Enhancing Indonesia's Transportation Infrastructure Planning Through Bim and Digital Twins

Heru Tri Saksena

Abstract— This research paper systematically examines the integration of Building Information Modeling (BIM) and Digital Twins within the realm of Intelligent Transportation Systems (ITS). The paper underscores the increasing importance of ITS in contemporary urban development, particularly in Southeast Asia, with a focus on Indonesia. Emphasizing the need for sophisticated methodologies such as BIM and Digital Twins to address transportation challenges and enhance infrastructure planning, the study navigates through the role of BIM in diverse facets of transportation infrastructure planning, backed by case studies on Indonesia's New Capital City Road and Bridge Infrastructure. The subsequent exploration of Digital Twins elucidates their conceptual framework and applications in real-time monitoring, control, and decision support within transportation contexts, illustrated through 3case studies on Indonesia's Road and Bridge Infrastructure. The paper meticulously dissects the synergies between BIM and Digital Twins, addressing integration challenges and delineating the multifaceted benefits arising from their collaborative approach, encompassing enhanced visualization, real-time monitoring, predictive maintenance, cognitive functions, and data-driven decision-making. The integration's implications for sustainability, resilience, and real-time decision support for adaptive traffic management are scrutinized. Shifting towards policy implications, the paper advocates for ethical considerations, emphasizing investments in training programs, standardization efforts, and collaborative initiatives to facilitate the ethical adoption of BIM and Digital Twins. It stresses the significance of cross-disciplinary collaborations, ethical policy recommendations, continuous research and development, and education programs to foster an ethical and supportive environment. In conclusion, the paper summarizes its main findings, ethical considerations, and future research directions, encapsulating a comprehensive exploration of ethical considerations in the integration of BIM and Digital Twins within the context of intelligent transportation systems, providing ethical guidelines and a roadmap for researchers and practitioners committed to ethical advancements in this domain. The publication adheres to the ethical standards and guidelines set forth by academic and research communities.

Keywords— Digital Construction, Building Information Modeling (BIM), Intelligent Transportation System (ITS), Collaboration, Resilience, Sustainability, Adaptive Decision-Making.

1 Introduction

Intelligent Transportation Systems (ITS) have become increasingly significant in modern urban development due to their ability to address various transportation challenges using information and communication technologies (ICT) [1]. ITS aims to improve transport performance and quality by applying information and control technologies to transportation system operations [2]. The implementation of ITS offers safer, greener, and more convenient mobility while reducing the impact on the environment [3]. Furthermore, ITS optimizes traffic in major cities, saving money, improving living standards, ensuring safety, and reducing environmental impact [4].

In the context of Southeast Asia, particularly Indonesia, the implementation of ITS hold's great potential. As evident from a study on carbon emissions from the transportation sector during the Covid-19 pandemic in the Special Region of Yogyakarta, Indonesia, government policies have significantly impacted energy demand and transportation patterns [5]. This underscores the need for advanced methodologies like Building Information Modeling (BIM) and Digital Twins in improving transportation infrastructure planning. BIM-based descriptions of ITS for roads can provide valuable insights into the integration of advanced methodologies for transportation infrastructure planning.

The objectives of this paper are to highlight the significance of ITS in modern urban development, emphasize the need for BIM and Digital Twins integration in transportation infrastructure planning, and outline the specific contributions of these advanced methodologies to the implementation of ITS in Southeast Asia, particularly Indonesia. By synthesizing the existing research on ITS and its applications, this paper aims to provide a comprehensive understanding of the potential implementation of advanced methodologies in the context of Southeast Asia, with a specific focus on Indonesia.

2 Building Information Modeling (BIM) in Transportation Infrastructure Planning

2.1 Introduction to BIM

Building Information Modeling (BIM) is a transformative approach that has gained significant traction in the construction and infrastructure domains. It involves creating digital representations of physical and functional characteristics of a facility, providing a reliable basis for decision-making throughout its lifecycle. BIM applications have been widely utilized in various

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Fig. 1. Augmented Reality on road and bridge infrastructure in Indonesia's New Capital City Construction

Fig. 2. Driving simulator on road and bridge infrastructure in Indonesia's New Capital City Planning

construction projects, including rapid transit systems, infrastructure projects, road infrastructure, and bridge construction. In the context of rapid transit systems, BIM has been employed for planning and delivery, enabling metro management companies, design and construction firms, and construction software vendors to leverage their capabilities for efficient project execution [6]. Furthermore, in infrastructure projects, collaboration-based BIM model development management systems have been instrumental for general contractors, emphasizing the need for effective construction management during BIM implementation [7]. Additionally, case studies have demonstrated the successful implementation of BIM in infrastructure projects, highlighting its potential for enhancing project outcomes and efficiency [8].

Specifically focusing on road infrastructure, BIM has been utilized to enhance the planning process, design, and construction of projects, offering a novel approach to design, construction, and facility management [9]. Moreover, in the realm of bridge infrastructure, BIM has been instrumental in the development of detection and safety evaluation systems, providing a comprehensive framework for ensuring the structural integrity and safety of bridges [10]. Additionally, BIM-based mixed-reality applications have been employed for bridge inspection and maintenance, showcasing the potential of BIM in revolutionizing traditional inspection processes and enhancing maintenance activities for bridges [11].

2.2 BIM in Transportation Planning

Building Information Modeling (BIM) methodologies offer significant potential to enhance accuracy and efficiency in the planning and design of transportation infrastructure. BIM provides a novel approach to design, construction, and facility management, utilizing digital representations of the infrastructure process to facilitate the exchange and interoperability of information in digital format [9]. The implementation of 4D BIM in infrastructure construction time planning enhances communication quality from the infrastructure contractor perspective, thereby increasing planning efficiency and overall project performance [12]. Furthermore, the use of road microsimulation software within BIM environments has been preliminarily assessed, demonstrating the promising application of BIM in transportation infrastructure planning. In the context of road rehabilitation and reconstruction projects, the implementation of BIM is believed to improve planning accuracy, mitigate construction risks, and better plan the entire life cycle of infrastructure asset projects [13]. Additionally, the application of BIM techniques to infrastructure lifecycle management has rapidly increased, aiming to improve the efficiency of infrastructure management systems [14]. Moreover, BIM's procedural modeling-based approach for railway design has revolutionized the field of architecture and construction, minimized errors and made the entire design, construction, and management process more efficient [15].

The utilization of BIM in smart cities has been associated with optimized mathematical models for energy-efficient construction management, ensuring the integrity and accuracy of information data interchange, and maintaining the efficiency of information exchange in intelligent construction [16]. Furthermore, understanding the relationship between BIM application behavior and sustainable construction is crucial for improving the application efficiency of BIM in sustainable construction [17]. In the Ghanaian construction industry, the assessment of BIM awareness, knowledge, and adoption has highlighted the intelligent 3D model-based process that provides professionals with the insight and tools to efficiently plan, design, construct, and manage buildings and infrastructures [18]. Additionally, the practical use of BIM modeling for road infrastructure facilities has removed the human factor from final drawings and 3D models, improving the efficiency of the transport infrastructure facilities management system [19].

2.3 Case Studies: BIM Implementation on Indonesa's New Capital City Road and Bridge Infrastructure

Jakarta, Indonesia's existing capital and economic hub, grapples with several challenges such as land subsidence, pollution, and congestion, while accommodating a significant population of at least 31.5 million, constituting 11% of the nation's populace. In response to these issues, a plan has been set in motion to relocate the national capital from Jakarta to Nusantara. Nusantara is situated on the eastern coast of Borneo, specifically in the province of East Kalimantan. Spanning an area of 2,560 km2 (990 sq mi), the city will be surrounded by picturesque hilly landscapes, lush forests, and a natural bay.

The overarching design philosophy for Indonesia's New Capital City revolves around five core principles. Firstly, the

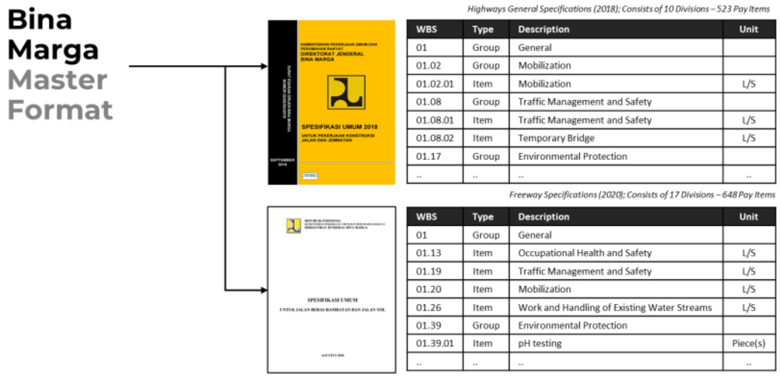

Fig. 3. Directorate General of Highways classification system on BIM Objects

concept of a "Smart Workplace" aims to foster collaboration and connectivity, prioritizing healthy and green office spaces. Secondly, "Smart Living" emphasizes high-performance, efficient, and inclusive community living. The third principle, "Smart Mobility and Transportation," centers on fast, efficient, and healthy transportation options, with a strong reliance on public transit and smart transport systems. "Smart Nature Preservation," the fourth principle, underscores the importance of maintaining a balance with nature, including the conservation of flora and fauna diversity and the development of green spaces. Lastly, the fifth principle, "Smart National and Cultural Transformation," seeks to promote national and cultural unity through symbolic shared spaces.

To successfully implement Building Information Modeling (BIM) in the development of Indonesia's New Capital City, a collaborative effort is essential among various entities, including government agencies, project stakeholders, and industry professionals. The key components of this implementation strategy involve the establishment of BIM standards, protocols, and training programs aimed at facilitating a seamless adoption and effective utilization of the technology. The integration of BIM holds the potential to revolutionize the development process, offering advantages such as streamlined workflows, enhanced collaboration, and optimized infrastructure development within Indonesia's new capital city. Through careful coordination and adherence to BIM principles, the stakeholders can capitalize on the technology's capabilities to ensure the success of the numerous projects that make up the new capital city.

One significant aspect of this development initiative is the sheer scale, encompassing a total of 158 projects. A detailed breakdown of the progress of these projects is presented in the accompanying slide. Notably, the projects are categorized, with 40 dedicated to Road and Bridge development. This categorization provides a glimpse into the diverse range of undertakings that constitute the comprehensive development plan for Indonesia's New Capital City.

In Indonesia, the implementation of Building Information Modeling (BIM) is regulated by various laws and instructions. Government Regulation 2021 focuses on the Implementing Regulations of Law 2002 related to Buildings. Additionally, PUPR Ministerial Instruction Number 2022 outlines strategies to prevent deviations in the PUPR Ministry's Goods/Services Procurement Process from 2022 to 2024. Other regulations, such as PUPR Ministerial Regulation 2021 on Construction Implementation Guidelines and PUPR Ministerial Regulation 2018 regarding State Building Construction, contribute to the overall framework governing the use of BIM. For the road and bridge sector, Road and Bridge Sector Guidelines 2023 provide comprehensive guidance on the application of BIM in road and bridge construction. These guidelines intricately regulate the implementation of BIM, emphasizing its role in various aspects, particularly in bridge asset management across Indonesia. Circular letters from relevant authorities, like Circular Letter 2023 from the Director General of Water Resources and Circular Letter 2022 from the Director General of Housing, offer detailed technical instructions and guidelines for leveraging BIM in infrastructure construction and housing projects, respectively.

The implementation of Building Information Modeling (BIM) in the construction of Indonesia's New Capital City Road and Bridge Infrastructure, managed by the Directorate General of Highways, involves the development of information-rich BIM models, cloud-based project management, and the utilization of cutting-edge technologies such as Augmented Reality (Fig. 1), Laser Scanning Technology, and Driving Simulator (Fig. 2).

In the creation of BIM models, the Directorate General of Highways employs a classification system based on the Bina Marga MasterFormat as shown on Figure 3. This involves breaking down payment items according to national specifications and payment item standards, specifically the Highways General Specifications (2018) and Freeway Specifications (2020). The classification system serves multiple purposes, including simplifying the sorting of digital assets, streamlining the quantification process, eliminating repetitive work, and ensuring that each element in the BIM model aligns with specifications or payment item standards. The Bina Marga MasterFormat consists of three-digit numbers separated by points, indicating division, subdivision, and the crucial payment item. To support this classification system, various add-ins items were created for Authoring Tools like Revit Assembly code, Civil 3D Pay Item, and Navisworks Quantification Catalog. These tools are essential for infrastructure projects, allowing the creation of federated BIM models. The objective of the Bina Marga MasterFormat and associated tools is to facilitate asset sorting during

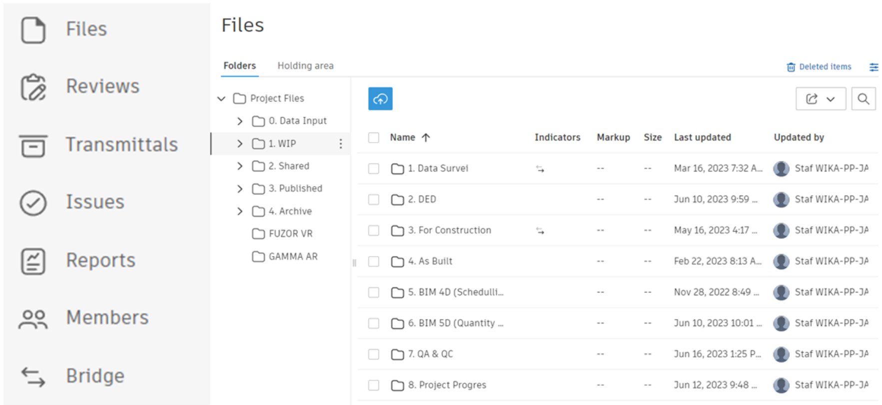

Fig.4. Common Data Environment (CDE) as collaboration platform

asset Management, standardize BIM Objects in the country, and provide quantification templates for Navisworks to ensure compliance with standards during the quantification process. The goal is to help maximize the Self-Estimated Price and Engineering Estimate based on BIM Models, enabling efficien budget planning and proof of payment management for the Appointed party.

Cloud-based project management is conducted using the Autodesk Construction Cloud platform as a common data environment (CDE). Autodesk Construction Cloud, particularly ACC Docs (illustrates on Figure 4), serves various functions such as storing data, facilitating document approval through Reviews, managing records via Transmittals, coordinating issues with the Issues feature, streamlining project processes through Reports, and supporting the PUPR Data Center with the Bridge tool. Within the CDE, the processes of defining, managing, and keeping in touch are crucial. The defining process involves establishing workflows by defining members and their roles, ensuring a smooth collaboration. The management process focuses on regulating folders, data, and security to maintain clean and secure data. Keeping in touch involves converting traditional processes into digital ones by regulating and assisting the appointed party in carrying out activities such as reviews, transmittals, issues, and bridges within the CDE.

All these data are subsequently integrated into a dashboard to facilitate the monitoring process of ongoing projects. This comprehensive approach to BIM implementation and cloud-based project management aims to enhance efficiency, collaboration, and overall project success.

The integration of advanced technologies in the realm of Intelligent Transportation Systems (ITS) has become increasingly vital for optimizing transportation infrastructure. One notable application involves the utilization of a driving simulator, underpinned by a sophisticated combination of Building Information Modeling (BIM) and Augmented Reality (AR) platforms. This innovative approach facilitates the creation of a comprehensive digital representation of road infrastructure, offering a myriad of benefits ranging from design evaluations to safety assessments. To commence this integrated process, a Federated model is generated, commonly authored on platforms such as Civil 3D, Revit, and Infraworks. Subsequently, 3D model editing is undertaken to align the model with the Asetto Corsa Driving Simulator platform, a popular choice accessible on platforms like Steam. However, the conversion of BIM Models to be compatible with driving simulators necessitates careful considerations.

3 Digital Twins For Transportation Networks

3.1 Understanding Digital Twins

Digital twins have emerged as a transformative concept, playing a pivotal role in creating high-fidelity virtual replicas of physical assets. The concept of digital twins involves the use of information such as physical models, data acquisition, historical data, and more to achieve a high-fidelity virtual mapping from physical space to digital virtual space [20]. This concept was first proposed in 2003 and has since been integrated into various domains, profoundly impacting the planning, construction, and governance of warehousing, smart manufacturing, and infrastructure projects.

Digital twins serve as fundamental tools for smart manufacturing, enabling the creation of high-fidelity virtual models for physical objects to simulate their behavior [21]. They are dynamic virtual representations of physical objects or systems across their lifecycle, utilizing real-time data to enable understanding, learning, and reasoning [22]. The essential components of a digital twin model include the real object, the virtual object, and the gathering and processing of data between the physical asset and its digital replica.

One of the defining characteristics of digital twins is their ability to act and behave as their physical counterparts, with an automated transfer of data or information between the physical system and the model [23]. They are integrated multiphysics, multiscale, and probabilistic simulations of complex products, utilizing the best available physical models and sensor updates to mirror the life of their corresponding twin [24]. Digital twins are digital informational constructs of physical systems, providing insight and tools to efficiently plan, design, construct, and manage buildings and infrastructures [25].

The concept of digital twins builds upon advancements in IoT systems and data analytics technologies, allowing for the creation of accurate, real-time digital simulation models for any physical system [26]. They integrate both physical and virtual scenarios/worlds, offering a flourishing tool for various

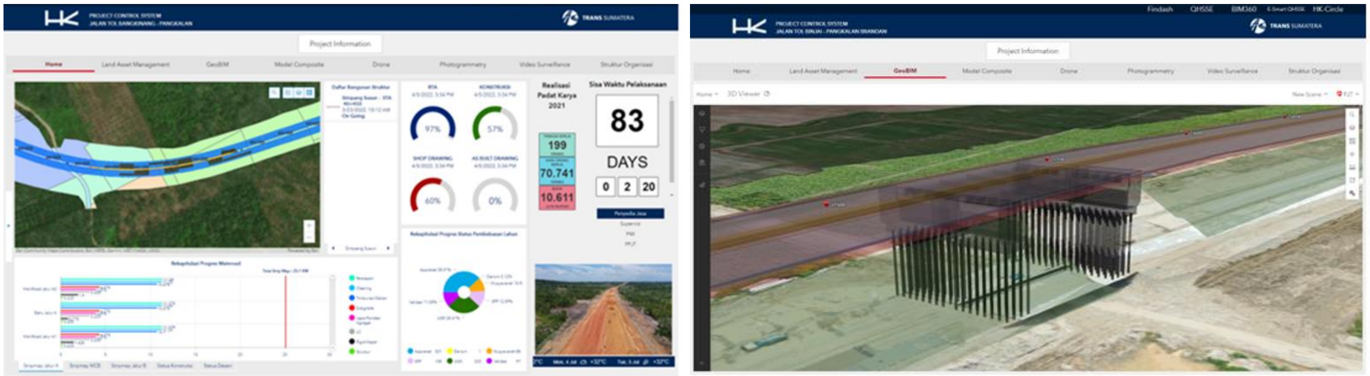

Fig. 5. Hutama Karya's digital twin on road and bridge infrastructure

applications, including safety and comfort, smart homes, and maintenance optimization for multi-unit systems [27].

3.2 Digital Twins in Transportation

Digital twins are virtual representations of physical assets that play a crucial role in the dynamic simulation, monitoring, and management of transportation networks. They enable real-time monitoring, control, and decision-making support, and have been utilized in industries such as manufacturing, aerospace, and healthcare for simulation, monitoring, and control purposes [28].

In the context of transportation networks, digital twins have been applied to bridge groups, traffic load monitoring, and electrical power communication networks, allowing for real-time monitoring and control, as well as analysis, prediction, and management of physical equipment [29], [30]. Furthermore, digital twins have been instrumental in smart manufacturing, creating high-fidelity virtual models for physical objects to simulate their behavior, thus offering valuable insights for transportation network management [21]. Their applications extend to safety and comfort, predictive maintenance, and intelligent monitoring of substations, making them widely applicable in environmental monitoring equipment, power transmission, and transformation shipment inspection, among others [31].

Additionally, digital twins have been utilized in healthcare facility management, roadway construction management, and as a geodata hub for digital twin cities [32], [33], [34]. The integration of artificial intelligence (AI) in digital twins has further enhanced their capabilities, enabled autonomous management of roadway construction and provided opportunities for network digital twins [35]. Digital twins have also been explored for their potential in situation-specific choreography of decentralized things, highlighting their versatility in managing complex systems [36].

3.3 Case Studies: Digital Twin on Indonesia's Road and Bridge Infrastructure

In the dynamic landscape of Indonesia's infrastructure development, the integration of cutting-edge technologies has become pivotal, and the concept of Digital Twins is emerging as a transformative force in the management of road and bridge infrastructure. A Digital Twin, essentially a virtual counterpart of a physical object or system, harnesses real-time data and sensor technologies to create a comprehensive digital representation.

The implementation of Digital Twins in the domain of road and bridge infrastructure offers a significant advantage through its continuous monitoring and maintenance capabilities. Utilizing real-time data streams, authorities gain valuable insights into the condition of critical assets, facilitating early detection of issues such as structural wear and tear. This proactive approach not only minimizes downtime but also streamlines maintenance efforts effectively.

Moreover, Digital Twins provides avenues for simulation and planning. Decision-makers can harness this technology to simulate a range of scenarios, enabling a comprehensive assessment of potential impacts on the infrastructure. This proves indispensable in the planning of new construction projects, optimizing traffic flow, and making well-informed decisions regarding upgrades or expansions. Notably, Hutama Karya, one of Indonesia's State-Owned Enterprises (SoE), has adopted Digital Twins for managing the planning phase. This involves integrating project monitoring statuses, 3D projects representations, GIS, and BIM Models to enhance the efficiency and precision of their planning processes as shown on Figure 5.

Asset management in the realm of infrastructure is significantly enhanced by Digital Twins. The technology provides a holistic view of the entire infrastructure, enabling effective management of individual components. Predictive analytics can be employed to forecast maintenance needs, optimizing resource allocation and extending the lifecycle of assets. Informed decision-making is a cornerstone of effective governance, and Digital Twins play a pivotal role in facilitating data-driven decisions. By collecting and analyzing real-time data, decision-makers gain the insights needed to manage infrastructure efficiently. This includes informed choices on infrastructure management strategies, targeted investments, and the formulation of policies that align with the evolving needs of the region. Directorate General of Highways also implemented Digital Twin by using laser scanning (as shown on Figure 6) to replicate the as-built bridge before injecting the information like sensors, IoT, etc [37].

Collaboration is another dimension where Digital Twins foster efficiency. This technology facilitates seamless collaboration between various stakeholders, including government agencies, construction firms, and maintenance teams

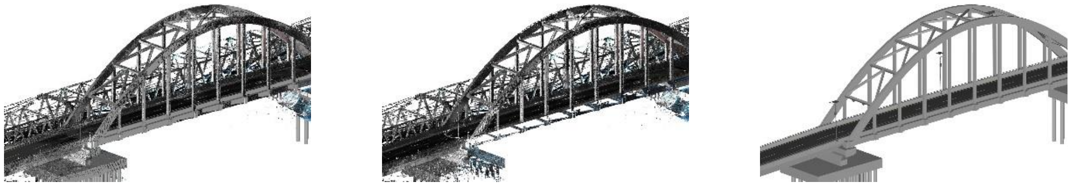

Fig. 6. Directorate General of Highways's digital twin on bridge asset management

Information is shared in a centralized and accessible manner, fostering a collaborative ecosystem that contributes to the overall success of infrastructure projects.

4 Synergies Between BIM And Digital Twins

4.1 Integration Challenges and Solutions

When integrating Building Information Modeling (BIM) and Digital Twins in transportation infrastructure planning, several challenges and potential solutions arise. The integration of these digitalization tools at the organizational level poses not only opportunities but also some challenges for the actors involved in infrastructure projects [38]. The introduction of environmental information requires integration of BIM and Geographic Information Systems (GIS), which, however, brings new challenges, as GIS and BIM follow different paradigms [39]. Furthermore, as the stakeholders' requirements range of Digital Twins (DTs) expands from a single building to multiple buildings and regional/city levels, the information and data management gaps (e.g., BIM and GIS data integration) are more challenging and critical [40].

One of the challenges is the interoperability between BIM and Digital Twins, as they often use different data formats and standards. This can lead to difficulties in exchanging and integrating data between the two systems. To address this, a novel approach of technical/environmental decision-making process in transport infrastructure design has been proposed, aiming to integrate BIM and GIS data for better decision-making [41]. Additionally, approaches for integrating information from semantic 3D city modeling and BIM, such as semantic transformation between CityGML and IFC, have been described, providing a potential solution for interoperability challenges [42].

Another challenge is the complexity of integrating BIM and Digital Twins for existing infrastructure. A semi-automatic approach has been developed to establish a systematic, accurate, and convenient digital twinning system based on images and CAD drawings, addressing the challenge of geometric digital twinning for existing buildings [43]. Furthermore, the use of road microsimulation software within BIM environments has been proposed, offering a comparative analysis of different approaches relying on BIM-based tools for transport simulation tasks [44].

The integration of advanced information technologies in civil infrastructure construction and maintenance, such as roads, highways, and bridges, has been a focus of industry and academia collaboration. This collaboration aims to apply BIM for civil infrastructure projects, providing potential solutions for the challenges associated with integrating BIM and Digital Twins in transportation infrastructure planning [45].

4.2 Benefits of Combined Approach

The integration of BIM and Digital Twins offers a wide array of benefits, ranging from enhanced visualization and simulation capabilities to real-time monitoring and control of transportation infrastructure as shown on Table 1. This integration has the potential to revolutionize the planning, design, and management of transportation systems, ultimately leading to improved operational efficiency and sustainability. The current state-of-the-art technologies enabling Digital Twins have been summarized, providing a foundation for the development of cognitive digital twins with autonomous reaction capabilities. This advancement allows for buildings and infrastructure to dynamically react to environmental changes, enhancing adaptability and resilience. Additionally, the integration of BIM and Digital Twins supports data-driven decision-making processes, leveraging rich health information data and accurate health indicators to inform strategic and operational decisions, leading to improved efficiency and performance.

Furthermore, the utilization of BIM and Digital Twins facilitates predictive maintenance and lifecycle management of transport systems, enabling the prediction of asset performance and the optimization of maintenance schedules, leading to cost savings and improved asset longevity. The integration of advanced information technologies in civil infrastructure construction and maintenance, such as roads, highways, and bridges, has been a focus of industry and academia collaboration. This collaboration aims to apply BIM for civil infrastructure projects, providing potential solutions for the challenges associated with integrating BIM and Digital Twins in transportation infrastructure planning.

The current implementation of BIM and Digital Twins in Southeast Asia, particularly in Indonesia, presents a significant opportunity to enhance the efficiency and sustainability of transportation infrastructure. By leveraging the synergies between BIM and Digital Twins, intelligent transportation systems can benefit from improved visualization, real-time monitoring, predictive maintenance, and data-driven decision-making, ultimately leading to more resilient and sustainable transportation network

TABLE 1
Benefits Of Combined Approach of Bim and Digital Twin

N	Benefits	Description
1	Enhanced Visualization and Simulation Capabilities	The integration of BIM and Digital Twins provides enhanced visualization and simulation capabilities, allowing for the creation of high-fidelity virtual models that accurately represent physical assets, leading to improved planning and design processes [46], [47].
2	Real-Time Monitoring and Control	The combination of BIM and Digital Twins enables real-time monitoring and control of transportation infrastructure, allowing for the seamless integration of data from physical assets into virtual models, leading to improved decision-making and operational efficiency [20], [24].
3	Predictive Maintenance and Lifecycle Management	The utilization of BIM and Digital Twins facilitates predictive maintenance and lifecycle management of transport systems, enabling the prediction of asset performance and the optimization of maintenance schedules, leading to cost savings and improved asset longevity [48], [49].
4	Cognitive Functions and Autonomous Reaction	The integration of BIM and Digital Twins allows for the development of cognitive digital twins with autonomous reaction capabilities, enabling buildings and infrastructure to dynamically react to environmental changes, leading to improved adaptability and resilience [46], [50].
5	Data-Driven Decision Making	The synergy between BIM and Digital Twins supports data-driven decision-making processes, leveraging rich health information data and accurate health indicators to inform strategic and operational decisions, leading to improved efficiency and performance [48], [51].
6	Integration with IoT and AI Systems	The combination of BIM and Digital Twins with Internet of Things (IoT) networks and artificial intelligence (AI) systems facilitates the development of cognitive digital twins, enabling autonomous and dynamic responses to environmental changes, leading to improved operational intelligence [46], [52].
7	Circular Economy and Sustainability	The role of digitalization in facilitating circular economy principles is enhanced through the integration of BIM and Digital Twins, supporting sustainable practices and resource optimization in the built environment, leading to reduced environmental impact [51], [53].
8	Improved Asset Management and Automation	The integration of BIM and Digital Twins supports improved asset management and automation, enabling real-time updates of building status and big data volume, leading to streamlined operations and maintenance [47], [49].

4.3 Future Trends

The collaboration between Building Information Modeling (BIM) and Digital Twins in the context of Intelligent Transportation Systems (ITS) is undergoing transformative changes, with numerous trends and technologies shaping their integration, particularly in Southeast Asia, including Indonesia. This exploration of emerging trends delves into advancements that foresee a future marked by evolution in transportation infrastructure planning and management.

A systematic review by Deng et al [47] identifies technologies propelling the evolution from BIM to Digital Twins in built environments, providing comprehensive insights into the evolving landscape of intelligent building representations. X. Zhang et al [54] focus on an intelligent transportation multi-source data collaboration framework based on Digital Twins, emphasizing the significance of seamless data integration for effective transportation management. Meschini et al [46] explore cognitive digital twins, demonstrating their potential in optimizing space use and real-time wayfinding during evacuation. Jiang et al [55] highlight BIM's key role in driving technological advancements in construction and its expanding scope in transportation infrastructure planning.

Reviewing digital twin technology in the AEC-FM industry, Hosamo et al [20] underscore the significance of information standardization in realizing the potential of digital twins. Yan, Zhou, et al [56] examine intelligent pumped storage power stations based on digital twins' technology, showcasing the role of information technologies in advancing intelligent infrastructure, including transportation systems. Agostinelli et al [57] focus on renewable energy systems controlled by open-source tools and digital twin models, contributing to energy-saving procedures for sustainable mobility.

Peng et al [50] present a case study on digital twin hospital buildings, demonstrating the potential of digital twins in enhancing the management of healthcare facilities. Hetemi [38] emphasize digitalization's role in accelerating the transition of the transport sector, augmented by concepts such as artificial intelligence and smart city technologies. Yogatama et al [58] explore the implementation of Mobility as a Service (MaaS) in Bandung City, showcasing big data integration's potential in transforming transportation systems. Pan et al [59] propose an HDF-based data compression and integration approach, emphasizing multisource associated event-driven city planning and management. Chen et al [60] present a conceptual framework for estimating building embodied carbon based on digital twin technology and life cycle assessment, highlighting sustainable construction practices. Shabelnikov et al [61] propose a digital platform at marshalling yards, emphasizing data fusion for improved infrastructure maintenance planning. Rezaei et al [62] explore digital twins and 3D information modeling in a smart city for traffic control, highlighting the potential advantages of smart cities in achieving sustainability and efficiency. A. Wang et al [63] conduct a preliminary study on the integration control platform of construction waste based on "BIM+GIS" technology, showcasing the potential of integrated control platforms in managing construction waste.

These emerging trends and technologies signify a paradigm shift in the collaboration between BIM and Digital Twins within Intelligent Transportation Systems. From enhanced visualization and simulation capabilities to improved asset management and sustainability practices, the integration of BIM and Digital Twins is poised to revolutionize the transportation infrastructure landscape, paving the way for more efficient and resilient networks.

5 Applications And Implications For Intelligent Transportation Systems

5.1 Resilience and Sustainability

The combined use of Building Information Modeling (BIM) and Digital Twins contributes significantly to the resilience and sustainability of transportation infrastructure. The integration of these technologies offers a wide array of benefits that span from enhanced visualization and simulation capabilities to real-time monitoring and control, ultimately leading to more efficient and resilient transportation networks.

A real-world use case of the Minnamurra Railway Bridge (MRB) in Australia, demonstrating the extended application of BIM (i.e., the DT) to enhance the operation, maintenance, and asset management to improve the sustainability and resilience of the railway bridge. This study showcases the practical application of Digital Twins in managing railway infrastructure, emphasizing the role of BIM in enhancing the resilience and sustainability of critical transportation assets [64]. In their work, Kaewunruen et al [65] highlight the potential of Digital Twins in conducting sustainability and vulnerability audits for subway stations. The study emphasizes the integration of life cycle assessment (LCA) with digital twin applications to enable sustainable development, ultimately enhancing the resilience of metro railway systems globally. This research underscores the role of Digital Twins in promoting sustainability and resilience in urban transportation infrastructure. Furthermore, Hetemi et al [38] explore the potential advantages of smart cities in achieving sustainability, efficiency, optimization, collaboration, and creativity. The study emphasizes the role of smart city technologies in transforming transportation systems, offering insights into the future of smart city technologies in transportation infrastructure. This research provides valuable perspectives on the potential of smart cities in enhancing the sustainability and resilience of urban transportation networks.

Discuss the operationalization of concepts of Digital Twins on different maturity levels for the architectural design process. This study offers insights into the potential of Digital Twins in enhancing the resilience and sustainability of architectural and urban infrastructure, providing valuable perspectives on the application of Digital Twins in transportation infrastructure planning [66].

The combined use of BIM and Digital Twins significantly contributes to the resilience and sustainability of transportation infrastructure. These technologies offer valuable tools for enhancing visualization, real-time monitoring, predictive maintenance, and data-driven decision-making, ultimately leading to more efficient and resilient transportation networks.

5.2 Real-time Decision Support

The seamless integration of Building Information Modeling (BIM) and Digital Twins represents a powerful alliance that revolutionizes the landscape of adaptive traffic management and infrastructure maintenance. This collaboration harnesses advanced technologies and data-driven insights to facilitate real-time decision-making, providing transportation infrastructure stakeholders with the tools to enhance operational efficiency, optimize maintenance activities, and dynamically manage traffic flow in response to changing conditions.

Several studies contribute valuable insights into the potential of this integration. Xie et al [67] emphasize standardized and modularized paradigms for real-time decision-making, highlighting the importance of data integration from diverse sources. Liu et al [68] offer decision tools for safety risk control, focusing on effective control schemes to improve information integration and sharing in the context of transportation infrastructure. Gao et al [69] leverage digital twin and machine learning approaches to address AGV path planning in evolving operational environments, showcasing real-time decision-making applications.

Levy & Subburaj [70] delve into real-time data processing, illustrating how it aids in predicting behavior, generating actionable recommendations, and improving decision-making for adaptive traffic management and infrastructure maintenance. Meanwhile, Lopez-Arevalo et al [71] evaluate the effectiveness of sentinels in gathering data from IoT sensors, supporting decision-making processes, and transforming data into actionable information for real-time decision-making.

In essence, the integration of BIM and Digital Twins offers a holistic approach to data management, analysis, and visualization, ultimately enabling real-time decision-making for adaptive traffic management and infrastructure maintenance. This transformative collaboration emerges as a cornerstone for cultivating more efficient and resilient transportation networks.

5.3 Policy Recommendations

In the realm of intelligent transportation systems (ITS), the integration of Building Information Modeling (BIM) and Digital Twins has emerged as a transformative approach with profound implications for urban development. As policymakers navigate the complex landscape of modern transportation challenges, a strategic focus on incentivizing and facilitating the adoption of these technologies becomes imperative. Policymakers are encouraged to invest in training programs to enhance the expertise of professionals engaged in transportation projects, thereby fostering a workforce capable of leveraging the capabilities offered by BIM and Digital Twins.

Furthermore, a crucial aspect lies in the standardization and interoperability of these technologies. Policymakers should actively promote the development and adherence to industry standards for seamless data exchange between BIM and Digital Twins. This standardization effort not only ensures compatibility across different phases of projects but also facilitates collaboration and knowledge-sharing among diverse stakeholders. Establishing clear guidelines on data security, privacy, and ownership is equally vital to address concerns associated with the digital representation of physical assets.

Collaboration emerges as a key theme, calling for concerted efforts between government agencies, industry stakeholders, and research institutions. Policymakers should foster an environment that encourages the exchange of knowledge, best practices, and successful case studies. Encouraging public-private partnerships becomes instrumental in driving innovation and investment in BIM and Digital Twins technologies. Pilot projects showcasing the practical applications and benefits of these technologies can instill confidence and inspire broader adoption within the industry.

A proactive stance on education is essential, with policymakers investing in programs that integrate BIM and Digital Twins concepts into engineering and architecture curricula. Workshops, seminars, and conferences can serve as platforms for building awareness and enhancing the capacity of professionals involved in transportation projects. Policymakers are urged to keep regulatory frameworks aligned with technological advancements, supporting the responsible use of these technologies.

Additionally, a strong emphasis on continuous research and development is paramount. Allocating funds to support ongoing exploration of emerging trends and technologies ensures that the industry remains at the forefront of innovation. Policymakers can further promote an environmentally sustainable focus by integrating metrics within BIM and Digital Twins, contributing to eco-friendly decision-making in transportation infrastructure projects.

Finally, fostering international collaboration is crucial for staying informed about global best practices and advancements. Policymakers are encouraged to engage with international organizations and other countries to share experiences and insights, contributing to a collective effort in shaping the future of intelligent transportation systems through the integration of BIM and Digital Twins.

6 Conclusions

6.1 Summary of Key Findings

In this comprehensive exploration of Intelligent Transportation Systems (ITS) integration with Building Information Modeling (BIM) and Digital Twins, key findings underscore the transformative potential of these technologies in modern urban development. The study establishes the significance of ITS in addressing transportation challenges through the application of information and communication technologies. Emphasizing the environmental impact and changing transportation patterns, particularly in Southeast Asia, specifically Indonesia, the paper advocates for advanced methodologies like BIM and Digital Twins to enhance transportation infrastructure planning.

The role of BIM in transportation infrastructure planning is elucidated, demonstrating its transformative impact on rapid transit systems, infrastructure projects, road infrastructure, and bridge construction. The integration of BIM in road rehabilitation, construction projects, and railway design emerges as a crucial aspect, showcasing its versatility in enhancing accuracy, efficiency, and sustainability throughout the infrastructure lifecycle. Case studies on Indonesia's New Capital City Road and Bridge Infrastructure further highlight the practical applications and benefits of BIM in the region.

Digital Twins, as high-fidelity virtual replicas of physical assets, are explored for their role in creating dynamic simulations, monitoring, and management of transportation networks. The paper emphasizes the real-time monitoring and control capabilities of Digital Twins in bridge groups, traffic load monitoring, and electrical power communication networks. Case studies on Indonesia's Road and Bridge Infrastructure underscore the diverse applications of Digital Twins in the context of transportation.

The paper addresses challenges and solutions in integrating BIM and Digital Twins, emphasizing the importance of interoperability and data integration. The benefits of combining BIM and Digital Twins, including enhanced visualization, real-time monitoring, predictive maintenance, cognitive functions, and data-driven decision-making, are detailed. The integration is seen as a catalyst for improved asset management, automation, and sustainability, fostering more efficient and resilient transportation networks.

Future trends in the collaboration between BIM and Digital Twins are discussed, showcasing advancements such as cognitive digital twins, intelligent transportation multi-source data collaboration, and the integration with IoT and AI systems. The research highlights emerging technologies and their potential contributions to the evolution of transportation infrastructure planning.

In the context of Southeast Asia, policy recommendations emphasize the need for policymakers to invest in training, standardization, collaboration, education, and continuous research and development. The proactive stance on international collaboration is underscored as a vital element in shaping the future of intelligent transportation systems through BIM and Digital Twins. Ultimately, the study paints a comprehensive picture of the transformative potential of integrating BIM and Digital Twins in the realm of Intelligent Transportation Systems, offering valuable insights for academics, professionals, and policymakers involved in the construction and transportation sectors.

6.2 Future Directions

The integration of Building Information Modeling (BIM) and Digital Twins for transportation infrastructure has paved the way for promising areas of future research and development. As the field progresses, various avenues emerge, each holding the potential to advance the efficiency, sustainability, and resilience of intelligent transportation systems. One area deserving attention involves the exploration and development of advanced interoperability solutions. Researchers can focus on standardized protocols, data formats, and information exchange mechanisms to ensure seamless collaboration among diverse stakeholders in the integration of BIM and Digital Twins.

Another promising avenue is the investigation of methodologies for real-time data fusion and analytics within the integrated framework. This entails exploring advanced analytics techniques, machine learning algorithms, and applications of artificial intelligence to derive meaningful insights for dynamic decision-making in transportation management. Efforts can also be directed towards extending the capabilities of Digital Twins in dynamic simulation and optimization of transportation networks. Research in this domain could concentrate on developing models capable of predicting and optimizing traffic flow, infrastructure performance, and energy consumption in real-time, contributing to more adaptive and resilient systems.

Human-centric design principles can be integrated into BIM and Digital Twins for transportation infrastructure to enhance usability and accessibility. Research should focus on ensuring that digital representations are effectively interactive and insightful for transportation professionals, policymakers, and end-users. A critical area for exploration is the development of comprehensive lifecycle management strategies that leverage BIM and Digital Twins for efficient maintenance planning. Methodologies for predictive maintenance, asset performance optimization, and long-term sustainability can be developed, emphasizing the extension of the lifespan of transportation infrastructure.

Addressing cybersecurity challenges associated with the integration of BIM and Digital Twins is crucial. Research in this area can investigate robust cybersecurity measures and protocols to protect sensitive transportation data, ensuring the integrity, confidentiality, and availability of information within the integrated digital environment. Understanding public perception and acceptance of BIM and Digital Twins in transportation projects is another valuable research direction. Investigating the attitudes, concerns, and expectations of the public, stakeholders, and policymakers can inform strategies for widespread adoption and successful implementation.

Researchers can explore the integration of BIM and Digital Twins within the broader context of smart cities, investigating how these technologies align with other smart city initiatives, such as IoT networks, to create synergies contributing to more intelligent, connected, and sustainable urban transportation systems. In-depth studies on the environmental impact assessment capabilities within integrated BIM and Digital Twins systems are warranted. Methodologies for assessing and mitigating the environmental footprint of transportation projects can be developed, aligning with global sustainability goals. Encouraging cross-disciplinary collaborations between academia, industry, and government agencies is essential. Research initiatives that bring together experts from fields such as urban planning, environmental science, and social sciences can holistically address the challenges and opportunities of integrated BIM and Digital Twins in transportation infrastructure.

These suggested future directions collectively offer a roadmap for researchers and practitioners to contribute to the evolving landscape of intelligent transportation systems through the integration of BIM and Digital Twins. The interdisciplinary nature of these directions reflects the need for holistic approaches that consider technological advancements, user perspectives, and broader societal impacts.

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