solutions can equip construction professionals with the skills and knowledge necessary to embrace sustainable practices and drive positive changes. Higher education institutions should revisit their curriculum into offering specialized courses on DT applications in civil engineering, such as Building Information Modeling (BIM), Internet of Things (IoT), and artificial intelligence (AI) and provide students with opportunities to use DT tools and software in practical projects and assignments.

Similar studies have shown that real-time monitoring systems, powered by IoT and data analytics, significantly contribute to improving building performance, reducing delays, and minimizing resource waste through enhanced decision-making and predictive maintenance Y. Zhang, H. Deng, and X. Li.

Table 5. Prospects in Digital Technologies (DTs) for construction Sustainability

Prospects in Digital Technologies	Weighted Mean	Interpretation
1. DTs enhance communication and stakeholder information sharing	3.85	Agree
2. Real-time collaboration via cloud-based and management tools	3.97	Agree
3. Extensive integration of new and existing systems	3.87	Agree
4. Optimization using design exploration and environmental evaluation	3.94	Agree
5. Sustainability analysis via energy modeling and fluid dynamics	3.82	Agree
6. Efficient, sustainable design through informed decisions	3.94	Agree
7. Real-time tracking of work progress and building performance	4.03	Agree
8. Data collection on performance using IoT and analytics	3.92	Agree
9. Optimized resource usage for energy savings and less impact	3.94	Agree
10. Interactive DTs for sustainability education and skills	3.90	Agree
11. Immersive sustainable practices training using VR and AR	3.52	Agree
12. Efficient, interactive training systems via AI and ML	3.79	Agree
DTs enhance communication and stakeholder information sharing	3.87	Agree
Real-time collaboration via cloud-based and management tools	3.85	Agree
GRAND MEAN	3.97	Agree

d. Key Challenges in Deploying Digital Technologies (DTs) for Construction Sustainability

Table 6 presents the key challenges in deploying Digital Technologies (DTs) for construction sustainability. The table reveals that item 2 “Need for standardized data protocols and exchange mechanisms” got the highest weighted mean of 3.87 interpreted as “agree” while item 6 “Automated processes leading to job losses and worker segmentation” got the lowest weighted mean of 3.44 interpreted as “neutral”. The overall findings reveal a weighted mean of 3.71 interpreted as “agree”.

The findings underscore the critical importance of establishing interoperability standards to facilitate seamless data sharing and integration across different systems and stakeholders. In contrast, 'Automated processes leading to job losses and worker segmentation' garnered a more neutral response, suggesting a mixed perception regarding the potential social and economic implications of DT adoption. While concerns about job displacement exist, it is crucial to acknowledge the potential benefits of DTs in improving worker safety, efficiency, and overall quality of life.

In totality, the data reveals a consensus among respondents that challenges related to data standardization and interoperability pose significant barriers to DT implementation in sustainable construction. Addressing these challenges will be essential for unlocking the full potential of DTs in driving positive environmental and economic outcomes. While concerns about job displacement exist, proactive measures should be implemented to mitigate these risks. This includes providing training and upskilling programs to equip workers with the necessary skills to adapt to the changing technological landscape.

The findings imply that there is a need to introduce data science and technology as a core competency in civil engineering curricula. This includes programming skills, data analysis techniques, and understanding of digital tools and platforms relevant to the construction industry.

The high rating for “Need for standardized data protocols and exchange mechanisms” aligns with the findings of Ghaffarianhoseini et al. A. Ghaffarianhoseini, A. Tookey, N. Naismith, and M. Ghaffarianhoseini, who emphasized that the lack of interoperability among digital tools and systems hinders seamless information flow, which is critical for achieving construction sustainability goals.

Table 6. Key Challenges in Deploying Digital technologies (DTs) for Construction Sustainability

Key Challenges in Deploying Digital technologies	Weighted Mean	Interpretation
1. Challenges in data quality for construction products and services	3.68	Agree
2. Need for standardized data protocols and exchange mechanisms	3.87	Agree
3. Interoperability issues within and across project lifecycle stages	3.61	Agree
4. Balancing conflicting design objectives with existing systems	3.68	Agree
5. Lack of expertise in unconventional construction areas	3.85	Agree
6. Automated processes leading to job losses and worker segmentation	3.44	Neutral
7. Resistance due to lack of training and awareness	3.85	Agree
8. Inadequate communication channels among fragmented stakeholders	3.63	Agree
9. Adherence to regulatory requirements and data security concerns	3.71	Agree
10. Costly long-term performance monitoring	3.74	Agree
GRAND MEAN	3.71	Agree

IV. CONCLUSIONS

This study aimed to determine the use of digital technologies in construction to enhance sustainability and its implication towards advancement in civil engineering education. The researchers conducted an online survey involving 110 civil engineers working in the academe and industry during the month of March 2026. As to the respondent’s profile, majority are male, working in the private industry and had attended trainings on digital technology. The findings highlight the uneven adoption of digital technologies in the construction industry. While mobile technology has become a standard tool, there is significant room for growth in the utilization of UAVs and AR. The findings conclude that there is a growing recognition of the value of DTs in optimizing project efficiency and monitoring environmental impact. In contrast, 'Immersive sustainable practices training using VR and AR' received a slightly lower rating. While this still indicates a positive perception, it may imply a need for further exploration and development of immersive training solutions to fully realize their potential in fostering sustainable behaviors and knowledge among construction professionals. As regards the prospects of the use of digital technology, the findings demonstrate a positive outlook on the integration of DTs into sustainable construction. The strong support for real-time tracking underscores the potential of DTs to revolutionize project management and decision-making. In terms of the challenges posed using digital technology, the data reveals a consensus among respondents that challenges related to data standardization and interoperability pose significant barriers to DT implementation in sustainable construction. Addressing these challenges will be essential for unlocking the full potential of DTs in driving positive environmental and economic outcomes. While concerns about job displacement exist, proactive measures should be implemented to mitigate these risks. This includes providing training and upskilling programs to equip workers with the necessary skills to adapt to the changing technological landscape. The overall findings imply that there is a need to introduce data science and technology as a core competency in civil engineering curricula.

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V. REFERENCES

- [1] Lu, W. et al. (2024). Digital technologies for construction sustainability: Status quo, challenges, and future prospects, *Materials Sustainability*, (2024) 2:10.
- [2] Pan, Y., and Zhang, L. (2024), Integrating BIM and AI for Smart Construction Management: Current Status and Future Directions. *Arch Computat Methods Eng* **30**, 1081–1110 (2023). <https://doi.org/10.1007/s11831-022-09830-8>
- [3] Muhammad Asif, Ghinwa Naeem, and Muhammad Khalid, (2024). Digitalization for sustainable buildings: Technologies, applications, potential, and challenges, *Journal of Cleaner Production*, Volume 450, 2024, <https://doi.org/10.1016/j.jclepro.2024.141814>.
- [4] Sargiotis, D., (2024). Integrating Digital Transformation and AI in Civil Engineering: A Multidisciplinary Approach to Disaster Management and Sustainable Urban Development.
- [5] Yue Pan, and Limao Zhang, (2021). Roles of artificial intelligence in construction engineering and management: A critical review and future trends, *Automation in Construction*, (2021) Volume 122 <https://doi.org/10.1016/j.autcon.2020.103517>.
- [6] F. D. Davis, “Perceived usefulness, perceived ease of use, and user acceptance of information technology,” *MIS Quarterly*, vol. 13, no. 3, pp. 319–340, Sep. 1989.
- [7] V. Venkatesh and F. D. Davis, “A theoretical extension of the technology acceptance model: Four longitudinal field studies,” *Management Science*, vol. 46, no. 2, pp. 186–204, Feb. 2000.
- [8] H. Li, J. Kong, and X. Pang, “Mobile technology in construction management: The state of the art and future directions,” *Automation in Construction*, vol. 93, pp. 241–251, Sep. 2018.
- [9] B. Sacks, C. Brilakis, and R. Pikas, “Construction with augmented reality: Towards adoption in the industry,” *Journal of Computing in Civil Engineering*, vol. 32, no. 1, pp. 04017075, Jan. 2018.
- [10] Y. Zhang, H. Deng, and X. Li, “Real-time construction performance monitoring using IoT and data analytics,” *Automation in Construction*, vol. 124, pp. 103558, Jul. 2021.
- [11] A. Ghaffarianhoseini, A. Tookey, N. Naismith, and M. Ghaffarianhoseini, “Building Information Modelling (BIM) uptake: Clear benefits, understanding its implementation, risks and challenges,” *Renewable and Sustainable Energy Reviews*, vol. 75, pp. 1046–1053, Aug. 2017.