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# Digital Transformation and Program Adaptivity in Megaprojects: A Systematic Literature Review and Future Research Agenda

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**Abstract**

*Megaprojects are key drivers of national transformation, yet their inherent complexity—spanning multiple entities, packages, and timelines—demands governance models that are both adaptive and digitally enabled. While digital transformation has advanced through tools such as Building Information Modelling (BIM), digital twins, and data-driven dashboards, their integration into program-level management remains fragmented. This study conducts a systematic literature review (SLR) of 65 Scopus-indexed articles published between 2018 and 2025 to explore how digital transformation enhances program adaptivity in megaprojects. Using the PRISMA framework, three thematic domains are identified: (1) Digital Tools Enabling Governance Integration, (2) Adaptive Learning and Decision Systems, and (3) Organizational and Cultural Challenges to Digital Adoption. Findings indicate that digital transformation strengthens adaptive capacity through feedback mechanisms, real-time risk monitoring, and cross-entity data integration. However, theoretical and practical gaps persist in aligning digital governance with adaptive program structures, particularly in emerging economies. This paper proposes a conceptual model linking digital transformation, program adaptivity, and program performance as an integrative foundation for understanding how digital-enabled adaptivity emerges in megaproject governance. Beyond synthesizing existing literature, the study also outlines a forward-looking research agenda to guide the development and empirical validation of adaptive digital governance frameworks, particularly for large-scale national infrastructure programs such as Indonesia's Ibu Kota Nusantara (IKN).*

**Keywords:** *Adaptive Program Management, BIM, Digital Governance, Digital Transformation, Infrastructure Innovation, Megaprojects, Resilience.*

## 1. INTRODUCTION

Megaprojects have emerged as the backbone of national infrastructure transformation, often representing the most ambitious and resource-intensive endeavors in modern civil engineering. Characterized by multi-billion-dollar investments, complex stakeholder networks, and extended implementation timelines, megaprojects demand not only technical excellence but also adaptive management capabilities that can respond to uncertainty, change, and inter-organizational complexity. In this context, program management serves as the integrative layer that aligns objectives, resources, and governance mechanisms across multiple interconnected projects within a unified strategic framework.

Recent advancements in digital technology have reshaped the landscape of infrastructure delivery. Tools such as Building Information Modelling (BIM), digital twins, Internet of Things (IoT) systems, and data-driven decision platforms have enhanced visibility, coordination, and risk monitoring at the project level. However, despite significant technological progress, most digital transformation initiatives remain confined to the project execution layer, rather than being fully embedded within program-level governance and adaptive decision-making systems. This limitation constrains the potential of digital transformation to enable true program adaptivity—the capacity to continuously learn, adjust, and realign resources and strategies in response to emerging challenges.

The ongoing transformation of Indonesia's Ibu Kota Nusantara (IKN), a new national capital megaproject, exemplifies this challenge. The project integrates hundreds of work packages across

ministries, agencies, and private entities, requiring adaptive program management supported by digital information systems. Yet, there remains a gap between the theoretical promise of digital integration and its actual application in managing complex program interdependencies.

To address this gap, this paper conducts a Systematic Literature Review (SLR) to investigate how digital transformation contributes to adaptive program management… and propose a future research agenda that supports the advancement and potential empirical validation of adaptive digital governance in national megaprojects. By systematically analyzing recent global studies (2018–2025), this research seeks to:

1. Identify the core themes linking digital transformation and program adaptivity;

2. Synthesize conceptual models and frameworks emerging from current literature; and

3. Propose a future research agenda for developing adaptive digital governance applicable to national megaprojects.

The results of this study are expected to contribute both theoretically and practically to the evolution of resilient infrastructure governance—where adaptive learning, digital intelligence, and stakeholder collaboration converge to enhance program success. The findings also serve as a foundation for empirical validation within Indonesia's megaproject ecosystem, including the IKN program.

## 2. RESEARCH METHODOLOGY

This paper employs a Systematic Literature Review (SLR) to synthesize current academic discourse on the relationship between digital transformation and program adaptivity in megaprojects. The SLR approach was selected because it provides a structured and transparent method for identifying, evaluating, and integrating relevant research findings, thereby minimizing bias and ensuring reproducibility. The review process follows the PRISMA 2020 (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines, which include four sequential phases: Identification, Screening, Eligibility, and Inclusion.

### 2.1. Search Strategy

The literature search was conducted across three primary academic databases—Scopus, Web of Science, and ScienceDirect—due to their comprehensive coverage of peer-reviewed journals in civil engineering, construction management, and digital governance. The search focused on publications between January 2018 and September 2025 to capture the most recent advancements in digitalization and adaptive program governance.

The following search string was applied with Boolean operators and wildcard symbols to maximize coverage. The summary of database queries and the number of articles identified in each source is presented in Table 1.

**Table 1. Summary of database search strategy and result**

| Database | Year Range | Keywords / Search Terms | Boolean Logic | Initial Results (n) |
|---|---|---|---|---|
| **Scopus** | 2018–2025 | "digital transformation" OR "BIM" OR "digital twin" AND "program management" OR "megaproject" | AND / OR | 145 |
| **Web of Science** | 2018–2025 | "digitalization" OR "governance" AND "resilience" OR "adaptivity" | AND / OR | 108 |
| **ScienceDirect** | 2018–2025 | "BIM" OR "adaptive management" AND "program governance" OR "infrastructure" | AND / OR | 59 |
| **Total Articles Identified** | — | — | — | **312** |

The initial search yielded 312 articles, which were exported to Mendeley for screening and duplicate removal.

### 2.2. Inclusion and Exclusion Criteria

To ensure the relevance and quality of selected studies, the following inclusion and exclusion criteria were applied:

**Table 2. Inclusion And Exclusion Criteria**

| Inclusion Criteria | Exclusion Criteria |
|---|---|
| Articles published between 2018–2025 | Non-English publications |
| Peer-reviewed journal or conference papers | Editorials, notes, or book reviews |
| Focus on megaprojects, infrastructure, or program-level management | Studies unrelated to program management or digital governance |
| Discusses digital transformation, adaptivity, or governance frameworks | Duplicated records or inaccessible full texts |

After applying these criteria, 65 articles were deemed suitable for full-text review and synthesis.

## 2.3. Data Extraction and Thematic Analysis

Each article was analyzed using a standardized data extraction sheet capturing:

1. Publication year, author(s), and country;
2. Research objective and methodology;
3. Key digital tools or systems discussed;
4. Conceptual or empirical contributions to program adaptivity; and
5. Identified challenges or barriers to digital integration.

The extracted data were coded and categorized into themes through thematic synthesis using NVivo 15 software. The process resulted in three dominant clusters:

1. Digital Tools Enabling Governance Integration – focusing on technologies that enhance coordination and decision-making;
2. Adaptive Learning and Decision Systems – emphasizing dynamic feedback and learning mechanisms within program structures; and
3. Organizational and Cultural Barriers – identifying resistance, capacity gaps, and fragmented digital ecosystems.

## 2.4. Quality Assessment and Reliability

To ensure methodological rigor, all included papers were evaluated using the Mixed Methods Appraisal Tool (MMAT 2018). Studies scoring below 60% on methodological quality were excluded. Inter-rater reliability between reviewers reached a Cohen's Kappa of 0.83, indicating strong consistency in the inclusion decisions. A visual representation of this conceptual relationship is shown in Figure 1.
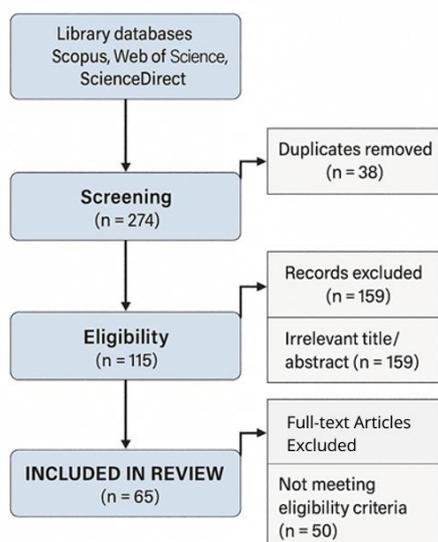


**Figure 1. PRISMA 2020 flow diagram showing the identification, screening, eligibility, and inclusion process of articles in the systematic literature review (n = 312 → 65).**

The final synthesis integrates these high-quality studies into a conceptual model linking digital transformation, program adaptivity, and program performance, which is elaborated in the next section.

## 3. FINDINGS AND DISCUSSION

The systematic review identified sixty-five (65) peer-reviewed publications that collectively describe the evolving intersection between digital transformation and program adaptivity in the management of megaprojects. From the thematic synthesis, three major clusters emerged: (1) Digital Tools Enabling Governance Integration, (2) Adaptive Learning and Decision Systems, and (3) Organizational and Cultural Challenges to Digital Adoption. These clusters highlight the multidimensional pathways through which digitalization contributes to the adaptability, responsiveness, and overall performance of complex infrastructure programs. A visual representation of the keyword co-occurrence map is shown in Figure 2.



**Figure 2. Keyword co-occurrence map of digital transformation and program adaptivity research (2018–2025).**

## 3.1. Digital Tools Enabling Governance Integration

Digital transformation in megaprojects often begins with the adoption of advanced tools and data platforms that enhance transparency and coordination among diverse stakeholders. The most frequently cited technologies include Building Information Modelling (BIM), digital twins, Internet of Things (IoT), Geographic Information Systems (GIS), and integrated Program Management Information Systems (PMIS).

Studies by Love et al. (2021) and Succar et al. (2022) show that BIM and digital twins enable cross-package visualization and data-driven decision-making across multiple entities within a program structure. Similarly, program-level dashboards and PMIS platforms are increasingly used to synchronize timelines, financial controls, and risk registers among government agencies, contractors, and

consultants.

However, while these tools significantly enhance information interoperability, most systems still operate within isolated domains—limiting the potential for adaptive governance. Integrating these platforms into unified program architectures remains a major challenge, particularly in developing contexts where digital maturity levels vary among participating organizations.

### 3.2. Adaptive Learning and Decision Systems

The second cluster reveals how digital transformation contributes to learning adaptivity within megaproject programs. Adaptive systems are characterized by their ability to process feedback, update decisions, and realign objectives in real time. Literature from digital governance (e.g., Davies & Brady, 2020; Turner et al., 2023) emphasizes that the shift from reactive to predictive program management is largely enabled by the use of data analytics, artificial intelligence (AI), and real-time monitoring platforms.

In adaptive programs, digital dashboards act as learning interfaces—allowing decision-makers to simulate scenarios, test trade-offs, and anticipate potential disruptions before they escalate into systemic failures. Feedback loops generated through IoT-enabled sensors and AI-based analytics have been shown to enhance flexibility and resilience, particularly in programs involving interdependent infrastructure systems such as transport, utilities, and smart urban services.

These adaptive learning mechanisms are consistent with the emerging concept of the digital nervous system in infrastructure governance, where continuous sensing and response cycles sustain alignment between strategic intent and operational realities.

### 3.3. Organizational anda Cultural Challanges to Digital Adoption

Despite technological advances, the literature consistently identifies organizational and cultural inertia as key barriers to adaptive digital governance. Challenges include inconsistent digital literacy, reluctance to share data among entities, rigid procurement frameworks, and limited institutional support for digital integration.

Empirical studies (e.g., Liu et al., 2021; Hosseini et al., 2024) show that while many megaproject organizations invest in digital tools, they often lack program-level leadership structures capable of translating data insights into adaptive decisions.

Furthermore, governance models remain highly hierarchical, reducing the ability to rapidly respond to dynamic environmental or stakeholder changes.

For countries in the Global South, these barriers are compounded by fragmented digital infrastructure and varying readiness levels across government agencies. Overcoming such challenges requires not only investment in technology but also organizational transformation—where culture, policy, and leadership jointly support adaptive, data-driven decision-making.

### 3.4. Synthesis of Findings

The three clusters reveal that digital transformation enhances program adaptivity through a dual pathway:

1. Technological Enablement, which improves integration, visualization, and decision accuracy; and
2. Organizational Learning, which strengthens responsiveness, collaboration, and resilience.

The integration of these pathways results in a conceptual linkage that can be summarized as:

**Digital Transformation → Adaptive Capacity → Program Resilience → Program Success**.

This relationship implies that the success of megaproject programs depends not only on the sophistication of digital tools but also on the maturity of organizational systems that support continuous learning and adaptation. This synthesis therefore serves not only to categorize findings but also to establish the conceptual basis for subsequent model development, which is elaborated in the next section.

To strengthen the synthesis derived from the literature, the key findings were further organized into a thematic matrix that links the mechanisms of digital transformation with their corresponding outcomes at the program level. This classification aims to demonstrate how digital tools, adaptive learning systems, and organizational factors collectively influence program adaptivity and resilience in large-scale infrastructure settings. The thematic synthesis summarized in Table 3 integrates insights from multiple studies, revealing both the enabling mechanisms and the performance implications of adaptive digital governance in megaprojects.

**Table 3. Thematic synthesis linking digital transformation mechanisms to program-level outcomes.**

| Theme / Cluster | Representative Studies | Mechanisms Identified | Program-Level Outcomes |
|---|---|---|---|
| **Digital Tools Enabling Governance Integration** | Love et al. (2021); Succar et al. (2022); Jallow & Demian (2021) | BIM and Digital Twin platforms integrate multi-package data; PMIS improves inter-entity coordination | Enhanced visibility, data consistency, and cross-agency decision alignment |
| **Adaptive Learning and Decision Systems** | Davies & Brady (2020); Turner et al. (2023) | AI-based dashboards and real-time analytics create feedback loops for continuous learning | Improved responsiveness and predictive capability in program governance |
| **Organizational and Cultural Challenges** | Liu et al. (2022); Hosseini et al. (2024) | Limited digital literacy and hierarchical decision structures slow digital adoption | Delayed adaptation and reduced cross-entity resilience |
| **Integration and Learning Synergy** | Synthesis (2025) | Combination of technological and organizational adaptivity | Institutionalized learning and resilient program performance |

Within the context of Indonesia's Ibu Kota Nusantara (IKN) program, this synthesis underscores the necessity of building a national-level adaptive digital governance framework capable of connecting multiple infrastructure packages under one unified data ecosystem. Such a framework would enable real-time monitoring, transparent coordination, and agile decision-making across ministries, contractors, and consultants—ultimately improving the delivery and sustainability of megaproject outcomes.

## 4. CONCEPTUAL FRAMEWORK

The synthesis of reviewed literature led to the formulation of a conceptual framework that explains how digital transformation enhances program adaptivity and how this adaptivity contributes to program performance and resilience. This framework also provides a structured foundation for conceptualizing adaptive digital governance and for guiding subsequent empirical investigations.. This framework integrates technological, organizational, and learning dimensions into a cohesive model of adaptive digital governance (Figure 1).

At its core, the model conceptualizes digital transformation as a multidimensional enabler comprising three primary components: (1) Digital Tools and Integration Platforms, (2) Data-Driven Decision Systems, and (3) Governance Digitalization. These components collectively strengthen the flow of information and foster cross-entity coordination.

The second dimension, program adaptivity, represents the system's capability to anticipate, respond, and learn from environmental or stakeholder changes. Adaptivity emerges from three core attributes identified in the literature: (a) Feedback Loops and Learning Mechanisms, (b) Responsiveness and Flexibility, and (c) Continuous Improvement Culture. These attributes translate digital intelligence into organizational agility, allowing programs to evolve dynamically during implementation.

Finally, program performance is conceptualized not merely as the achievement of cost, schedule, and quality objectives, but also as the attainment of broader strategic outcomes such as stakeholder satisfaction, benefit realization, and resilience under uncertainty.

Collectively, these relationships form an adaptive cycle, as illustrated below:

**Digital Transformation → Program Adaptivity → Program Performance and Resilience.**

This causal pathway suggests that digital tools alone cannot ensure program success. This conceptual model therefore serves as a theoretical bridge to the development of the Digital Adaptive Program Governance Framework (DAPGF), which provides a structured approach for future research and empirical validation.

In the context of national infrastructure megaprojects such as Indonesia's Ibu Kota Nusantara (IKN), this model provides a conceptual foundation for designing a Digital Adaptive Program Governance Framework (DAPGF) — a system that integrates real-time information, multi-entity coordination, and risk-based learning into the management of interdependent projects. The proposed conceptual structure is illustrated in Figure 3, integrating technological, organizational, and learning perspectives into an adaptive governance model.

**Figure 3.** **Digital Adaptive Program Governance Framework (DAPGF)**

The framework emphasizes that digital transformation should not be viewed as a technological project, but as an organizational transformation journey, where digital intelligence and adaptive management converge to achieve sustainable infrastructure delivery. This insight forms the theoretical bridge between global literature and practical implementation challenges observed in developing megaproject contexts. A visual representation of this conceptual model as shown in Figure 4.
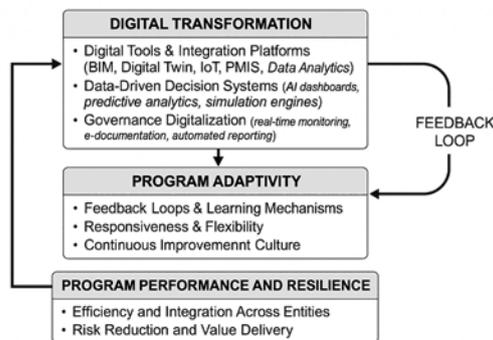


**Figure 4.** **Conceptual Model of Digital Transformation and Program Adaptivity in Megaprojects.**

# 5. RESEARCH GAPS AND FUTURE AGENDA

The systematic synthesis of existing studies reveals gaps that highlight the need for further inquiry not only to expand theoretical clarity but also to support the development and future empirical testing of adaptive digital governance models that can better align digital transformation with program performance outcomes. Consequently, several theoretical and practical gaps persist, highlighting opportunities for future research and model development.

## 5.1. Theoretical Gaps

First, there is a fragmented theoretical linkage between digital transformation and program adaptivity. Many studies conceptualize digital tools—such as BIM, digital twins, or data analytics—as isolated enablers of efficiency, without integrating them into a broader governance model. Few frameworks explicitly explain how digitalization contributes to learning cycles, feedback systems, and adaptive decision-making at the program level.

Second, the construct of program adaptivity itself is still underdeveloped in the literature. Existing frameworks often equate adaptivity with agility or flexibility, overlooking its multidimensional nature that involves responsiveness, institutional learning, and benefit realization. This conceptual limitation restricts the advancement of a unified theory of adaptive digital governance for megaprojects.

## 5.2. Methodological Gaps

Methodologically, most empirical studies rely on single-project case studies or cross-sectional surveys, limiting the generalizability of findings. Longitudinal or multi-program comparative analyses remain scarce, especially in developing countries. Moreover, the integration of mixed-methods designs—combining quantitative performance analytics with qualitative governance observations—has been underutilized in assessing digital transformation outcomes.

Another gap lies in the limited use of digital maturity assessments at the program level. Current measurement instruments are designed for individual projects or organizations, not for multi-entity environments typical of national infrastructure programs.

## 5.3. Contextual Gaps

A significant contextual gap exists in the representation of emerging economies within the global literature. Most seminal studies originate from technologically advanced contexts such as Europe, North America, and East Asia. As a result, the unique challenges of digital adoption—such as regulatory fragmentation, uneven capability maturity, and policy discontinuity—remain underexplored in Southeast Asian settings.

For instance, in Indonesia's Ibu Kota Nusantara (IKN) program, digital governance must operate across multiple ministries, contractors, and consultants, creating high interdependence and systemic complexity. Yet, empirical evidence on how digital transformation supports adaptivity in such multi-entity structures remains minimal.

## 5.4. Future Research Directions

Future research should focus on developing and

empirically testing an Adaptive Digital Program Governance Framework (ADPGF) that integrates technological, organizational, and learning perspectives. Such a framework should be validated through multi-case analyses across national infrastructure programs to measure how digital transformation enhances adaptability, resilience, and long-term program performance.

Additionally, the use of advanced analytics, machine learning, and digital twins offers promising avenues for modeling real-time adaptive decision systems. Researchers are encouraged to examine how digital intelligence can predict cross-entity risks, optimize resource allocation, and generate data-driven policy recommendations for megaproject governance.

Lastly, greater attention should be directed toward capacity building and institutional readiness, exploring how digital leadership, organizational culture, and policy frameworks collectively shape adaptive capability in large-scale infrastructure programs.

Building upon the gaps identified in the preceding sections, This study proposes a structured research roadmap that serves as a foundation for developing, refining, and validating models and instruments that capture how digital transformation strengthens program adaptivity and resilience. The roadmap aligns theoretical, methodological, and contextual dimensions to guide future inquiries toward developing empirically validated and practically applicable frameworks. By addressing these gaps, researchers and practitioners can enhance the coherence between digital transformation, program adaptivity, and governance outcomes. The proposed agenda presented in Table 4 outlines potential research questions, methodological approaches, contextual focuses, and anticipated contributions that can shape the next phase of inquiry in this evolving field.

**Table 4. Future research roadmap for developing adaptive digital governance in megaprojects.**

| Gap Category | Research Question / Objective | Suggested Methodology | Context / Focus Area | Expected Contribution |
|---|---|---|---|---|
| **Theoretical Gap** | How can digital transformation be integrated into program adaptivity models? | Conceptual framework development + comparative case analysis | Global megaprojects / IKN context | Formulation of Adaptive Digital Governance Theory |
| **Methodological Gap** | How to measure digital maturity and adaptivity at the program level? | Mixed-methods design / PLS-SEM + qualitative validation | National infrastructure programs | Empirical validation tool for adaptive program performance |
| **Contextual Gap** | What are the barriers to digital governance in emerging economies? | Multi-case field study / thematic analysis | Indonesia / ASEAN megaprojects | Policy and institutional recommendations |
| **Practical Gap** | How can adaptive learning loops be institutionalized in program governance? | Action research / pilot implementation | Government agencies and PMOs | Implementation model for resilient digital program delivery |

The proposed research roadmap underscores the growing need for integrative studies that bridge technological innovation with adaptive governance mechanisms. By systematically addressing the theoretical, methodological, contextual, and practical gaps summarized in Table 4, future research can generate more robust evidence on how digital transformation fosters adaptive capacity within complex program environments. Such efforts are essential to develop validated models and measurable indicators that link digital maturity, organizational learning, and program performance across multi-entity infrastructure systems. Ultimately, these inquiries will expand the frontier of knowledge in adaptive digital governance, providing a strong foundation for both academic advancement and practical policy formulation — as elaborated in the following section on the Contribution to the Body of Knowledge.

### 5.5. Contribution to the Body of Knowledge

This paper contributes to the body of knowledge by:

1. Consolidating the fragmented discourse between digital transformation and adaptive program management;

2. Proposing a conceptual foundation for digital-enabled program adaptivity in megaprojects; and

3. Outlining a structured research roadmap toward the development of an empirically grounded Adaptive Digital Governance Model for emerging economies, enabling future studies to progress from conceptual synthesis to empirical validation.

The articulation of these gaps and future directions not only provides theoretical clarity but also

strengthens the practical relevance of adaptive digital governance as a cornerstone for resilient and sustainable infrastructure delivery.

# 6. CONCLUSION

The preceding analyses provide a comprehensive synthesis of how digital transformation enables program adaptivity and strengthens governance performance. This synthesis also establishes a conceptual foundation that supports the development of future models for adaptive digital governance. Through the integration of technological, organizational, and learning perspectives, this study consolidates fragmented knowledge and proposes a unified framework for adaptive digital governance. The insights derived from the systematic literature review not only advance theoretical understanding but also offer practical implications for policymakers, program managers, and implementing agencies seeking to enhance resilience and value realization in complex multi-entity environments.

This study has conducted a systematic literature review (SLR) to explore how digital transformation influences program adaptivity and contributes to enhanced performance and resilience within megaproject governance. The review of sixty-five recent publications (2018–2025) reveals that digital technologies—such as Building Information Modelling (BIM), digital twins, IoT networks, and data analytics platforms—have transformed the coordination and information-flow mechanisms of large infrastructure programs. However, their integration into program-level governance structures remains limited and uneven across global contexts.

The findings indicate that the effectiveness of digital transformation in megaprojects is contingent upon the maturity of adaptive systems and learning organizations that support continuous feedback, responsiveness, and cross-entity collaboration. The proposed conceptual framework articulates a causal linkage—Digital Transformation → Program Adaptivity → Program Performance and Resilience—which emphasizes that technological innovation must be embedded within adaptive governance processes to generate sustainable value.

From a theoretical perspective, this paper advances the discussion of adaptive digital governance by bridging previously fragmented research on digital tools, organizational learning, and program management. From a practical standpoint, it highlights the necessity for policy makers, program managers, and infrastructure authorities to integrate digital intelligence into strategic governance frameworks—particularly in multi-entity, multi-package programs such as Indonesia's Ibu Kota Nusantara (IKN) development.

Future empirical research should validate this conceptual framework through longitudinal or cross-program analyses, supported by digital maturity assessments and predictive analytics. Strengthening adaptive digital capabilities will be critical for ensuring the long-term sustainability, transparency, and resilience of national infrastructure megaprojects in the era of digital transformation.

Looking ahead, the transition toward adaptive and digitally empowered program governance will define the next frontier of infrastructure management. The conceptual and methodological foundations established in this study provide a platform for future empirical validation, ensuring that upcoming megaprojects embody adaptability, collaboration, and long-term public value.. The conceptual and methodological foundations established in this study provide a platform for continued exploration and empirical validation, ensuring that future megaprojects not only deliver physical infrastructure but also embody the principles of adaptability, collaboration, and long-term public value.

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