Proceedings of the Creative Construction Conference (2025)
Edited by: Miroslaw J. Skibniewski & Miklós Hajdu & Žiga Turk
https://doi.org/10.22260/CCC2025/0048

FROM DIGITIZATION TO DIGITAL TRANSFORMATION IN INFRASTRUCTURE ASSET MANAGEMENT: CHALLENGES AND FUTURE DIRECTION

Seungwon Baek[1], **Hongjo Kim[1]**, Tae-Hyun Kyung[2], Min-Wung Kim[2], Jiju Ahn[1]
1 Yonsei University, Seoul, Republic of Korea
2 Korea Authority of Land & Infrastructure Safety, Jinju, Republic of Korea

Abstract

Effective public infrastructure asset management is essential for ensuring the safety, sustainability, and resilience of societal systems. As infrastructure systems age and grow in complexity, data-driven approaches have become increasingly vital in supporting informed decision-making and resource optimization. However, effective infrastructure asset management planning is hindered by numerous challenges, such as financial constraints, data deficiencies, and technological barriers. This study examines the digital transformation of infrastructure asset management in the Republic of Korea, focusing on the key barriers and future directions for improvement. In particular, this paper analyzes these issues with a specific focus on data acquisition and analysis problems, highlighting the gaps in data collection, processing, and usage in decision-making. The findings provide valuable lessons on improving data quality, addressing data silos, advancing real-time monitoring, and fostering analytical capabilities. This study concludes with actionable recommendations by identifying areas to advance infrastructure management practices, such as the importance of component-level data collection, centralized data platforms, standardized governance, and global collaboration. The results of this study contribute to the expanding body of knowledge on digital asset management and provide policymakers and practitioners with a roadmap for enhancing infrastructure resilience through data-driven strategies.

Keywords: infrastructure asset management, digitization, digitalization, digital transformation.

Peer-review under responsibility of the scientific committee of the Creative Construction Conference 2025.

1. Introduction

Public infrastructure assets, including roads, bridges, water systems, and energy grids, form the backbone of modern society. Effective management of these assets is crucial to ensure long-term functionality, safety, and economic efficiency [1]. Among the numerous challenges in efficient asset management, data acquisition and analysis represent critical bottlenecks that significantly impact decision-making processes [2,3]. The rise of digital technologies has profoundly impacted the way public infrastructure assets are monitored, maintained, and upgraded. Traditional asset management approaches often relied on manual inspections and periodic evaluations that could not capture nuanced real-time changes in infrastructure performance. These limitations resulted in maintenance backlogs, budget overruns, and suboptimal resource allocation. As data-driven approaches gain traction, infrastructure agencies face the challenge of transitioning from paper-based or fragmented digital records to a fully integrated system that leverages advanced analytics and predictive modelling [2,3]. However, this process is far from straightforward; it entails significant organizational changes, investments in technology, and the development of specialized expertise. To address these concerns, this paper examines key issues related to data-driven asset management planning and reviews research conducted to address these challenges. The primary objective of this study is to identify the critical problems associated with data acquisition and analysis in public infrastructure asset management and to explore research-driven solutions. This paper sheds light on the data-related challenges and solutions in public infrastructure asset management, emphasizing financial, technological, and governance aspects. The remainder of this paper is organized as follows. Section 2 provides a deeper exploration

Corresponding author email address: hongjo@yonsei.ac.kr

of the research background, highlighting the pivotal role of data in asset management. Section 3 details the critical challenges in data acquisition and analysis, discussing issues such as fragmentation and limited real-time monitoring. Section 4 presents a practical example of a smart infrastructure management system implemented in the Republic of Korea, illustrating real-world applications and insights. Section 5 synthesizes lessons learned and offers guidelines for promoting digital transformation, integrating data silos, collecting detailed component-level data, investing in real-time monitoring, and building analytical capabilities. Finally, Section 6 concludes with a summary of findings and suggestions for future research directions.

2. Research background

2.1. Importance of data in asset management

Effective infrastructure asset management relies on accurate and comprehensive data as its foundation. Reliable data collection enables decision-makers to gain clear insights into the current state and performance of infrastructure assets, allowing for well-informed planning and prioritization of maintenance activities [4]. Data-driven approaches streamline the allocation of funds and resources, ensuring that investments are directed to areas with the highest impact [5]. Furthermore, historical and real-time data play a crucial role in predicting potential asset failures, enabling proactive maintenance strategies that reduce costs and prevent disruptions [6]. Without high-quality data, efforts to manage infrastructure assets efficiently are severely hindered, leading to increased risks and inefficiencies in public infrastructure systems.

2.2. Challenges in data acquisition and analysis

The process of acquiring and analyzing data for public infrastructure asset management involves multiple challenges that affect its effectiveness. Fragmentation in data sources is a significant issue, as information is often dispersed across various systems that are not integrated, leading to inefficiencies in decision-making [7]. Additionally, the quality of data collected is frequently inconsistent due to manual collection methods and outdated systems, which introduce inaccuracies and reduce reliability [8]. The financial burden of implementing advanced data collection systems, such as IoT sensors, poses another obstacle, especially for budget-constrained organizations [9]. Furthermore, the sheer volume of data generated can overwhelm infrastructure agencies, particularly when they lack the tools and expertise required for effective analysis. Addressing these challenges is essential to unlocking the full potential of data-driven asset management strategies.

2.3. Digitization, digitalization, and digital transformation

The journey from digitization to digital transformation represents a critical evolution in public infrastructure asset management. Digitization refers to converting physical records into digital formats, which forms the foundation for more sophisticated data handling [10]. By digitizing asset inventories, agencies create centralized, accessible repositories of information. Digitalization involves leveraging digital tools to enhance existing processes [10]. This includes the use of sensors, drones, and Geographic Information Systems (GIS) for real-time data collection and monitoring, thereby improving decision-making and operational efficiency. Finally, digital transformation represents a holistic shift where digital technologies fundamentally reshape asset management strategies [10]. It integrates advanced analytics, machine learning, and predictive modeling into decision-making processes, enabling agencies to transition from reactive to proactive maintenance strategies. By analyzing the data produced by these interconnected systems, agencies can identify patterns of asset deterioration and develop targeted, cost-effective maintenance strategies that minimize service disruptions. In this environment, cross-departmental data sharing and stakeholder collaborations become increasingly feasible, promoting greater transparency and accountability throughout the asset life-cycle. While digital transformation holds immense potential, its successful implementation requires addressing barriers such as high costs, organizational inertia, and skill gaps.

3. Problem in data acquisition and analysis

3.1. Inconsistent and incomplete data collection

One of the fundamental issues in data acquisition is the lack of uniformity in data collection protocols [4,11]. Infrastructure management agencies often rely on different methodologies across regions or asset types, leading to variations in the quality and scope of the collected data. This inconsistency undermines the ability to create a unified maintenance strategy or perform comparative analysis across infrastructure networks [1]. For instance, while some regions may utilize advanced condition monitoring systems, others might still depend on manual inspections, resulting in incomplete and outdated datasets [12].

3.2. Limited real-time monitoring

Real-time monitoring is crucial for proactive maintenance, yet many agencies fail to implement it effectively due to the high initial costs and technical challenges [13]. Without real-time monitoring, infrastructure managers often rely on reactive maintenance strategies, addressing issues only after significant deterioration or failure [6]. For example, undetected structural stress in bridges or roads can lead to sudden collapses, endangering lives and increasing repair costs exponentially.

3.3. Data silos and fragmentation

The existence of data silos within and across agencies is a persistent issue. Different departments often maintain their datasets independently, using incompatible formats and systems [8,9]. This lack of integration hinders collaboration and reduces the efficiency of predictive models [1]. For instance, traffic data from urban planning departments might not be accessible to transportation agencies, resulting in missed opportunities for optimizing road maintenance schedules based on usage patterns.

3.4. Analytical skill gaps

The ability to derive actionable insights from data depends heavily on the analytical capabilities of the workforce. Many infrastructure agencies struggle with a shortage of trained data scientists and engineers who can effectively interpret complex datasets [14]. Additionally, the lack of advanced analytical tools compounds this problem, as agencies are unable to harness the full potential of machine learning or big data analytics [13].

3.5. Barriers to digital transformation

Digital transformation requires a comprehensive overhaul of existing workflows and systems, which presents significant challenges. High implementation costs deter many agencies, especially those with tight budgets [14]. Furthermore, resistance to change among employees can stall transformation initiatives. Legacy systems, often incompatible with modern digital tools, add complexity and require costly upgrades or replacements [15]. Organizations should also invest in upskilling their workforce to ensure that employees can effectively utilize new technologies [15].

4. Smart infrastructure management system in the Republic of Korea

The Ministry of Land, Infrastructure, and Transport (MOLIT) of the Republic of Korea launched the operation of the smart management system for national infrastructure, called “Giban-teo” (www.inframanage.go.kr) in 2024. This system aims to prevent safety accidents caused by aging infrastructure proactively. It manages about 480 thousand infrastructure assets based on the standardized life-cycle history information across 15 types of infrastructure, including roads, railways, ports, airports, water supply, electricity, gas, and telecommunications.

4.1. Data management

The system provides integrated data management, enabling management entities to systematically monitor facility information and take timely action. The system standardizes and integrates detailed information on facilities that are currently managed separately by various entities such as central government agencies, local governments, public institutions, and private investors. Through a comprehensive infrastructure survey, the MOLIT digitized life-cycle history data for each asset and built an initial database after validating the data and identifying errors. In order to ensure the continuous updating of standardized information, operating protocols for the system have been established, which require management entities to enter standardized information directly into the system. In addition, the system integrates with five existing infrastructure-related systems through an Application Programming Interface (API) for database updates.

4.2. Life-cycle performance and cost analysis

The system also enables life-cycle performance and cost analysis of assets to derive optimal maintenance strategies (Fig. 1). In the Republic of Korea, performance evaluations are conducted by type of infrastructure according to the Act on Safety Control and Maintenance of Establishments. The individual performance scores of the facilities, which vary according to the management and supervisory authorities, are converted into standardized grades according to predefined rules. The system then performs data-driven assessments of performance degradation and improvement by analyzing data from facilities similar to the target facility and using this sample data to identify trends. Meanwhile, the life-cycle cost consists of planning, design, construction, maintenance, rehabilitation, and demolition costs. The costs already incurred are calculated using historical data, while future maintenance and reinforcement costs are estimated by analyzing historical data from similar facilities. Afterward, the system automatically generates current and optimal maintenance scenarios to support decision-making for individual assets. Based on the construction completion date of each facility, it analyzes performance changes and compares factors such as timing, cost, and performance improvements for different strategies. It then selects the strategy that provides the greatest life extension relative to cost.

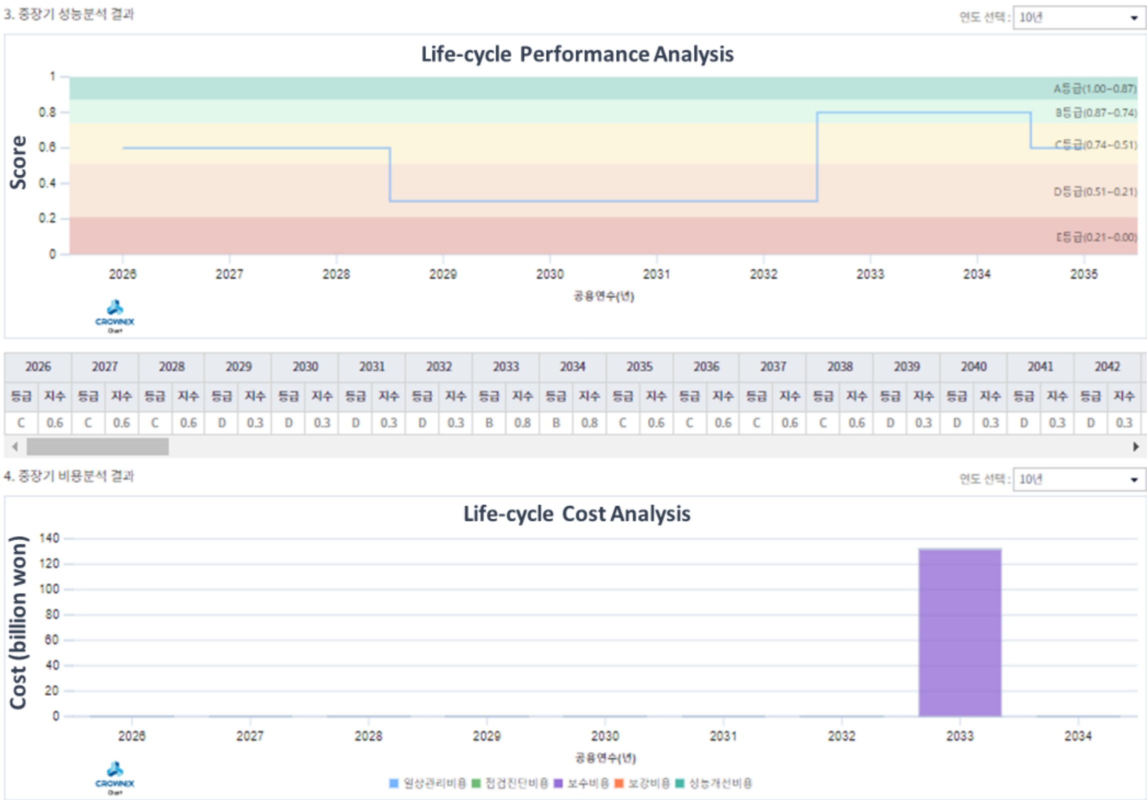

Fig. 1. Example of life-cycle performance and cost analysis.

5. Lessons learned for future improvements

Fig. 2 shows the digital-technology-enhanced infrastructure asset management framework for future improvements. This paper presents key challenges and future directions in digital transformation of infrastructure asset management, providing a detailed explanation of how these approaches address current challenges and align with the proposed framework.

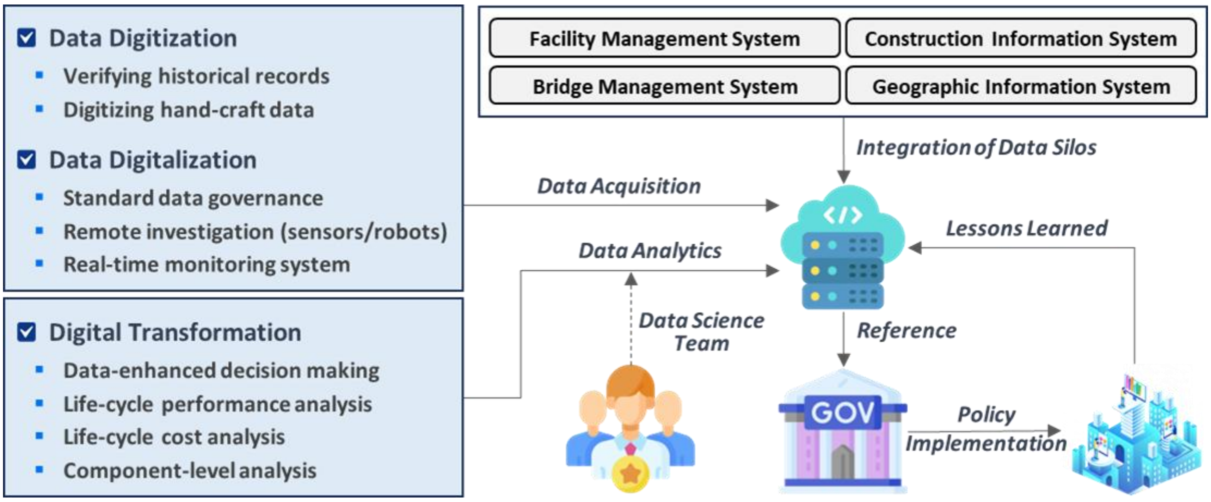

Fig. 2. Digital technology-enhanced infrastructure asset management framework.

5.1. Promoting digital transformation

The current system has adopted standardized protocols to ensure consistency in data acquisition across management entities and asset types, as mentioned above. For improvement, leveraging automated tools for the data collection and validation process is essential to ensure the rigor and reliability of analyses by minimizing human error. A phased approach to digital transformation is recommended, progressing toward full-scale implementation of advanced analytics and AI tools. Agencies should develop a roadmap that outlines key milestones, resource requirements, and expected outcomes. Data governance and collection protocols should be revisited and updated periodically to accommodate emerging technologies and methodologies. In addition, machine learning and AI tools should be integrated into asset management workflows to enable data-driven decision-making. Agencies should focus on building high-quality datasets and ensuring that predictive models are regularly validated and updated. These tools can help optimize resource allocation and extend the lifespan of infrastructure assets. Collaboration with private sector technology providers can help reduce costs and accelerate adoption.

5.2. Integration of data silos

The Republic of Korea's current facilities management systems are fragmented across various management entities and supervision organizations, highlighting the need for integrated management through improved linkages between individual systems. To address the issue of fragmented data, agencies should invest in centralized, cloud-based platforms that enable interoperability and real-time data sharing. Although the current system has data pipelines with five related systems, future improvements should focus on diversifying data sources. The future system should be designed with robust cybersecurity measures to ensure data privacy and protection.

5.3. Component-level historical data of facilities

Repairs, reinforcements, and performance improvements for facilities are made at the component level. However, the current system only accumulates performance grade information at the facility level. As a result, after repair, reinforcements, or performance improvement work, the system doesn't take account into the deterioration level of other components and applies an assumed rate of deterioration acceleration in life expectancy projections. Moreover, the system classifies asset conditions into five levels, but most assets are concentrated on the C or D level, which reduces the differentiation between standard indices. Therefore, it is necessary to refine asset-level information by collecting and managing data at the component level to achieve accurate and reliable performance and cost predictions.

5.4. Investment in real-time monitoring

Currently, facility condition assessments are conducted periodically as required by law, and real-time condition assessments are not conducted. Expanding the use of IoT sensors and other real-time monitoring technologies with the digital twin can significantly improve the ability to proactively identify and address problems. Governments should establish pilot programs to evaluate the cost effectiveness and scalability of such technologies before broader implementation. Additionally, integrating real-time monitoring data with predictive models can provide actionable insights for prioritizing maintenance tasks.

5.5. Building analytical capabilities

Agencies should establish dedicated data science teams and invest in ongoing training programs to improve analytical skills. Collaborations with universities and professional organizations can provide access to cutting-edge research and training materials. Providing clear career paths and incentives can help retain skilled professionals in government. In addition, establishing a separate organization focused on public infrastructure analytics can foster innovation and serve as hubs for knowledge sharing. Such initiatives can foster cross-disciplinary collaboration, combining expertise in engineering, data science, and public policy to address complex infrastructure challenges.

5.6. Fostering global collaboration

International collaboration can play a critical role in advancing data-driven infrastructure management. Agencies should participate in global forums and partnerships to share best practices and access funding opportunities. Collaborative frameworks such as joint working groups or regional alliances can streamline knowledge sharing and enable the co-creation of innovative tools. Joint research initiatives can help address common challenges and develop scalable solutions, while promoting mutual learning through shared case studies and pilot projects. Promoting cross-border data sharing agreements can further enhance the collective capacity to address large-scale infrastructure challenges. Joint research initiatives can help address common challenges and develop scalable solutions.

Table 1. Challenges and future directions in digital transformation of infrastructure asset management.

Challenge	Description	Future direction	Expected result
Inconsistent & incomplete data	- Lack of uniform data collection - Variable quality across agencies - Limited component	- Standardize data protocols - Utilize automated data collection tools - Adopt component-level data tracking	- Improved data reliability - Better performance assessments - More accurate cost forecasting
Data silos & Fragmentation	- Information scattered in incompatible formats - Limited cross-departmental data sharing	- Centralization via cloud-based platforms - Adopt standardized APIs and data models - Ensure robust cybersecurity	- Enhanced interoperability - Real-time asset data sharing - Optimized resource allocation
Limited real-time monitoring	- Data managed at facility level - Poor investment in automated asset monitoring system - Reliance on reactive maintenance	- Collect component-level performance data - Utilize IoT sensors and digital twins for facility monitoring - Integrate real-time data into predictive models	- Improved accuracy in life prediction - Early fault detection & Proactive maintenance - Reduced service disruptions
Analytical skill gaps	- Shortage of data scientists and engineers - Limited use of advanced analytics	- Establish data science teams - Implement the talent development program	- Stronger analytics capabilities - Data-driven decision-making
Limited global collaboration	- Restricted cross-border data sharing - Few joint research initiatives	- Cross-border data sharing agreements - Conduct international pilot projects	- Global information & knowledge transfer - Access to global best practices

6. Conclusion

Data acquisition, digitalization, and digital transformation are critical to effective public infrastructure asset management. However, challenges such as inconsistent data collection, fragmented systems, and limited analytical capabilities hinder the potential of these strategies. By adopting standardized protocols, investing in real-time monitoring, and leveraging advanced technologies, governments can overcome these challenges and enhance the efficiency of infrastructure asset management. Future research should focus on developing scalable solutions to fully integrate data silos, apply emerging technologies, and build organizational capacity for digital transformation.

Acknowledgements

This work was supported by a National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIT) (No. RS-2024-00393515).

References

[1] Y. Yang, S. T. Ng, F. J. Xu, and M. Skitmore, “Towards sustainable and resilient high density cities through better integration of infrastructure networks,” Sustainable Cities and Society, vol. 42, pp. 407–422, Oct. 2018, doi: 10.1016/j.scs.2018.07.013.

[2] B. Laishram and R. Sood, “Challenges in Implementation of 7D-BIM for Infrastructure Asset Management: A Systematic Review,” Construction Economics and Building, vol. 24, no. 3, Jun. 2024, doi: 10.5130/ajceb.v24i3.8738.

[3] A. Prakash and S. Ambekar, “Digital transformation using blockchain technology in the construction industry,” Journal of Information Technology Case and Application Research, vol. 22, no. 4, pp. 256–278, Oct. 2020, doi: 10.1080/15228053.2021.1880245.

[4] W. Beitelmal, K. R. Molenaar, A. Javernick-Will, and E. Pellicer, “Challenges and barriers to establishing infrastructure asset management,” Engineering, Construction and Architectural Management, vol. 24, no. 6, pp. 1184–1202, Nov. 2017, doi: 10.1108/ecam-12-2015-0200.

[5] A. K. W. Chong, A. H. Mohammed, M. N. Abdullah, and M. S. A. Rahman, “Maintenance prioritization – a review on factors and methods,” Journal of Facilities Management, vol. 17, no. 1, pp. 18–39, Feb. 2019, doi: 10.1108/jfm-11-2017-0058.

[6] M. Uhm, G. Shin, H. Kim, H. D. Jeong, and H. Kim, “Exploring the Long-Term Impact of Preventive Road Treatments on Municipal Highways,” Journal of Management in Engineering, vol. 40, no. 4, Jul. 2024, doi: 10.1061/jmenea.meeng-5885.

[7] S. Abu-Samra, M. Ahmed, and L. Amador, “Asset Management Framework for Integrated Municipal Infrastructure,” Journal of Infrastructure Systems, vol. 26, no. 4, Dec. 2020, doi: 10.1061/(asce)is.1943-555x.0000580.

[8] S. Daulat, M. M. Rokstad, A. Klein-Paste, J. Langeveld, and F. Tscheikner-Gratl, “Challenges of integrated multi-infrastructure asset management: a review of pavement, sewer, and water distribution networks,” Structure and Infrastructure Engineering, vol. 20, no. 4, pp. 546–565, Sep. 2022, doi: 10.1080/15732479.2022.2119480.

[9] S. Park, S. I. Park, and S.-H. Lee, “Strategy on sustainable infrastructure asset management: Focus on Korea′s future policy directivity,” Renewable and Sustainable Energy Reviews, vol. 62, pp. 710–722, Sep. 2016, doi: 10.1016/j.rser.2016.04.073.

[10] J. Vrana and R. Singh, “Digitization, Digitalization, and Digital Transformation,” Handbook of Nondestructive Evaluation 4.0, pp. 1–17, 2021, doi: 10.1007/978-3-030-48200-8_39-1.

[11] A. Bosch, L. Volker, and A. Koutamanis, “BIM in the operations stage: bottlenecks and implications for owners,” Built Environment Project and Asset Management, vol. 5, no. 3, pp. 331–343, Jul. 2015, doi: 10.1108/bepam-03-2014-0017.

[12] F. Cevallos, “State of Good Repair Performance Measures: Assessing Asset Condition, Age, and Performance Data,” University of South Florida, Jun. 2016. doi: 10.5038/cutr-nctr-rr-2016-09.

[13] A. E. Aktan, I. Bartoli, and S. G. Karaman, “Technology Leveraging for Infrastructure Asset Management: Challenges and Opportunities,” Frontiers in Built Environment, vol. 5, May 2019, doi: 10.3389/fbuil.2019.00061.

[14] J. Koeleman, M. J. Ribeirinho, D. Rockhill, E. Sjödin, and G. Strube, “Decoding Digital Transformation in Construction,” Capital Projects & Infrastructure Practice, 2019.

[15] Z. Irani, R. M. Abril, V. Weerakkody, A. Omar, and U. Sivarajah, “The impact of legacy systems on digital transformation in European public administration: Lesson learned from a multi case analysis,” Government Information Quarterly, vol. 40, no. 1, p. 101784, Jan. 2023, doi: 10.1016/j.giq.2022.101784.