INTI

eISSN 2830-795X

Digital Twins for Sustainable Infrastructure Management at Various Organizational Scales

Rafadi Khan Khayru

Universitas Islam Negeri Maulana Malik Ibrahim Malang

Email: rafadi.khankhayru@gmail.com

ABSTRACT–This study discusses the application of digital twin technology in sustainable infrastructure management, reviewing the dimensions of management, human resources, MSMEs, and entrepreneurship. A digital twin is defined as a digital representation of a physical asset that enables condition monitoring, scenario simulation, and data-driven decision-making throughout the infrastructure lifecycle. The method used is a qualitative literature study with thematic synthesis of publications from the last two decades related to digital twins, asset management, sustainability, organisational capabilities, and digital entrepreneurship. The results show that the benefits of digital twins for sustainability are highly dependent on specific organisational capabilities. Key capabilities include the dynamic capability to recognise opportunities and reallocate resources, the capability to govern information technology and data, the human resource capability that combines technical and analytical expertise, and the entrepreneurial capability that drives the exploration of new business models. In large companies, digital twins are most effective when integrated with asset planning, risk management, and sustainability reporting processes. For SMEs and entrepreneurs, opportunities arise in the development of specialised services in specific parts of the digital twin value chain, provided they are able to leverage networks and learn from collaborative projects.

Keywords: digital twin, sustainable infrastructure, asset management, dynamic capabilities, data governance, SMEs, entrepreneurship.

A. INTRODUCTION

Technological changes in the last two decades have driven the transformation of how organizations plan, manage, and maintain infrastructure. Governments, large companies, and small businesses are increasingly faced with demands to provide reliable, secure, and sustainable infrastructure services, while controlling investment and operational costs. This human resource development must be viewed as an integral part of the organisation's sustainability strategy, where digital innovation not only transforms operations but also acts as a catalyst for building human capabilities that can support long-term economic, social and environmental goals (Mardikaningsih & Wardoyo, 2024). To meet these demands, improving human resource competencies in utilising digital technology has become a priority, with government policy playing a crucial role in creating a training ecosystem and relevant skill standards (Rojak, 2024). Amid environmental regulatory pressures, stakeholder demands for transparency, and global economic uncertainty, the need for accurate, up-to-date, and actionable information has become increasingly urgent. In this context, physical infrastructure, previously viewed as a tangible asset with a linear life cycle, is now understood as a dynamic socio-technical system that requires continuous monitoring and data-driven decision-making across management, operations, and finance functions.

At the same time, the adoption of sensors, the Internet of Things, and asset management information systems generates enormous volumes of data (Petrakis et al., 2018; Brous et al., 2019). Without a structured modeling framework, however, this data is often scattered across various applications, poorly connected, and difficult to utilize for long-term planning. Digital twins have emerged as an approach that offers a living digital representation of physical assets or systems, with the ability to mimic actual behavior, simulate scenarios, and predict the consequences of decisions. In infrastructure management, this digital representation opens up new opportunities in asset condition monitoring, predictive maintenance scheduling, and investment option evaluation that takes into account technical performance, life cycle

costs, and environmental impact in an integrated manner.

For management disciplines, the development of digital twins raises new questions about how organizations design structures, processes, and work cultures to leverage the potential of this technology. This challenge is in line with broader discussions on how digitalisation necessitates a re-evaluation of deeply rooted social practices and organisational values in order to achieve effective integration (Al Hakim, et al., 2021). The implementation of digital twins is not merely a technical issue, but is related to the arrangement of stakeholder roles, data governance, decision-making models, and human resource competency development. This transformation encompasses the field of managerial accounting, where digitalisation including data from digital twins can revolutionise the foundations of decision-making by integrating behavioural and operational data in real time (Gardi & Ali, 2025). This competency development must be twofold, encompassing both the advanced technical skills to operate digital systems and the critical social competencies such as collaboration across digital platforms and adaptive problem-solving required for teamwork in digitally mediated environments (Mendonca, et al., 2021). In companies that manage infrastructure, the functions of asset management, finance, operations, and sustainability need to move in harmony so that the use of digital twins does not end up as an isolated technology project, but is integrated with the organization's performance goals.

Beyond internal organisational challenges, the adoption of digital twins in infrastructure also intersects with broader socio-cultural dynamics. The implementation of advanced digital technology in public asset management can raise questions about how local values and cultural identities can be preserved or marginalised in the tide of global modernisation. Digital technology, including digital twins, has an ambivalent role it can be a tool for homogenisation that reinforces global standards, while also serving as a medium for documenting and preserving local distinctiveness (Zulkarnain, 2024).

For SMEs and entrepreneurs operating in the infrastructure value chain, such as specialist contractors, maintenance service providers, or digital solution developers, digital twins open up new business opportunities, but at the same time require managerial readiness. They are faced with the need to understand digital service-based business models, manage partnerships with large asset owners, and develop internal analytical capabilities. The development of these capabilities is part of a broader transformation, in which digitalisation as seen in the manufacturing sector is fundamentally reshaping task architecture, required skills, and work organisation (Triono et al., 2025). The research on digital twins in sustainable infrastructure management is therefore relevant for bridging the fields of technology, management, and entrepreneurship, especially when organizations seek to balance economic goals with environmental and social responsibilities.

Although digital twins are increasingly discussed in industrial and infrastructure technology discourse, many organizations still struggle to translate the concept into operational managerial practices. There is a considerable gap between the marketing narratives of technology providers that highlight advanced simulation capabilities and the actual ability of organizations to collect quality data, develop relevant models, and use them routinely in decision-making processes. Within infrastructure management companies, it is not uncommon for digital twin projects to stop at the technically impressive pilot stage, without being embedded in work procedures and performance indicators recognized by top management and operational units.

Another issue relates to how digital twins can contribute directly to sustainability goals. Many digital twin designs and implementations focus on technical reliability and cost savings, while environmental and social dimensions are not yet fully incorporated into the model structure or success metrics. Reducing emissions, energy consumption, water usage, or community impact are often considered additional variables rather than core components of decision-making architecture. As a result, opportunities to use digital twins as systematic sustainability management tools have not been fully explored, especially in infrastructure with a large environmental footprint such as transportation, energy, and public facilities.

At the SME and entrepreneurship level, the obstacles are increasingly complex. Many businesses with the potential to become digital twin solution providers or data-based maintenance partners do not yet have adequate

managerial capacity and human resources. Limited understanding of long-term service-based revenue models, contractual risk management, and the need for initial investment in software and employee training raises doubts about involvement in the digital twin ecosystem. On the part of medium-scale asset owners, difficulties in assessing long-term benefits, measuring the impact on environmental performance, and aligning digital twin projects with business priorities make investment decisions uncertain.

Developments in environmental regulations, sustainability reporting standards, and market expectations for infrastructure performance transparency require organizations to adopt a management approach that is resilient to uncertainty and based on proven information. In the context of the digital age, where the credibility of information and public opinion is highly dynamic and influenced by digital media, the reliability and communication capabilities of data sources are crucial (Zulkarnain & Al Hakim, 2023). Digital twins occupy an interesting position because they combine technical modeling, data analytics, and policy scenarios in a single interactive virtual environment. When designed with sustainability goals in mind, this technology has the potential to help organizations evaluate trade-offs between cost, service quality, and environmental impact before decisions are made in the real world. The scientific research on how digital twins used in sustainable infrastructure management is therefore relevant to enriching academic debate in the fields of management, entrepreneurship, and human resources.

The dynamics of the innovation ecosystem mean that digital twins are no longer the exclusive domain of large companies. The emergence of cloud-based solution providers, open platforms, and collaborative working models has created opportunities for SMEs and entrepreneurs to act as innovators, integrators, or analytics service providers. These opportunities, however, do not automatically materialize without an understanding of the managerial implications, organizational capability development, and talent management that are appropriate to digital needs. Research examining digital twins from a management and entrepreneurship perspective, with a focus on infrastructure sustainability, can help explain the prerequisites for success, implementation challenges, and realistic added value potential for various types of organizations.

This research aims to explain the use of digital twins in sustainable infrastructure management by examining managerial, human resource, SME, and entrepreneurship dimensions, as well as identifying organizational capabilities that support its successful implementation. Theoretically, this research is expected to enrich the management and entrepreneurship literature on advanced digital technologies in infrastructure management with a sustainability orientation. Practically, the results of this research are expected to provide insights that can be used by decision makers in infrastructure management companies and supporting businesses to design digital twin initiatives that are more focused, realistic, and aligned with sustainability goals.

B. METHOD

This research uses a qualitative literature study approach with a focus on scientific works on digital twins, sustainable infrastructure management, management, SMEs, and entrepreneurship. The general procedures for the literature study follow the guidelines for preparing structured reviews that emphasize the formulation of clear research questions, transparency of selection criteria, and systematic reporting of the process so that the findings can be traced and replicated (Snyder, 2019). The main stages include: determining the focus of the study based on the problem formulation, compiling main keywords and derivative keywords, selecting scientific databases, and determining the limits of publication year, document type, and language. Using this approach, the literature on digital twins in infrastructure management and sustainability-related management research was filtered to produce a collection of articles relevant to the research objectives, including works that examine organizational readiness and human resource capabilities.

The search strategy was conducted using reputable journal databases such as Scopus, Web of Science, and ScienceDirect, with keywords combining the terms “digital twin,” “sustainable infrastructure,” “asset management,” “SMEs,” “entrepreneurship,” “human resource management,” and “organizational capabilities.” The publication year range was set between 2005 and 2024 to align with the latest developments in digital

twins and modern management methodologies. Inclusion criteria included journal articles and academic book chapters discussing digital twins or similar technologies in infrastructure management, research on infrastructure sustainability with managerial relevance, and publications reviewing methods for developing organizational capabilities and human resources for digital technology adoption. Exclusion criteria include publications that are purely technical-computational without a managerial dimension, non-peer-reviewed reports, and articles that do not provide a clear methodological description. This procedure is in line with the principles of planned literature reviews that emphasize the use of explicit and consistent selection criteria (Snyder, 2019; Booth et al., 2016).

Articles that passed the selection process were analyzed using a thematic synthesis approach. The analysis process followed the coding steps suggested by Braun and Clarke (2006), starting with repeated readings to understand the main focus of each publication, followed by initial coding of meaning units related to the use of digital twins, infrastructure management strategies, organizational capability development, SME involvement, and sustainability implications. The initial codes were then grouped into intermediate themes, such as themes related to data governance, decision making, digital service business models, and the role of employee competencies. The next stage was a review of the themes to ensure internal coherence and differences between themes, accompanied by recording examples of quotations and key arguments from each source. Quality assurance was carried out through documentation of the audit trail of decisions during the selection and coding process, examination of the consistency of inclusion-exclusion criteria, and triangulation of concepts by comparing findings from various disciplines such as engineering, management, and entrepreneurship studies. This analytical framework allows for the structured integration of empirical and conceptual findings into two main sub-discussions of the study (Braun & Clarke, 2006; Booth et al., 2016; Snyder, 2019).

C. RESULTS AND DISCUSSION

Utilization of Digital Twins in Sustainable Infrastructure Management

The use of digital twins in sustainable infrastructure management can be understood as an organization's effort to build the ability to sense and reason about asset conditions on an ongoing basis through constantly updated digital models. Within the framework of strategic management, technologies such as digital twins can be viewed as part of a mechanism to improve an organization's ability to sense environmental changes, respond to opportunities, and reconfigure resources repeatedly (Teece, 2007). Digital twins provide a stream of operational data that can be reinterpreted as managerial information, for example, about component wear patterns, energy consumption, and variations in service loads over time. When this information is used consistently in planning and performance review meetings, digital twins serve as a medium for strengthening the organization's ability to learn from actual experiences, rather than just from static projections. Sustainable infrastructure management through digital twins is therefore closely related to an organization's ability to establish data-driven decision-making routines that can be updated over time (Teece, 2007; Snyder, 2019).

In traditional physical asset management, the decision-making cycle often relies on periodic inspections, separate technical reports, and average assumptions about service life. This approach tends to produce a fragmented view that is less sensitive to significant local variations, such as variations in road traffic loads, building usage, or energy consumption patterns in distribution networks. Digital twins introduce a new way of viewing infrastructure as a dynamic system that must be continuously monitored through sensor data and other data sources. The integration of this technology into sustainable infrastructure management, however, requires organizations to develop procedures for collecting, cleaning, and interpreting data that meet certain quality standards so that model outputs are reliable. A structured literature review approach helps identify thematic patterns regarding how organizations develop these procedures and how they link them to measurable sustainability goals (Snyder, 2019). In this framework, digital twins do not stand alone but must be placed within a consistent information management system, with clear accountability regarding data owners and data users.

The sustainability aspect in the use of digital twins is a key point that distinguishes them from mere technical efficiency projects. Sustainability-oriented infrastructure management means that

decisions regarding design, operation, and maintenance must consider the long-term impact on resource use, emissions, and public service quality. Digital twins can simulate alternative scenarios, such as changes in maintenance schedules, material replacements, or adjustments to operating patterns, allowing managers to evaluate the consequences of their choices before implementing them on physical assets. From a strategic management perspective, this ability to perform planned simulations is related to the functions of sensing and formulating adaptation options, which are part of an organization's dynamic capabilities (Teece, 2007). For the simulations to be a valid basis for decisions, however, organizations need to establish well-documented data governance and interpretation processes, which in qualitative literature studies can be examined through themes such as model transparency, stakeholder engagement, and performance measurement based on sustainability indicators (Braun & Clarke, 2006; Snyder, 2019).

From a human resources perspective, the use of digital twins requires a different set of competencies than more conventional infrastructure management approaches. Employee management does not stop at technical field expertise, but also includes the ability to read data visualizations, understand the associations between technical parameters and managerial consequences, and work across functions. The strategic human resource management literature suggests that developing this combination of technical and analytical skills can be a source of competitive advantage when organizations are able to link it to business objectives and manage it consistently (Delery & Roumpi, 2017). In a digital twin environment, technicians, data analysts, and asset managers need to collaborate in interpreting the signals generated by the model. Research examining training patterns, on-the-job learning, and knowledge-sharing mechanisms will help explain how organizations transform individual skill sets into collective capabilities to leverage digital twins in decision-making (Braun & Clarke, 2006; Delery & Roumpi, 2017).

For SMEs operating in the infrastructure value chain, the use of digital twins can be a means of service differentiation as well as a tool for strengthening long-term relationships with asset owners. Maintenance service providers, for example, can design performance-based service offerings where payments are linked to specific indicators such as asset availability, service stability, or reduced energy consumption. For this model to be economically viable, service providers need to manage technical uncertainty through more precise monitoring and the ability to anticipate disruptions before they occur, something that is facilitated by real-time data-based digital twins. Methodological literacy on how to assess evidence from various sources, group failure patterns, and formulate operational risk themes enables SMEs to develop stronger business arguments when discussing with clients (Braun & Clarke, 2006; Snyder, 2019). Digital twins thus serve not only as technical tools, but also as information infrastructure that supports the shift to performance-based service models that are more aligned with sustainability principles.

Entrepreneurship in the field of digital infrastructure and digital twin-related services also requires an understanding of how the necessary organizational capabilities can be developed gradually. Entrepreneurs working in this area face the need to combine technical understanding of data modeling and integration with the ability to read the needs of asset owners and regulators. This understanding must include regulatory aspects, given that start-ups developing platform-based service models need to navigate the legal implications related to data protection, consumers, and business competition to ensure their business sustainability (Marsal & Hardyansah, 2025).

The dynamic capabilities perspective provides a framework for examining how startups identify opportunities, develop digital twin-based service prototypes, and then modify their internal structures as their business models begin to evolve (Teece, 2007). In the literature review, this can be analyzed through themes such as knowledge management, strategic alliances, and learning from repeated pilot projects (Braun & Clarke, 2006; Snyder, 2019). In this way, digital twins are not merely objects of technological innovation, but also an entrepreneurial context that demands the formation of new working patterns between developers, clients, and public stakeholders.

At the level of large infrastructure management organizations, digital twins need to be placed within the framework of asset and project portfolio management. Decision-making regarding investment allocation, repair priorities, and the sequence of new infrastructure

development is highly dependent on a comprehensive understanding of the condition and capacity of existing systems. Digital twins can facilitate the consolidation of information that was previously scattered across various departments into a single representation that can be analyzed in an integrated manner. The ability to utilize this representation, however, requires structured review procedures and collective mechanisms for interpreting simulation results. Literature studies utilizing a thematic synthesis approach can identify patterns of how organizations organize cross-functional decision-making forums, how they document model assumptions, and how sustainability indicators are integrated into investment discussions (Braun & Clarke, 2006; Snyder, 2019). This process reflects how digital twins can contribute to the formation of organizational routines that are more reflective of both technical and sustainability dimensions (Teece, 2007).

In risk management and infrastructure resilience, digital twins offer a means to explore possible disruption scenarios and responses without having to bear the immediate consequences in the field. For example, operators can simulate the impact of flooding, energy supply disruptions, or extreme demand spikes on transportation networks, then assess the most reasonable combination of mitigation measures. This capability is a manifestation of broader digital transformation, where technologies such as big data and IoT are utilised to optimise decision-making in complex systems, including supply chains and infrastructure logistics (Putra & Arifin, 2021). From a management perspective, this capability relates to the development of anticipatory procedures that rely on data and models, rather than solely on historical experience. The dynamic capability framework emphasizes the importance of iterative learning from structured experimentation as the basis for forming organizational habits in dealing with uncertainty (Teece, 2007). By utilizing a systematic literature review approach, researchers can group practices that emerge across various sectors, identify common themes regarding how organizations develop digital model-based risk governance, and assess the extent to which these practices are linked to sustainability goals, such as reducing the impact of disasters on vulnerable groups or protecting key ecosystems (Braun & Clarke, 2006; Snyder, 2019).

The interaction between digital twins and sustainability performance reporting systems is also worth noting. When companies are required to compile sustainability reports with measurable indicators, the availability of data generated by digital twins can improve the quality of reporting, both in terms of update frequency and spatial and temporal detail. The utilization of this data, however, depends on human resource management procedures that promote accurate recording, an understanding of data ethics, and the ability to communicate analysis results to non-technical stakeholders. The strategic human resource management literature asserts that when organizations link HR practices, such as recruitment, training, and performance appraisal, to specific strategic objectives, these practices are more likely to have a real impact on competitive advantage (Delery & Roumpi, 2017). The digital twin's effectiveness in sustainability reporting depends on organizations explicitly defining employee roles and accountability for data quality and utilization, and incorporating analytical competencies into performance metrics (Delery & Roumpi, 2017; Snyder, 2019).

At the daily operational level, digital twins can help bridge the gap between field managers and managers operating at headquarters by providing easy-to-understand images and simulations. This application, however, requires a communication structure that recognizes that data interpretation is always tied to different work experiences and professional languages. A thematic analysis approach in the literature review shows that many organizations that have successfully utilized digital technology are those that consciously build routine cross-functional dialogue practices, so that data does not stop at being a display on a screen, but becomes a starting point for conversations about necessary actions (Braun & Clarke, 2006; Snyder, 2019). In this framework, digital twins help unify shared references regarding asset conditions, while an organization's capacity to discuss, negotiate, and interpret operational meaning becomes a determining factor in whether the technology truly contributes to sustainable infrastructure management.

From a broader management perspective, the use of digital twins in sustainable infrastructure management can be understood as a long-term journey, rather than a momentary intervention. Organizations need to move from the technical experimentation stage to a stage where digital models become part of their daily operations. In

the early stages, the focus may lie on proving the benefits through limited pilot projects. Long-term success, however, depends on the organization's ability to adapt its work structures, reporting patterns, and decision-making mechanisms so that information from digital twins flows naturally to key decision points. This fundamental transformation process requires leadership that is actively digitally oriented, which not only adopts technology but also fosters operational efficiency, team collaboration, and the culture of innovation necessary to integrate new technology into the DNA of the organisation (Darmawan & Gardi, 2024). In this journey, organizational leaders act as narrators who explain why investing in data, employee training, and technology upgrades is relevant to collectively recognized sustainability goals. Without a convincing narrative, digital twins can easily be perceived as technology projects that are far removed from practical concerns, especially by field implementers working under time and resource constraints.

At the ecosystem level, the use of digital twins in sustainable infrastructure invites new forms of collaboration between governments, companies, SMEs, and digital entrepreneurial entities. Digital representations of infrastructure can become a collaborative medium for sharing data, testing policies, and designing innovative service schemes that span across organizations. However, the promise of this collaboration is contingent upon equitable digital access. A significant digital divide can exclude certain stakeholders, especially smaller entities or community representatives, from meaningful participation, thereby undermining the legitimacy and comprehensiveness of the ecosystem (Issalillah & Hardyansah, 2022). This raises questions about data ownership, benefit sharing, and responsibility in the event of prediction errors or operational incidents.

The management of such collaborative risks is intrinsically linked to corporate reputation, as operational failures or perceived unfairness in data governance can rapidly escalate into public trust issues in the digital space, where information spreads quickly and is difficult to control (Darmawan, et al., 2022). These challenges show that managing sustainable infrastructure based on digital twins is not merely a technical and organizational issue, but is related to fair and transparent governance design. For SMEs and entrepreneurs, opportunities are open to participate in this ecosystem through specific expertise, modular solutions, or supporting services. Sustainable participation, however, requires the ability to read long-term dynamics, manage contractual risks, and continuously adapt internal competencies to technological developments and client preferences.

Organizational Capabilities for Successful Digital Twin Implementation

An organization's capability to implement digital twins in sustainable infrastructure management stems from the idea that technology alone is not enough; what matters is the company's ability to repeatedly reconfigure its resources to adapt to environmental demands and new opportunities. The literature on dynamic capabilities explains that organizations that successfully adopt new technologies usually have the ability to sense opportunities, capture value, and continuously transform their resource base (Teece, 2007; Pavlou & El Sawy, 2011). In this framework, digital twins are seen as triggers for restructuring business processes, role allocation, and patterns of interaction between units. This profound transformation in interaction patterns, triggered by literacy-based digitalisation, is reflected in tangible changes in working relationships and management-employee dynamics within organisations (Darmawan et al., 2023).

The capability to sense becomes important when management is able to identify areas of infrastructure that benefit most from digital modeling, while the capability to capture value is related to the ability to design cost-benefit models that are acceptable to internal stakeholders. At the same time, transformation capabilities determine whether an organization is able to change work procedures, data flows, and reporting mechanisms so that digital twins do not remain experimental projects but are embedded in managerial routines (Teece, 2007; Easterby Smith & Prieto, 2008; Pavlou & El Sawy, 2011).

Information technology capabilities are a critical foundation for the success of digital twins. Research on IT capabilities emphasizes that a combination of reliable IT infrastructure, human capabilities in the field of IT, and strong relationships between IT and business functions creates the basis for strategic use of technology (Fink & Neumann, 2009). Building these relationships requires an understanding

of the dynamics of social interaction in a digital context, as cross-functional collaboration is greatly influenced by the technology used for communication and knowledge management (Oluwatoyin, 2021).

In the application of digital twins, this is reflected in the organization's ability to integrate data from field sensors, asset management systems, and business applications into a coherent architecture. It requires data architecture design capabilities that enable interoperability and scalability, as well as security and privacy management. As digital twins often integrate sensitive operational and potentially personal data, establishing a robust cybersecurity framework and a shared organizational culture of data protection becomes a non-negotiable aspect of IT capability, demanding global best practices and collaboration (Gardi & Eddine, 2023). When the IT function has a partnership with business units, the design of digital twins tends to be more aligned with the needs of decision makers, not just the technical preferences of developers. Mature IT capabilities therefore go beyond hardware and software to include the ability to build a shared understanding of how digital twins support sustainability goals and infrastructure performance (Fink & Neumann, 2009; Bharadwaj et al., 2013). This process of constructing shared understanding can be viewed as a form of collective identity formation within the organization, where continuous interaction and negotiation around digital tools and data much like interactions on social platforms shape the social perceptions and aligned goals of different business units (Costa et al., 2022).

Beyond IT capabilities, data governance is a key element that determines the quality of digital twin results. The literature on data governance highlights the importance of defining the roles of data owners, data managers, and decision-making mechanisms regarding data quality standards and usage within an organization (Khatri & Brown, 2010). In digital twin projects, data comes from various sources with different formats, frequencies, and levels of reliability. Without clear rules regarding who is responsible for data definition, cleaning, and validation, digital models risk reflecting inconsistent assumptions between units. Organizational capability here is evident in the ability to develop a governance structure that combines technical and managerial dimensions: for example, a data committee involving representatives from IT, operations, finance, and sustainability, as well as standard procedures that outline minimum data quality for modeling. This is in line with the view that well-designed data governance strengthens the business value of information-based initiatives and reduces potential conflicts between functions (Khatri & Brown, 2010; Bharadwaj et al., 2013).

Human resource capabilities play a central role in bridging digital twin technology with organizational strategic objectives. Strategic human resource management research shows that HR practices that are coordinated and aligned with business strategy can build human capital that becomes a source of sustainable competitive advantage (Delery & Roumpi, 2017). In implementing digital twins, organizations require a combination of technical, analytical, and managerial expertise: engineers who understand modeling, data analysts who can process and visualize information, and managers who can interpret the implications of findings for asset policy and sustainability. HR capabilities are reflected in how organizations design new competency profiles, develop cross-functional career paths, and incorporate the ability to utilize digital data as part of performance criteria. Recruitment, development, and assessment practices that are consistent with the direction of digitalization help ensure that digital twins are not only operated by a handful of experts, but are understood and utilized widely at various levels of the organization (Easterby Smith & Prieto, 2008; Delery & Roumpi, 2017). The development of digital human resource capabilities also needs to be viewed within a healthy business ecosystem, where fair competition regulations can encourage innovation and growth in companies, including start-ups, that rely on this type of talent (Mustafa et al., 2025).

Managerial capabilities in the field of organizational change have also been proven to determine the success of new technology adoption. Research on planned change emphasizes the importance of clear communication regarding the objectives of change, the provision of support for employees, and consistency between management messages and actual actions (Armenakis & Harris, 2009). In adopting digital twins, leaders must be able to explain how this technology relates to improved infrastructure reliability, cost efficiency, and environmental sustainability, rather than

simply highlighting its innovative aspects. On the other hand, organizations need to have the ability to identify potential resistance, such as concerns that digital twins will replace the professional judgment of field technicians, and then respond with structured engagement and training mechanisms. Strong change capabilities make organizations better prepared to deal with uncertainty in the early stages of implementation and able to adjust project designs when new findings emerge during the process (Armenakis & Harris, 2009; Pavlou & El Sawy, 2011).

From a knowledge management perspective, organizations that want to make optimal use of digital twins need to have the capability to convert individual experiences into knowledge that can be accessed and used widely. Research on the relationship between dynamic capabilities and knowledge management shows that the ability to acquire, combine, and apply new knowledge is an important driver of successful organizational adaptation (Easterby Smith & Prieto, 2008). The ability of organisations to facilitate access to technology and develop digital skills is a critical prerequisite in this context, as discussed in the literature on readiness for the technological era (Arifin & Darmawan, 2021). In infrastructure management, the operation of digital twins generates a variety of lessons, ranging from how to model complex asset behavior to how to interpret data anomalies. Organizational capabilities are evident when these lessons do not remain as tacit knowledge of a few individuals, but are systematically documented and exchanged. Mechanisms such as regular technical meetings, case documentation, and internal knowledge bases can help transform operational findings into guidelines that enrich the next digital twin model and reinforce the continuation of iterative learning (Braun & Clarke, 2006; Easterby Smith & Prieto, 2008).

Entrepreneurial capabilities within organizations and start-ups involved in digital twin projects are also key factors, especially when this technology is still in the relatively early stages of adoption in many sectors. Entrepreneurship literature emphasizes that entrepreneurial orientation, which includes measured risk-taking, innovation, and proactivity, correlates with the performance of small and medium-sized enterprises (Wiklund & Shepherd, 2005). In the digital twin ecosystem, SMEs and new business units within large companies need to develop the ability to identify unmet niche needs, such as specialized analytical services for specific types of infrastructure or visualization modules that are user-friendly for non-technical decision makers. Entrepreneurial capabilities are also evident in the ability to experiment with subscription-based or performance-based revenue models, while managing uncertainty in demand and development costs. The digital twin is thus not only seen as a technology that is passively adopted, but as a foundation for the creation of new business opportunities (Wiklund & Shepherd, 2005; Nambisan, 2017).

The capabilities of SMEs differ from those of large companies, mainly due to limited financial and human resources. Research on small businesses shows that entrepreneurial orientation and networking capabilities are often key determinants of performance, as compensation for internal limitations is achieved through access to external resources (Wiklund & Shepherd, 2005; Zahra et al., 2006). In the application of digital twins, SMEs may not be able to build all technological components independently, but they can develop advantages in certain parts of the value chain, such as the development of specific modeling modules, field data calibration services, or operational parameter setting consultations. Organizational capabilities here are reflected in the ability to choose areas of focus, establish complementary working relationships with other actors, and organize internal processes so that knowledge gained from joint projects can be accumulated to improve future services (Zahra et al., 2006; Nambisan, 2017).

Strategic capabilities related to formulating the direction of digitalization also influence the extent to which digital twins can add value to infrastructure sustainability. Research on digital business strategies explains that organizations need the ability to integrate IT strategies with business strategies so that digital initiatives do not run separately from the corporate agenda (Bharadwaj et al., 2013). In practice, this means that digital twin projects must be linked to measurable targets in medium-term plans, such as reducing asset life cycle costs, improving the reliability of public services, or reducing carbon footprints. Strategy formulation capabilities are evident when management is able to map investment scenarios, plan for gradual development, and align project performance indicators with the organization's overall performance measurement system.

Without this capability, digital twin risk being viewed as experimental initiatives that easily lose support when budgetary pressures arise (Pavlou & El Sawy, 2011; Bharadwaj et al., 2013).

Analytical capabilities serve as the bridge between the data generated by digital twins and real-world actions. Studies on data utilization in organizations show that new business value is realized when companies have the ability to analyze data, interpret the results, and integrate the findings into the decision-making process (Snyder, 2019). In infrastructure, data flowing from sensors and digital twin simulations contains patterns regarding wear and tear, energy consumption, and potential disruptions. Analytical capabilities include expertise in statistics, modeling, and programming, but also the skill of explaining results in a form that can be used by operational managers and strategic leaders. Successful organizations tend to develop specialized roles, such as technical business analysts, who translate digital signals into actionable recommendations and assess their impact on sustainability performance. The digital twin thus becomes a source of insight that enriches managerial judgment, rather than merely a collection of graphical displays (Delery & Roumpi, 2017; Snyder, 2019).

In summary, an organization's capability to successfully implement digital twins in sustainable infrastructure encompasses a combination of interrelated technical, managerial, and entrepreneurial skills. Technology provides the means to model and observe asset behavior, but the quality of decisions depends heavily on how the organization manages data, designs accountability structures, and embeds new understandings into everyday work practices. At the individual level, employees need opportunities to develop analytical skills while maintaining practical sensitivity to field realities. At the group level, work units must learn to read the same model from different perspectives of expertise and reach a common understanding of the appropriate actions. At the organizational level, leaders need to maintain consistency of direction so that the use of digital twins remains connected to mutually recognized sustainability goals.

Ultimately, digital twins can serve as a mirror that helps organizations reflect on how they manage their infrastructure: how rigorously data is recorded, how open discussions about uncertainty are, and how prepared the organizational structure is to change when new evidence emerges. Organizations that have the capability to learn from this mirror tend to develop more adaptive asset management patterns that are responsible for environmental and social impacts. Organizations that view digital twins as an additional tool without reviewing their working methods risk losing potential benefits and merely adding layers of technical complexity. For SMEs and entrepreneurs, the ability to read opportunities in this space and build relevant capabilities will determine whether they can become an important part of a sustainable infrastructure ecosystem supported by living digital models.

D. CONCLUSIONS

This research shows that digital twins have strong potential to support sustainable infrastructure management when combined with the right managerial capabilities, human resources, and entrepreneurship. In terms of utilization, digital twins enable continuous monitoring of asset conditions, scenario simulations, and data-driven decision-making regarding technical performance, life cycle costs, and sustainability indicators. These benefits, however, can only be realized when organizations are able to manage data with discipline, develop work procedures that link modeling results to asset decisions, and foster a culture of collective reflection on the information generated. A review of organizational capabilities confirms that the successful implementation of digital twins is determined more by the ability to identify opportunities, design data governance, develop employee competencies, and manage change than by technological aspects alone. For SMEs and entrepreneurs, digital twins open up new business opportunities as long as they can focus their strengths on specific segments of the value chain and build complementary networks. In general, digital twins can be an important tool for steering infrastructure management toward a more balanced economic, social, and environmental orientation, provided that organizations consistently reorganize their work processes, decision-making structures, and internal capability development.

Theoretically, the results of this research reinforce the view that the use of advanced digital technology in infrastructure management needs to be analyzed through the framework of dynamic capabilities, knowledge management, and strategic human resource

management. Digital twins can be understood as learning environments that facilitate the formation and testing of new routines within organizations, making them relevant to the development of theories on iterative learning and adaptation. In practical terms, these findings provide a basis for policymakers, asset managers, and entrepreneurs to plan digital twin initiatives with an emphasis on data governance, analytical capacity building, and planned change management. Large infrastructure management companies are advised to make digital twin part of their long-term decision-making architecture, while SMEs and entrepreneurs can take advantage of opportunities in specialist services that support modeling, data calibration, or analysis. Digital twins should therefore not be viewed merely as a technology project, but as a driver for restructuring infrastructure management systems towards more responsible practices.

Further research should combine literature research with empirical approaches, such as comparative case studies or cross-organizational surveys, to examine how specific capability combinations influence the success of digital twins in different infrastructure sectors. It is also necessary to develop more specific measurement instruments for data governance capabilities, analytical capabilities, and digital entrepreneurship capabilities, so that the relationship between these variables and sustainability performance can be tested in a more structured manner. For practitioners, it is recommended to develop a digital twin implementation roadmap that includes stages of data maturity improvement, the creation of new roles such as technical business analysts, and periodic evaluation mechanisms for environmental and economic benefits. The government and industry associations can provide support through technical guidelines, data standards, and incentive schemes for pilot projects that are open to shared learning. These efforts are expected to accelerate the formation of a sustainable infrastructure ecosystem supported by reliable digital modeling and adaptive organizational management.

REFERENCES

Al Hakim, Y. R., Rojak, J. A., & Triono, B. (2021). Transformation of Cultural Values and Social Practices in the Digital Age. Journal of Social Science Studies, 1(1), 173-178.

Arifin, S., & Darmawan, D. (2021). Technology Access and Digital Skills: Bridging the Gaps in Education and Employment Opportunities in the Age of Technology 4.0. Journal of Social Science Studies, 1(1), 163-168.

Armenakis, A. A., & Harris, S. G. (2009). Reflections: Our Journey in Organizational Change Research and Practice. Journal of Change Management, 9(2), 127–142.

Bharadwaj, A., El Sawy, O. A., Pavlou, P. A., & Venkatraman, N. (2013). Digital Business Strategy: Toward a Next Generation of Insights. MIS Quarterly, 37(2), 471–482.

Booth, A., Sutton, A., & Papaioannou, D. (2016). Systematic Approaches to a Successful Literature Review (2nd ed.). SAGE Publications, London.

Braun, V., & Clarke, V. (2006). Using Thematic Analysis in Psychology. Qualitative Research in Psychology, 3(2), 77–101.

Brous, P., Janssen, M., & Herder, P. (2019). Internet of Things Adoption for Reconfiguring Decision-Making Processes in Asset Management. Business Process Management Journal, 25(3), 495-511.

costa, S. da, Darmawan, D., & Isaac, A. de J. (2022). Self-Identity Formation and Social Perception of Individuals through Interaction on Social Media in a Digital World. Journal of Social Science Studies, 2(2), 273-278.

Darmawan, D., & Gardi, B. (2024). Digital-Oriented Leadership and Organizational Transformation: Fostering Operational Efficiency, Team Collaboration, and Innovation in the Digital. International Journal of Service Science, Management, Engineering, and Technology, 5(1), 37–42.

Darmawan, D., Gardi, B., & Da Silva, E. B. (2023). Exploration of Changes in Management and Employee Work Relations in Multinational Companies in the Era of Literacy-Based Digitalization. Journal of Science, Technology and Society (SICO), 4(2), 43–54.

Darmawan, D., Mendonca, C. N., & Isaac, A. de J. (2022). Managing Corporate Reputation in the Digital Age: Challenges and Solutions for Maintaining a Positive Image on Social Media. Journal of Social Science Studies, 2(1), 283-288.

Delery, J. E., & Roumpi, D. (2017). Strategic Human Resource Management, Human Capital and Competitive Advantage: Is the Field Going in Circles?. Human Resource Management Journal, 27(1), 1–21.

Easterby Smith, M., & Prieto, I. M. (2008). Dynamic Capabilities and Knowledge Management: An

Integrative Role for Learning?. British Journal of Management, 19(3), 235–249.

Fink, L., & Neumann, S. (2009). Exploring the Perceived Business Value of the Flexibility Enabled by Information Technology Infrastructure. Information & Management, 46(2), 90–99.

Gardi, B., & Ali, R. (2025). Digitalization of Behavioral Accounting as a Foundation for Managerial Decision Making. Bulletin of Science, Technology and Society, 4(2), 51–60.

Gardi, B., & Eddine, B. A. S. (2023). Cyber Security and Personal Data Protection in the Digital Age: Challenges, Impacts, and Urgency of Global Collaboration. Bulletin of Science, Technology and Society, 2(3), 58–63.

Issalillah, F., & Hardyansah, R. (2022). The Impact of the Digital Divide and Misinformation on Partici-pation and Trust in Local Communities. Journal of Social Science Studies, 2(2), 7-12.

Khatri, V., & Brown, C. V. (2010). Designing Data Governance. Communications of the ACM, 53(1), 148–152.

Mardikaningsih, R., & Wardoyo, D. T. W. (2024). The Role of Technology in Human Resource Development for Sustainability: A Literature Review on Digital Innovation. Bulletin of Science, Technology and Society, 3(3), 20–26.

Marsal, A. P., & Hardyansah, R. (2025). Legal Implications of Digital Platform Models: Regulatory Approaches to Consumer Protection, Data, and Competition for Start-up Sustainability. Bulletin of Science, Technology and Society, 4(2), 17–26.

Mendonca, C. N., Wahyudi, Kabalmay, R. N. K., & Amri, M. W. (2021). Developing Technical and Social Competencies for Future-Ready Education in Digitally Mediated Labor Environments. Journal of Social Science Studies, 1(2), 259-266.

Mustafa, A. R., Hardyansah, R., Putra, A. R., Wibowo, A. S., & Negara, D. S. (2025). Competition Law in the Digital Era: Perspective on Startup Companies in Indonesia. Bulletin of Science, Technology and Society, 4(1), 1–10.

Nambisan, S. (2017). Digital Entrepreneurship: Toward a Digital Technology Perspective of Entrepreneurship. Entrepreneurship Theory and Practice, 41(6), 1029–1055.

Oluwatoyin, F. (2021). The Dynamics of Social Interaction in the Digital Age: Technological Implications for Interpersonal Relationships and Psychosocial Well-Being. Journal of Social Science Studies, 1(2), 137-142.

Pavlou, P. A., & El Sawy, O. A. (2011). Understanding the Elusive Black Box of Dynamic Capabilities. Decision Sciences, 42(1), 239–273.

Petrakis, E. G., Sotiriadis, S., Soultanopoulos, T., Renta, P. T., Buyya, R., & Bessis, N. (2018). Internet of Things as a Service (Itaas): Challenges and Solutions for Management of Sensor Data on the Cloud and the Fog. Internet of Things, 3, 156-174.

Putra, A. R., & Arifin, S. (2021). Supply Chain Management Optimization in the Manufacturing Industry through Digital Transformation: The Role of Big Data, Artificial Intelligence, and the Internet of Things. Journal of Social Science Studies, 1(2), 161-166.

Rojak, J. A. (2024). Government Policy in Improving Human Resource Competencies Based on Digital Technology. Bulletin of Science, Technology and Society, 3(2), 1–8.

Snyder, H. (2019). Literature Review as a Research Methodology: An Overview and Guidelines. Journal of Business Research, 104, 333–339.

Teece, D. J. (2007). Explicating Dynamic Capabilities: The Nature and Microfoundations of (Sustainable) Enterprise Performance. Industrial and Corporate Change, 17(3), 1319–1350.

Triono, B., Darmawan, D., Djaelani, M., Safitri, F. S. A., & Masithoh, N. (2025). How Digitalization Reshapes Labor and Task Architecture in the Manufacturing Sector. International Journal of Service Science, Management, Engineering, and Technology, 7(2), 11–16.

Wiklund, J., & Shepherd, D. (2005). Entrepreneurial Orientation and Small Business Performance: A Configurational Approach. Journal of Business Venturing, 20(1), 71–91.

Zahra, S. A., Sapienza, H. J., & Davidsson, P. (2006). Entrepreneurship and Dynamic Capabilities: A Review, Model and Research Agenda. Journal of Management Studies, 43(4), 917–955.

Zulkarnain, M. A. B. (2024). The Dynamics of Globalization and Local Cultural Identity: Challenges, Opportunities, and the Role of Digital Technology in Cultural Preservation. Bulletin of Science, Technology and Society, 3(1), 71–77.

Zulkarnain, M. A. B., & Al Hakim, Y. R. (2023). Digital Media Evolution and Public Opinion Formation: Implications for Information Credibility and Social Dynamics. Bulletin of Science, Technology and Society, 2(1), 49–55.