

From BIM and Geospatial Technology to AI-Driven Digital Twins: Integrating Policy, Geospatial Intelligence, and Technological Synergies in Malaysia

Abdul Rahman, S. A. F. S. A.,^{1*} Shaharuddin, S.,¹ Shapiai, M. F.² and Ahmad, A.³

¹Coordinating and Mapping Policy Division, Department of Survey and Mapping Malaysia (JUPEM), Jalan Sultan Yahya Petra, 50578 Kuala Lumpur, Malaysia, E-mail: syedfadhli@jupem.gov.my,* sarah@jupem.gov.my

²Integrated Asset Planning Branch, Public Works Department Malaysia, Jalan Sultan Salahuddin 50480 Kuala Lumpur, Malaysia, E-mail: faizs@jkr.gov.my

³Policy and Corporate Management Branch, Public Works Department Malaysia, Jalan Sultan Salahuddin 50480 Kuala Lumpur, Malaysia, E-mail: abdullah@jkr.gov.my

*Corresponding Author

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Abstract

As Malaysia embraces digital transformation in the construction and geospatial sectors, the integration of Building Information Modelling (BIM), geospatial technology, and Artificial Intelligence (AI) becomes increasingly critical. Central to this transformation is the concept of the Digital Twin, a data-rich virtual counterpart of physical infrastructure. However, despite the rise of BIM and spatial standards, Malaysia's progression beyond early-stage digital maturity remains limited. Current implementations are fragmented, with minimal integration between BIM, geospatial datasets, and AI systems. This paper addresses the policy gaps inhibiting Malaysia's advancement along the Digital Twin Maturity Model (DTMM), which ranges from Maturity Level (ML) 0 (No Twin) to ML5 (Autonomous). The study employs a qualitative methodology that combines a Rapid Review of strategic documents with Qualitative Content Analysis. Key policy instruments such as National Construction Policy 2030, Construction 4.0 Strategic Plan, JKR's directive circular, JUPEM's regulatory circulars and PLANMalaysia's Smart City Implementation Guidelines were evaluated and coded against DTMM benchmarks. The findings reveal that Malaysia's current frameworks support ML1–ML2 maturity, enabling visualization and historical data integration. However, limited legal interoperability, institutional fragmentation, and absence of AI-readiness protocols prevent progression toward predictive (ML3), optimization (ML4), and autonomous (ML5) capabilities. This study contributes a maturity-aligned policy mapping and proposes strategic interventions including the creation of a Digital Twin Coordination Unit, legal reform for cross-domain integration, and DTMM-linked KPIs in public infrastructure mandates. The paper offers a policy roadmap for elevating Malaysia's Digital Twin readiness in alignment with its broader Industrial Revolution 4.0 goals.

Keywords: AI-Enabled Infrastructure, BIM-GIS Integration, Digital Twin Maturity, Malaysia Construction Policy

1. Introduction

The construction and geospatial industries are undergoing rapid digital transformation as part of a broader global shift toward Industrial Revolution 4.0 (IR 4.0) [1]. Technological integration, particularly through the convergence of Building Information Modelling (BIM), geospatial technology, and Artificial Intelligence (AI), is redefining the way infrastructure is designed, developed, and managed [2]. In Malaysia, digitalization efforts have intensified with the launch of national blueprints

such as the Malaysia Digital Economy Blueprint (MyDIGITAL), Construction 4.0 Strategic Plan (2021–2025) (Construction 4.0) and National Construction Policy 2030 (NCP2030), all of which underscore the role of digital tools in enabling productivity, sustainability, and governance in the built environment. Central to this agenda is the notion of the Digital Twin, a virtual representation of physical assets that enables real-time monitoring, simulation, and predictive decision-making [3].

BIM and Geographic Information Systems (GIS) lay the groundwork for Digital Twins but transitioning to AI-enhanced autonomous systems remains a major challenge in Malaysia [4].

BIM has been widely promoted as a transformative tool for managing lifecycle information across construction projects. Through standardized data structures such as Industry Foundation Classes (IFC) and protocols outlined in ISO 19650, BIM facilitates collaboration among architects, engineers, and contractors [5]. GIS, on the other hand, supports spatial analysis, integration of topographical data, and geolocation-based decision-making at macro scales [6]. The integration of BIM and GIS is therefore crucial for scaling from isolated project-based modeling toward citywide digital infrastructure. Despite its recognized value, Malaysia's adoption of BIM-GIS integration remains uneven, with fragmented technical implementations, disparate institutional mandates, and weak regulatory enforcement [7]. Although the Public Works Department (JKR) has developed comprehensive BIM execution guidelines, and Department of Survey and Mapping Malaysia (JUPEM) has provided spatial data governance through geomatics frameworks such as JUPEM's Director General of Survey and Mapping Malaysia circular Peraturan Ukur Geomatik 2021 (PKPUP 12/2021) and Guidelines for Cadastral Survey Work Practices in the eKadaster Environment (PKPUP 6/2009), their coordination toward Digital Twin maturity is underexplored.

To assess readiness, this paper adopts the Digital Twin Maturity Model (DTMM) that introduced by [8], which categorizes development from basic visualization (ML1–2) to predictive and autonomous systems (ML3–5). Existing studies in urban informatics and construction technology recognize that most Digital Twin implementations in developing countries [9], rarely progress beyond ML2, where data is visualized in real-time but not used for predictive modeling or autonomous control. This paper hypothesizes that while technical maturity may be constrained by institutional capacity and investment, the primary impediment lies in the policy ecosystem, which remains underdeveloped in defining maturity targets, enabling data interoperability, and institutionalizing AI-readiness protocols.

The Construction 4.0 envisions a digitally advanced construction sector through Smart Construction pillars and advocates the use of BIM, prefabrication, and digital quality assurance systems [10]. Similarly, NCP2030 articulates digitalization as a core enabler of construction industry reform, referencing AI, Blockchain, and Virtual Modelling

as key technologies [11]. Nevertheless, these policy documents remain largely conceptual and lack a detailed operationalization plan to progress from BIM implementation to Digital Twins. Notably absent are regulatory indicators or funding mechanisms to incentivize progression beyond ML2. Institutional fragmentation further complicates the picture, as technical agencies such as Construction Industry Development Board (CIDB), JUPEM, Town and Country Planning Department (PLANMalaysia), and JKR operate within parallel jurisdictions (in the context of Digital Twins), each pursuing isolated digitization initiatives with minimal cross-agency integration.

Moreover, the JKR BIM Guideline and Standard provides prescriptive instructions for BIM coordination, model submission, and Common Data Environment (CDE) structuring across government projects [12]. However, its focus is confined to project-level deliverables and lacks explicit directives for integration with geospatial platforms or AI content. In contrast, JUPEM's PKPUP 12/2021 and PKPUP 6/2009 govern the spatial data standards and geomatics protocols necessary to underpin digital cadastral infrastructure [13] and [14]. Although JUPEM's eKadaster, SmartKADASTER and National Digital Cadastral Database (NDCDB) initiatives represent significant strides in spatial data digitalization [15], they do not yet articulate how such data infrastructure can be mobilized toward predictive analytics or AI-based automation, which are necessary components of higher Digital Twin maturity levels (ML3–ML5).

Given these developments, there is a need for a comprehensive analysis that situates current Malaysian policies within the Digital Twin framework and evaluates their capacity to facilitate technological integration across the construction and geospatial sectors. Therefore, this study is timely and significant, offering a critical perspective on Malaysia's digital transformation through the lens of maturity benchmarking. The integration of BIM and GIS is framed not merely as a technological challenge but as a policy problem, requiring governance reforms, institutional coordination, and new regulatory instruments that explicitly target Digital Twin progression.

This paper has three objectives. First, it examines how national policies and sectoral strategies support DTMM in Malaysia. Second, it maps current practices against the DTMM using qualitative policy analysis. Third, it proposes a roadmap to harmonize BIM, GIS, and AI policies for developing scalable and autonomous Digital Twin systems aligned with national digital transformation goals. This paper contributes to both academic discourse and policy

formulation by aligning national digital construction strategies with an internationally recognized maturity model. It also bridges theoretical frameworks with operational realities, drawing attention to the structural, legal, and institutional reforms needed to transition from fragmented 3D modeling to autonomous AI-integrated digital ecosystems.

2. Literature Review

The literature on BIM, Digital Twins, geospatial integration, and AI adoption within the built environment has expanded significantly over the past decade. Nevertheless, there remains a lack of cohesive policy-aligned study, particularly in the Malaysian context. This section critically reviews the relevant literature across four thematic areas: (i) the conceptual and practical development of Digital Twins, (ii) BIM-GIS integration as a foundation for Digital Twins, (iii) the application of AI in built environment systems, and (iv) the policy and governance frameworks that shape digital construction trajectories. The review is guided by the DTMM, positioning each theme in relation to Malaysia's potential to evolve from ML0 to ML5 maturity levels.

2.1 Digital Twin Development: From Visualization to Autonomy

Digital Twins have been defined as dynamic virtual replicas of physical entities that synchronize in real-time with their physical counterparts [8]. Originating from aerospace and manufacturing, the concept has evolved to include infrastructure and urban systems, where it enables lifecycle monitoring, predictive maintenance, and decision simulation [8]. The DTMM introduced by [8] delineates six maturity levels from ML0 (no twin) to ML5 (autonomous) as shown in Table 1. At ML1, systems provide static 3D or 2D representations with real-time sensor data. ML2 incorporates historical or normative benchmarks to inform operations. ML3 introduces predictive analytics through machine learning or physics-based models. ML4 supports optimization through scenario testing, and ML5 enables

autonomous decision-making based on real-time and predictive data synthesis.

In Malaysia, this study academic literature finds that the current practices remain within ML1–ML2 boundaries. For instance, CIDB's MyCREST have made references to digital monitoring and sustainability scoring, yet these implementations lack feedback loops, predictive simulation, or autonomous actuation capabilities [16]. Most Digital Twin applications remain conceptual and limited to pilot projects (e.g., traffic or flood models), with little alignment to regulatory frameworks for maturity progression. What is notably absent is an empirical or policy-based benchmarking of Malaysian Digital Twin projects against maturity levels. Without clear targets or classification criteria, it becomes difficult to assess readiness, institutional alignment, or the systemic value generated from such initiatives. As such, the DTMM provides a much-needed evaluative structure to bridge theory with practice and identify where Malaysian systems fall short in their digital transformation trajectory.

2.2 BIM-GIS Integration as a Foundation for Digital Twins

The integration of BIM and GIS is widely recognized as the cornerstone for establishing foundational digital infrastructure in the construction and urban planning domains [16]. BIM offers high-resolution, object-oriented data models centered on building geometry, materials, and lifecycle information [5]. GIS, conversely, operates at broader spatial scales, emphasizing topological relationships, terrain modeling, and locational intelligence [6]. Integration enables a seamless shift from macro planning to micro execution, offering the holistic view needed for Digital Twin development. In practical terms, successful BIM-GIS integration enables not only the visualization of 3D models in geospatial contexts but also the correlation of infrastructure with environmental, cadastral, and transport data layers which are critical for ML1 (Status) and ML2 (Informative) maturity levels [18].

Table 1: The DTMM [8]

No.	Level	Description
1.	ML0	<i>No Twin:</i> Absence of sensors, digital models, or integrated data flows.
2.	ML1	<i>Status:</i> Basic digital replication (e.g., 3D BIM or GIS) with real-time visualization.
3.	ML2	<i>Informative:</i> Historical and real-time data integration for status reporting.
4.	ML3	<i>Predictive:</i> Use of ML/physical models for future state forecasting.
5.	ML4	<i>Optimization:</i> Simulation and evaluation of "what-if" scenarios for decision support.
6.	ML5	<i>Autonomous:</i> AI-driven control with minimal human intervention.

In Malaysia, initiatives such as the eKadaster, SmartKADASTER and NDCDB program developed by JUPEM illustrate substantial investment in spatial data infrastructure [15]. Simultaneously, the JKR BIM Guidelines and Standard promote standardization in model development, submission protocols, and coordination across project phases [12]. Nonetheless, these developments occur in silos, lacking a unified framework that ensures interoperability across spatial and design datasets. BIM models generated in project silos are rarely aligned with geospatial datasets maintained by municipal or federal agencies, thereby limiting their contribution to real-time digital twin environments. While both BIM and GIS platforms are increasingly implemented in Malaysian public projects, an absence of institutional policies mandating their integration. This represents a critical gap, as DTMM at ML1 and ML2 depends heavily on robust foundational data that bridges the digital-physical divide. Without this integration, real-time monitoring, and scenario modeling (ML3 and above) remain technically unattainable.

2.3 AI in Built Environment Systems

AI plays a transformative role in elevating Digital Twin systems [19] from informative platforms (ML2) to predictive (ML3), optimized (ML4), and autonomous (ML5) ecosystems. In the built environment, AI is increasingly applied for structural health monitoring, predictive maintenance, energy optimization, and urban analytics [19]. Machine Learning (ML) algorithms can detect patterns and anomalies across sensor datasets, enabling forecasts related to traffic congestion, structural degradation, or energy consumption. Deep learning models extend these capabilities into more complex domains such as automated fault detection, object recognition in satellite imagery, and natural language processing for infrastructure documentation [20].

In Malaysia, the National AI Roadmap 2021 outlines sectoral priorities and ethical governance frameworks for AI adoption [21]. Conversely, the roadmap largely focuses on healthcare, finance, and agriculture, with limited references to the construction or geospatial sectors. As such, AI adoption built environment systems remain exploratory. Case studies on smart lighting, traffic control, or CCTV analytics in smart city pilots show limited interoperability with BIM-GIS platforms or Digital Twin frameworks [22]. Although AI's potential is recognized, a wide gap remains between policy vision and real-world implementation. The lack of AI-capable datasets, standardized protocols, and technical talent in urban governance bodies further impedes progress. For Malaysia to transition

toward ML4 and ML5 maturity, AI-readiness must be embedded not only in technological terms but through legal, institutional, and capacity-building initiatives aligned with national development goals.

2.4 Policy and Governance Frameworks in Malaysia

Digital transformation of the construction and geospatial sectors is not only a technological effort but also a regulatory challenge. The previous study by [23] points to the importance of policy consistency, inter-agency collaboration, and legal mandates in ensuring successful implementation of complex digital systems. In Malaysia, the Construction 4.0 promotes for smart construction and BIM implementation across government projects. It defines key performance indicators (KPIs) for digital adoption [10] but does not establish enforceable mandates for data interoperability or DTMM progression. Similarly, NCP2030 aligns with international trends in digitalization [11] but remains aspirational in its operational details. While AI and digital tools are mentioned in policy documents, there is no structured alignment with DTMM stages or maturity assessment frameworks to guide the transition toward predictive or autonomous infrastructure systems.

The JKR BIM Guideline and Standard provides the most concrete technical document, specifying CDE usage, model layering standards, and project coordination protocols [12]. Nevertheless, its application is limited to JKR-led projects and does not interface with geospatial datasets or support Digital Twin development. On the spatial data side, JUPEM's circular PKPUP 12/2021 ensure high-quality geomatics data collection [13] and [14], yet these frameworks do not integrate with AI workflows or BIM schemas. There is an obvious absence of a national Digital Twin governance structure, or a coordinating body tasked with synchronizing efforts across ministries and agencies.

Comparative studies reveal that countries like the United Kingdom and Singapore have advanced Digital Twin strategies underpinned by legal frameworks and institutional mandates. The UK's Centre for Digital Built Britain spearheads its National Digital Twin Programme, integrating BIM, GIS, and AI across sectors through a federated architecture and data interoperability standards [24]. In contrast, Singapore's Virtual Singapore project combines 3D city models, real-time data, and AI simulations for planning and resilience, aligned with ML4 in the DTMM [3]. Compared to these benchmarks, Malaysia's approach remains policy-fragmented and lacks enforcement mechanisms. Although aligned in ambition, Malaysia still lacks cross-sector maturity staging, legal enablers, and

centralized Digital Twin governance bodies. The literature suggests that without such institutional framework, pilot projects will remain isolated, and DTMM will stagnate at ML1–ML2 levels, incapable of scaling into fully optimized and autonomous systems.

2.5 Synthesis and Research Gap

Across all themes, the literature reveals significant fragmentation between technical capability, institutional mandates, and regulatory coherence. Though Malaysia exhibits growing BIM and GIS usage and has made strategic investments in spatial data infrastructure, there is insufficient integration to progress meaningfully beyond ML2 maturity. The absence of a coordinated legal and institutional framework, particularly regarding AI-readiness and BIM-GIS interoperability, presents a critical bottleneck. This conceptual model (Figure 1) illustrates how different functional domains, BIM, geomatics, GIS, and AI, interact over time to support the evolution of a comprehensive Digital Twin. Each domain contributes at different stages, reflecting both their temporal utility and alignment with the DTMM. The figure emphasizes the cumulative and layered nature of the ecosystem and highlights the importance of interoperability and policy cohesion.

Figure 1 reinforces the argument that Digital Twin development is not the product of a single domain but rather a temporally layered, interdisciplinary ecosystem. It emphasizes that achieving higher DTMM levels requires the seamless integration of these domains throughout the asset lifecycle. The layered contribution from Geomatics (early spatial definition), BIM (construction and asset lifecycle), GIS (lifecycle spatial analytics), and AI (post-construction intelligence) highlights the urgent need for policy frameworks that accommodate both their temporal overlaps and maturity dependencies. This study addresses this gap by conducting a comprehensive policy analysis

guided by the DTMM. It seeks to evaluate how current frameworks support or constrain Malaysia's progression toward predictive and autonomous digital infrastructure systems and proposes strategic interventions to realign policy with technological potential.

3. Methodology

To evaluate Malaysia's policy readiness for Digital Twin adoption and the integration of BIM-GIS-AI within the national digital construction ecosystem, this study adopts a qualitative research design. The methodology is guided by two complementary approaches: the Rapid Review research protocol for systematic evidence synthesis, and Relational Qualitative Content Analysis (QCA) for thematic interpretation. This dual approach enables a comprehensive, structured, and interpretive investigation of the diverse policy documents, technical standards, and institutional instruments relevant to the evolution of Digital Twin frameworks in Malaysia.

3.1 Rapid Review for Structured Policy Synthesis

The Rapid Review method was selected due to its efficiency in capturing the span of relevant knowledge within constrained timeframes, while still retaining the demand of systematic review principles [25]. This method is particularly suitable for evaluating policy ecosystems where academic literature is often supplemented, or replaced, by grey literature, government reports, planning guidelines, and legislative documents. A targeted document search was conducted using inclusion criteria focused on relevance to BIM, Digital Twin, GIS integration, AI adoption, and spatial data governance in Malaysia. The review excluded documents not officially gazette or lacking institutional endorsement. The selected documents were imported into a qualitative data analysis tool for content coding.

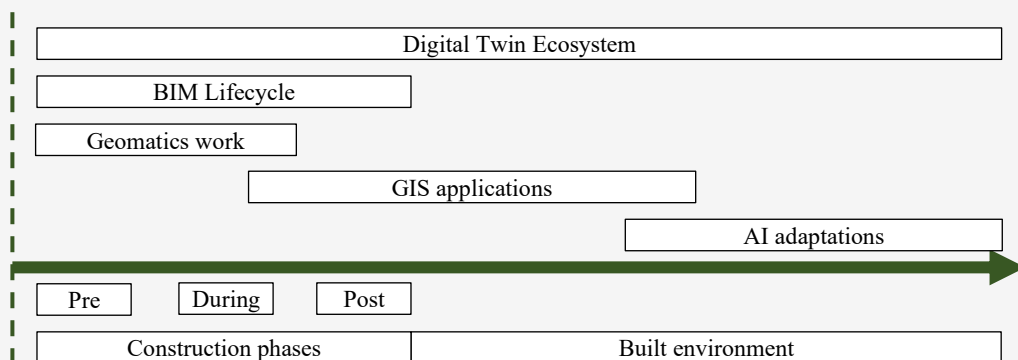


Figure 1: Temporal alignment of domain contributions within the Digital Twin Ecosystem across construction phases and the built environment lifecycle

3.2 Qualitative Content Analysis (QCA) for Thematic Interpretation

To facilitate deeper insight into policy direction and institutional readiness from the selected documents from Rapid Review process, this study employed Relational Qualitative Content Analysis (QCA) as a framework for systematically interpreting text-based data [26]. This method is well-suited to policy analysis because it accommodates both inductive and deductive coding, enabling the identification of emergent patterns while remaining grounded in theory. The coding process followed three stages:

- i. Initial Familiarization: Reading and re-reading of policy documents to identify manifest content.
- ii. Code and Thematic Themes: Creation of a coding schema and aggregation of codes into themes.
- iii. Interpretive Synthesis: Examination of how these themes reflect institutional alignment, regulatory gaps, and technological maturity.

Relational QCA allowed the study to move beyond descriptive summarization by interpreting how different agencies conceptualize and operationalize digital transformation. Thematic information was reviewed iteratively by the authors to ensure consistency with DTMM criteria and inter-policy alignment. The analysis focused on policy connectivity and the lack of references to maturity targets, feedback loops, or AI readiness, key factors for Digital Twin progression.

3.3 DTMM as an Analytical Lens

As continuity from Relational QCA process, the DTMM was employed as the central analytical framework for classifying and benchmarking policy content. This model defines six levels of maturity as described in Table 1. Each document reviewed was coded for references to these maturity levels.

This DTMM coding allowed for a cross-comparative evaluation of how different policy instruments align with or fall short of Digital Twin evolution. It also highlighted which agencies are most actively engaged in maturity development and where strategic gaps remain.

4. Policy Analysis and Discussion

The rapid advancement of digital technologies in the construction and geospatial sectors has placed increasing pressure on national policy frameworks to evolve in support of intelligent infrastructure systems. In Malaysia, the integration of BIM, geospatial technology, and AI remains a key objective of the digital transformation agenda, as reflected in major policies. Nonetheless, the transition from 3D modelling to predictive and autonomous Digital Twins is not merely a technological progression, it is fundamentally a policy-driven journey. This section critically analyses the Malaysian policy landscape in relation to the DTMM, identifying strengths, gaps, and pathways for institutional alignment and regulatory enhancement.

4.1 Rapid Review: Sources Overview

The Rapid Review process identified seven core policy and technical documents that form the backbone of Malaysia's digital transformation in the construction and geospatial sectors. These documents were selected based on institutional authorship, legal status, and thematic relevance to BIM, Digital Twin development, GIS integration, AI application, and spatial data governance. Each document was critically examined to assess its alignment with the DTMM. The following Table 2 summarizes the documents, their issuing bodies, and their thematic contributions to Digital Twin maturity, followed by an interpretive synthesis.

Table 2: Reviewed policy and technical documents

No.	Document	Issuing Body	Thematic Focus
1.	Construction 4.0	CIDB	Digitalization in construction, BIM adoption, smart construction vision.
2.	NCP2030	Ministry of Works (KKR)	Digitalization policy horizon, references to AI, Blockchain, Big Data.
3.	JKR BIM Guideline and Standard (2021 Edition)	JKR	BIM execution workflows, CDE, project-level model structuring and standardization.
4.	PKPUP 12/2021	JUPEM	Geomatics centralized, geospatial data acquisition, cadastral and GNSS survey standards.
5.	PKPUP 6/2009	JUPEM	Cadastral centralized, focusing on cadastral survey workflow in digital environment
6.	MyDIGITAL Blueprint (2021)	Economic Planning Unit (EPU)	Public sector digitalization, data infrastructure, cloud governance.
7.	National AI Roadmap (2021)	MOSTI	Strategic AI priorities, ethics, talent, and governance.
8.	Smart City Implementation Guidelines at the Proposal Development Level (PPBP)	PLANMalaysia	Smart urban governance, digital infrastructure, IoT integration, multi-domain city services.

Table 3: The identified content in relation to digital transformation, BIM, geospatial integration, and AI

No.	Policy Document	Manifest Content Identified
1.	Construction 4.0	"Smart construction", "BIM implementation", "digital transformation", "productivity through digitalization", "lifecycle project management", "modularization and prefabrication"
2.	NCP2030	"Artificial Intelligence (AI)", "Big Data", "Blockchain", "digital innovation", "advanced construction technologies", "sustainable built environment"
3.	JKR BIM Guideline and Standard	"Common Data Environment (CDE)", "Level of Detail (LoD)", "coordination model", "discipline-specific modelling", "model submission protocol", "BIM Execution Plan"
4.	PKPUP 12/2021	"survey standard", "GNSS accuracy", "topographic data", "control point network", "spatial integrity", "national geodetic reference system", "BIM"
5.	PKPUP 6/2009	"cadastral survey", "field measurement protocol", "digital boundary", "parcel accuracy", "survey workflows"
6.	MyDIGITAL Blueprint (2021)	"cloud-first", "data interoperability", "smart infrastructure", "public sector digitalization", "cybersecurity governance", "digital economy"
7.	National AI Roadmap (2021)	"AI talent ecosystem", "ethical AI", "AI adoption in key sectors", "trustworthy AI", "cross-sectoral AI governance", "machine learning model development"
8.	PPBP	"Smart Governance", "AI", "IoT", "big data", "digital Infrastructure", "real-time monitoring"

Each of these documents contributes to different layers of the Digital Twin ecosystem. The Construction 4.0, developed by CIDB, frames BIM adoption as part of the Smart Construction agenda [10]. Although it champions digitalization, it stops short of mandating GIS integration or AI-based scenario modelling. Similarly, the NCP2030 envisions digital technologies, such as AI, Blockchain, and Big Data, as enablers of future construction practices [11]. However, it remains aspirational and offers no concrete mechanisms or KPIs for progressing through DTMM stages. The JKR BIM Guideline and Standard is arguably the most operational document, detailing workflows, model submissions, and interdisciplinary coordination [12]. It reinforces standardized BIM practices across public works projects and establishes CDE usage, LoD compliance, and discipline-specific deliverables. From the geospatial domain, JUPEM's PKPUP 12/2021 and JUPEM PKPUP 6/2009 demonstrate JUPEM's leadership in geomatics application, spatial data quality, GNSS positioning, and cadastral mapping [13] and [14]. These instruments ensure survey precision and metadata integrity but lack semantic and technical interoperability with BIM schemas such as IFC or CityGML.

At the macro policy level, the MyDIGITAL Blueprint [21] outlines national priorities for digital government, data economy, and infrastructure modernization. Though not construction-specific, its emphasis on cloud platforms, data interoperability, and digital ID systems offers enabling infrastructure, especially in supporting real-time analytics. Nonetheless, it lacks sectoral alignment with BIM, GIS, or the built environment. The National AI Roadmap [27] by Ministry of Science, Technology,

and Innovation (MOSTI) articulates strategic intent for AI innovation across sectors, including governance, ethics, and capacity building. Unfortunately, it does not explicitly address the application of AI in the built environment, nor does it propose a maturity model for infrastructure systems. Lastly, the PPBP [28] contributes a municipal-scale perspective, framing smart city development through seven strategic domains including smart governance, digital infrastructure, and IoT integration. While it promotes real-time systems and data-driven service delivery, its guidance remains thematic and lacks operational directives for BIM-GIS-AI convergence or progression through DTMM levels.

4.2 Initial Familiarization

In this phase, the core content of each policy document was reviewed through repeated reading to identify explicit content, terminologies, and stated objectives. The purpose was to detect how each document positions itself in relation to digital transformation, BIM, geospatial integration, and AI. This familiarization stage revealed the policy vocabulary, priority areas, and scope of digitalization across different institutions. It confirmed that while BIM and digitalization are mentioned frequently as shown in Table 3, references to maturity staging, semantic interoperability, or cross-platform coordination are largely absent.

4.3 Code and Thematic Themes

From the manifest content, an initial theme was developed from inductive keywords that emerging from the policy text. Six themes were generated as shown in Table 4.

Table 4: The developed themes based on the policy keywords

No.	Themes	Emerging Policy Keywords
1.	BIM-GIS interoperability	"integrated platform", "cross-platform data exchange", "data interoperability"
2.	AI governance and strategy	"ethical AI", "AI roadmap", "AI talent", "predictive systems"
3.	Spatial data governance	"spatial integrity", "survey regulation", "GNSS standard", "metadata accuracy"
4.	Institutional fragmentation or siloed implementation	"agency-specific mandate", "disconnected systems", "lack of coordination"
5.	Smart city or infrastructure modernization efforts	"smart lighting", "IoT infrastructure", "sensor integration"
6.	Absence of enforceable regulation or standards	No binding clauses, policy lacks legislative support or implementation protocols

4.4 Interpretive Synthesis: Key Insights

In the final analytical stage, thematic categories were synthesized to derive key insights. This synthesis was designed not only to inform the narrative flow of the results but also to support the strategic framing of Malaysia's digital transformation readiness. Two key insights were synthesized which are (i) institutional and regulatory fragmentation and (ii) implementation gaps and operational constraints.

4.4.1 Institutional and regulatory fragmentation

Malaysia's Digital Twin ecosystem operates within a fragmented institutional and legal landscape. Multiple agencies lead various digital initiatives, but their efforts often remain siloed and uncoordinated. CIDB promotes BIM through the Construction 4.0 Strategic Plan, JKR enforces BIM standards in public projects, JUPEM governs surveying, spatial data, and geodetic infrastructure via PKPUP circulars, while PLANMalaysia focuses on urban planning. National-level AI policies are shaped by EPU and MOSTI. However, despite this broad engagement, there is no centralized authority or shared governance framework to align BIM, geospatial, and AI systems into an integrated Digital Twin strategy. For instance, JKR's BIM Guideline emphasizes project coordination, Common Data Environments (CDE), and Level of Detail (LoD) compliance. Yet, it lacks guidance on spatial integration or predictive analytics, which are essential for achieving DTMM levels ML3–ML5.

Similarly, JUPEM's PKPUP 12/2021 ensures spatial data accuracy, but the absence of semantic compatibility with BIM formats such as IFC or CityGML hinders interoperability for dynamic modelling. Overlapping mandates and fragmented inter-agency collaboration continue to impede Malaysia's Digital Twin implementation. While multiple agencies are actively involved, CIDB in digital construction, JKR in BIM execution, JUPEM in spatial data regulation, PLANMalaysia in smart

city planning, and EPU and MOSTI in AI policy, there is no centralized governance structure to align their roles. This results in fragmented strategies, duplicated initiatives, and digital systems that operate in parallel rather than through integrated workflows. These institutional gaps mirror challenges faced in other Southeast Asian nations, Malaysia's progress currently aligns with ML1–ML2 stages, similar to Jakarta's smart city efforts [29], while Singapore's Virtual Singapore demonstrates more advanced maturity (ML3–ML4) through strong policy coordination and integrated BIM-GIS platforms [9].

The legal environment also reflects this disconnect. While Construction 4.0 promotes digitalization, it does not mandate cross-platform interoperability or define maturity pathways aligned with DTMM. Its strategic focus lacks legal enforcement. The NCP2030 and MyDIGITAL Blueprint highlight AI and Big Data for smart infrastructure, yet they remain aspirational, without statutory mechanisms to support real-time modelling, data standards, or ethical automation. JUPEM's spatial governance framework offers robust control over spatial accuracy and metadata, but it is not linked legally to BIM, digitalization of cities or simulation models. Likewise, PLANMalaysia's PPBP framework identifies smart city domains like real-time monitoring and digital infrastructure, but without enforceable mandates or technical interoperability requirements. As a result, existing instruments support only foundational maturity (ML1–visualization), falling short of enabling simulation, optimization, or autonomy required in ML3–ML5 environments. In summary, Malaysia's fragmented institutional responsibilities and non-binding legal instruments collectively hinder Digital Twin progression. Without unified governance and enforceable technical standards, integration between BIM, GIS, and AI remains theoretical rather than operational.

4.4.2 Implementation gaps and operational constraints

Despite policy ambitions and technical guidelines, the implementation landscape reveals significant bottlenecks. First, there is no standardized framework for evaluating digital maturity levels in infrastructure projects. Project teams may adopt BIM without integrating geospatial data, and vice versa. As a result, BIM models often lack geographic referencing, while geospatial data is underutilized in detailed design and asset modelling. This separation inhibits ML2–ML3 maturity. Second, the use of AI remains conceptual. While NCP2030 and MyDIGITAL Blueprint reference AI applications in transport and utilities, there is no mechanism requiring infrastructure tenders or urban planning submissions to demonstrate AI-readiness or predictive capability. This gap is further compounded by the absence of AI-compatible data standards in the JKR BIM ecosystem and the lack of temporal data integration in JUPEM's spatial databases. Without historical and real-time data fusion, ML3 (Predictive) maturity remains unattainable.

Third, talent gaps persist. The integration of BIM, geospatial technology, and AI requires multidisciplinary skills that are currently fragmented across agencies and consultancies. Local authorities and state governments face challenges in sourcing professionals trained in both spatial intelligence and data science. Moreover, training programs remain focused on foundational BIM or geospatial skills, rarely addressing AI-model deployment, ethical data handling, or scenario simulation. Furthermore, challenges related to talent capacity, data infrastructure readiness, and maturity benchmarking worsen implementation gaps. One critical enabler that remains underutilized is a comprehensive data management system, including structured CDE platforms, governed by standards such as ISO 19650-1:2018 (Part 1: Concepts and principles) [30] and ISO 19650-2:2018 (Part 2: Delivery phase of the assets) [31]. Without such systems, data generated through BIM, GIS, and sensor networks remains fragmented and difficult to leverage across project lifecycles. Equally important is the institutionalization of digital work processes that allow for seamless collaboration, data validation, and traceable decision-making from design to decommissioning. These processes are essential for achieving full lifecycle value and driving continuous improvement across the built environment.

Finally, there is limited funding support for Digital Twin pilot zones. While certain municipalities like Cyberjaya and Putrajaya have launched Smart City testbeds [32] and [33], these initiatives are technology-centric and lack policy guidance aligned to maturity frameworks. The absence of KPIs referencing DTMM levels or AI performance outcomes limits their evaluative utility and scalability. A case in point is the Putrajaya Smart City Blueprint, which outlines initiatives such as IoT-based traffic systems, integrated CCTV monitoring, and e-participation dashboards [33]. While these efforts align with ML1 (Status) and ML2 (Informative) stages in the DTMM, providing real-time data feeds and basic service integration, they lack the institutional mechanisms and policy alignment to scale toward predictive modelling or AI-led decision systems. Particularly, despite deploying digital technologies, the initiative does not embed BIM-GIS interoperability or AI-readiness frameworks, nor does it reference DTMM benchmarks in project planning.

In practical terms, BIM-GIS integration allows 3D building models to be georeferenced within spatial databases, enabling city-scale analysis. For example, BIM's IFC data can be converted into CityGML or imported into geodatabases. Geospatial layers (e.g., flood zones, utilities) can then be overlaid for scenario testing. AI algorithms, especially in Python or cloud-based systems like Google Earth Engine (GEE), can be deployed to detect anomalies, simulate occupancy trends, or optimize space utilization. However, Malaysia lacks standardized workflows to automate these exchanges, and interoperability remains a challenge due to inconsistent schemas and platform siloing. This underscores the central proposition of the paper, without cross-agency coordination and policy mandates, even technologically advanced municipalities risk plateauing at low maturity levels.

4.5 Strategic Opportunities and Policy Recommendations

Despite the fragmented landscape, Malaysia possesses the institutional infrastructure and policy awareness necessary to leapfrog into higher maturity tiers. Several strategic interventions are recommended as shown in Table 5. These strategies offer a practical roadmap to bridge policy and implementation gaps, helping Malaysia advance digital integration and strengthen its position in the global Digital Twin landscape.

Table 5: Strategic interventions recommendation

Focus Area	Policy Action	Target Maturity Level
Institutional Integration	Establish a Digital Twin Coordination Unit (DTCU) to oversee cross-ministerial digital convergence.	ML2–ML5
Legal Reform	Develop a Unified Digital Infrastructure Act mandating BIM-GIS-AI interoperability and aligning public procurement with maturity benchmarks.	ML3–ML5
Technical Standardization	Mandate use of model standards such as IFC, CityGML, ISO 19650, and AI in all public digital infrastructure projects.	ML1–ML4
Talent and Capacity	Launch a BIM-GIS-AI Fellowship Program for urban digital leaders across public agencies and local councils.	ML2–ML5
Funding and Evaluation	Create Smart Twin Pilot Zones with allocated funding, maturity-linked KPIs, and longitudinal monitoring.	ML3–ML5

5. Conclusion

The digital transformation of Malaysia's construction and geospatial sectors is undeniably underway, driven by national strategies such as the Construction 4.0, NCP2030, and the MyDIGITAL Blueprint. Central to this transformation is the aspiration to move beyond isolated digital tools such as BIM and GIS, toward integrated, intelligent systems known as Digital Twins. These virtual environments, when fully realized, can transform the design, construction operation, and governance of infrastructure assets through real-time monitoring, predictive modelling, and autonomous control. Conversely, as this study has demonstrated, Malaysia's current policy and institutional landscape supports only the early stages of this maturity journey. By applying the DTMM as an analytical lens, this study has critically examined how Malaysian policies align with the progressive stages of digital maturity, from ML0 (no twin) to ML5 (autonomous control). The findings show that while current frameworks, including the JKR BIM Guideline and Standard, JUPEM PKPUP circulars, and strategic plans under Construction 4.0 and NCP2030, establish important foundations for 3D modeling and data standardization (ML1–ML2), they fall short of advancing toward predictive (ML3), optimization (ML4), and autonomous (ML5) maturity levels. Institutional fragmentation remains a primary barrier. Despite commendable efforts by CIDB, JUPEM, PLANMalaysia, and JKR, the absence of a central coordinating body for Digital Twin development results in overlapping mandates, duplicated efforts, and missed opportunities for data interoperability. Legal instruments are similarly fragmented. While each agency governs its domain effectively, there is no integrated legislative framework that compels cross-platform digital integration, mandates AI-readiness, or incentivizes progression along the DTMM. As such, pilot initiatives in smart city development and

infrastructure modernization often lack the systemic coherence necessary to scale into mature, replicable, and autonomous digital twin environments.

Implementation gaps are further compounded by limited talent capacity, underdeveloped data infrastructures, and the absence of evaluative mechanisms that benchmark maturity levels. Without KPIs aligned to DTMM or regulatory mandates requiring predictive modelling, Malaysia's digital infrastructure projects risk stagnation at intermediate stages. Additionally, the ethical, legal, and social implications of AI integration, critical for ML4 and ML5, remain underexplored within policy narratives, thus stalling long-term strategic planning. Yet, the potential for transformation remains significant. This study has outlined a multi-dimensional roadmap for reform, emphasizing the establishment of DTCU, legislative consolidation under a Unified Digital Infrastructure Act, and the institutionalization of DTMM-linked KPIs within public procurement and infrastructure funding mechanisms. It also underscores the need for professional development programs that integrate technical, regulatory, and ethical competencies across BIM-GIS-AI domains. Malaysia's Digital Twin progress is evident but advancing maturity levels depends more on policy vision and institutional interconnection than on technology alone. This paper offers a maturity framework, cross-agency evaluation, and policy roadmap to help Malaysia build a digitally resilient, AI-driven built environment.

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