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Enhancing Stakeholder Engagement in Transportation Infrastructure Projects through Building Information Modelling

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Abstract – This paper explores the transformative role of Building Information Modelling (BIM) in enhancing stakeholder engagement in transportation infrastructure projects. Drawing on literature, real-world case studies, and survey results from 32 stakeholders, the research examines BIM's capacity to improve communication, collaboration, and decision-making processes. Findings indicate that BIM is widely perceived as effective in visualizing project impacts, supporting early engagement, and influencing design modifications. Despite persistent challenges such as technical integration and training gaps, the study concludes that BIM remains a powerful tool in fostering inclusive and efficient project delivery.

Keywords – Building Information Modelling (BIM), Construction Industry, Stakeholder Engagement, Transportation Infrastructure, Project Management

I. Introduction

Stakeholder engagement is a critical component in the success of infrastructure projects, especially in the complex and often controversial field of transport [1]. As cities expand and public infrastructure demands evolve, project teams face the dual challenge of meeting technical performance standards while aligning with the expectations of diverse interest groups, including government agencies, local communities, and private operators [2]. Traditional methods of communication and coordination have proven inadequate in promoting timely and inclusive dialogue, resulting in project delays, cost overruns and public resistance [3].

BIM offers a digital, collaborative solution to these challenges. Initially adopted for design efficiency and construction coordination, BIM has increasingly been recognized for its potential to support meaningful stakeholder engagement. Through its integrated visualization, simulation, and data management capabilities, BIM facilitates better transparency and real-time interaction among project participants. It enables stakeholders to observe proposed developments in three dimensions and to influence planning outcomes through more accessible consultation processes [4].

This paper explores how BIM supports stakeholder engagement within the context of transportation infrastructure, with a particular focus on its practical applications, associated challenges, and the lessons derived from case studies and survey data. It argues that BIM has the capacity to enhance decision-making processes, align project outcomes with stakeholder expectations, and contribute to more sustainable and socially responsive infrastructure delivery.

II. Key Concepts: Transportation Systems and BIM

Modern transport systems consist of multiple and interconnected networks designed to support the efficient movement of people and goods. These networks include roads, railways, air transport systems, and maritime routes, each underpinned by a complex set of infrastructure assets such as bridges, tunnels, stations, terminals, and interchange nodes [5]. Urban transport systems, in particular, need to navigate spatial, regulatory, and environmental constraints while meeting growing demands for safety, accessibility, and environmental performance [6].

The planning and construction of such infrastructure involves a range of disciplines and stakeholders, from engineers and architects to environmental consultants, planners and the public. As the number of actors increases, so does the challenge of maintaining consistent, timely communication and decision-making processes throughout the project lifecycle [7]. Effective stakeholder engagement is essential to achieving technical success, avoiding conflict, and gaining community support. BIM is a digital methodology that enables the generation, organisation, and sharing of data-rich models across all stages of a project's lifecycle from conceptual design to operation and maintenance [8]. In transport projects, BIM provides an integrated platform where engineers, designers, contractors, and stakeholders can access consistent, updated information, visualise project components, and simulate real-world performance [9].

The core function of BIM is in its ability to represent physical infrastructure in three dimensions (3D), enriched with schedule (4D), cost (5D) and life cycle data (6D and beyond) [10]. This allows for enhanced coordination between disciplines and improves decision-making by highlighting conflicts and dependencies early in the planning process. When integrated with Geographic Information Systems (GIS), BIM can provide context-aware modelling, facilitating site analysis, environmental impact assessments, and scenario testing [11].

The integration of BIM into transport infrastructure projects serve benefits in terms of planning accuracy [12], resource efficiency [13] and stakeholder participation [14]. It allows multidisciplinary teams to collaborate on a common platform, share data in real time, and test various design options using simulation tools. These capabilities can significantly enhance engagement efforts and reduce the uncertainty that often surrounds large-scale infrastructure developments [15]. Figure 1 shows the integration of BIM into transportation infrastructure.

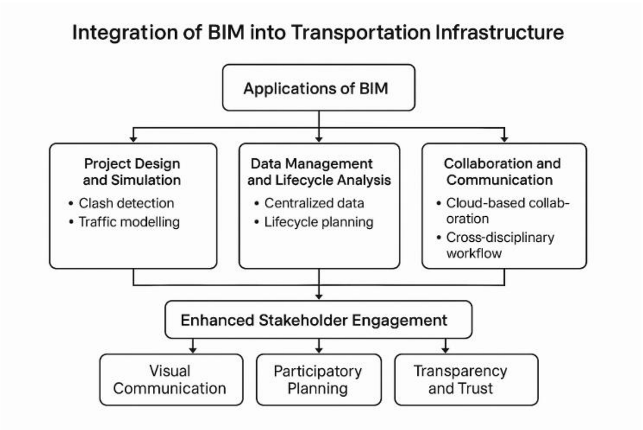

Figure 1: BIM based Transportation Infrastructure

One of the primary advantages of BIM in the pre-construction phase is its ability to support advanced simulations. By enabling teams to model different design scenarios, assess their spatial and functional implications, and visualise outcomes in real time, BIM allows for data-driven and participatory design processes [16]. For example, simulations can illustrate how a proposed tunnel alignment may affect nearby buildings, traffic patterns, or environmental features information that is important for both technical approval and public consultation [17].

This capability also supports “what-if” analyses, allowing stakeholders to compare alternatives and contribute to value engineering decisions. Projects are more likely to incorporate local knowledge, avoid major objections and be aligned with wider community objectives [18]. BIM's contribution to construction efficiency is based on the ability to identify design conflicts, coordinate sequencing and manage logistics through digital proofs. Clash detection tools automatically identify conflicts between structural, mechanical, electrical, and civil components before construction begins. This reduces costly rework and supports the sequencing of activities to avoid delays. For stakeholders, pre-construction coordination and all these increases confidence in the reliability of the project. It also reduces public disruption by optimising phasing strategies and minimising the possibility of unforeseen disruption during delivery [19].

III. Case Studies and Comparative Analysis

This section presents three international case studies illustrating how BIM has facilitated enhanced stakeholder engagement in transportation infrastructure projects. By comparing diverse project types and contexts, the analysis identifies the specific benefits of BIM in overcoming the shortcomings of traditional engagement methods. Also, it highlights the varying levels of public participation, stakeholder influence, and project outcomes associated with each case.

A. Singapore Downtown Line

The Singapore Downtown Line, overseen by the Land Transport Authority (LTA), is a strong example of BIM integration in urban rail development. LTA adopted tools such as Autodesk Revit and Navisworks, along with 4D and 5D BIM processes, to enhance design coordination, conduct clash detection, and support real-time construction planning. These tools facilitated not only internal collaboration but also public communication. LTA organised 3D model-based public consultation sessions and incorporated Virtual Reality (VR) simulations, allowing residents to visualise station layouts and anticipate construction impacts. Feedback gathered during these sessions led to improvements in areas like accessibility and pedestrian flow. Project stakeholders reported measurable benefits in coordination efficiency, with fewer on-site clashes and enhanced project scheduling outcomes [20].

B. Amsterdam

Amsterdam’s integrates BIM principles with GIS and sensor data. While conventional BIM tools supported infrastructure design, real-time data models and traffic simulations allowed the city to forecast outcomes of proposed interventions. Engagement strategies included public exhibitions and sustainability-focused visual tools. These methods successfully built political and community support for initiatives such as road reconfigurations and emission reduction policies. Notably, the city’s participatory planning process empowered citizens to co-shape transport solutions, an uncommon feature in traditional infrastructure projects [21].

C. Cancello–Benevento Railway Line (Italy)

The Cancello–Benevento railway project applied openBIM and Industry Foundation Classes (IFC) standards to create a federated digital model for asset assessment and upgrade coordination. Stakeholders included the railway operator (EAV), academic researchers, software developers, and maintenance crews. Interactive digital model workshops facilitated cross-disciplinary collaboration. Public engagement was moderate, focusing primarily on operational stakeholders rather than broader community participation. Nevertheless, the project was recognised at the buildingSMART Awards for innovations in asset management and interdisciplinary coordination [22].

Table 1 presents the BIM-enabled stakeholders engagement strategies and outcomes.

Table 1: BIM-Enabled Stakeholder Engagement Strategies and Outcomes

Case Study	BIM Tools and Platforms	Engagement Strategies	Outcomes
Singapore Downtown Line	Autodesk Revit, Navisworks, 4D/5D BIM	3D model workshops, VR experiences	Improved accessibility, reduced design conflicts, improved timelines
Amsterdam	GIS simulations, sensor-integrated models	Public exhibitions, visual sustainability tools	Public support for road changes, emissions reduction
Cancello–Benevento Railway	openBIM, IFC standards	Interactive meetings, cross-disciplinary collaboration	Improved asset management, maintenance efficiency, industry recognition

D. Thematic Comparison

The projects share several core engagement strategies while also demonstrating unique adaptations to local contexts and stakeholder expectations provided in Table 2.

Table 2: Comparative Analysis of BIM-Enabled Stakeholder Engagement

Dimension	**Singapore Downtown Line**	**Amsterdam**	**Cancello–Benevento Railway**
Project Context	Urban mass transit	Urban smart mobility	Regional railway upgrade
Primary BIM Tools	Autodesk Revit, Navisworks, 4D/5D BIM	GIS-based models, real-time data	openBIM, IFC
Stakeholder Types	Government, engineers, public	Municipal, private sector, public	Government, academia, maintenance teams
Public Participation Level	High	Moderate	High
Design Adaptations	Station redesigns, accessibility changes	Road redesigns, emission policies	Maintenance planning improvements
Efficiency Gains	Timeline acceleration, clash reduction	Public support, sustainable transport	An award winning maintenance innovation

E. BIM vs Traditional Stakeholder Engagement

Comparative analysis further clarifies how BIM enhances traditional stakeholder engagement processes shown in Table 3.

Table 3: BIM-Based vs Traditional Stakeholder Engagement

Engagement Feature	**BIM-Based Approach**	**Traditional Approach**
Visualisation	3D/4D models, real-time simulations, VR experiences	2D drawings, static reports, verbal descriptions
Accessibility of Information	High—complex data made understandable for all stakeholders	Low—technical data often inaccessible to non-experts
Feedback Integration	Dynamic design modifications based on iterative input	Static limited opportunities for design adaptation
Collaboration	Multi-disciplinary, real-time collaboration	Sequential, discipline-siloed communication
Transparency & Trust	Increased through shared models and simulations	Often limited by technical barriers and top-down communication
Conflict Mitigation	Proactive clash detection and scenario testing	Reactive issues often arise during or after construction
Time & Cost Efficiency	Improved due to early issue resolution	Prone to delays and cost overruns

The range of BIM functionalities used across the projects is summarised below in Table 4:

Table 4: BIM Tools Functionality Comparison

BIM Functionality	**Singapore Downtown Line**	**Amsterdam**	**Cancello–Benevento Railway**
3D Visualisation	✓	✓	✓
Clash Detection	✓	Limited	✓
Real-time Simulations	✓ (VR)	✓	✕
Digital Twin Capability	✕	✓	Limited (asset data only)
openBIM Interoperability	Limited	Limited	✓

Across all case studies, BIM contributed to more transparent, flexible, and participatory stakeholder engagement compared to traditional methods. While each project varied in technological sophistication and public empowerment levels, they shared a common trend: BIM transformed stakeholders from passive recipients of information to active participants in design and decision-making. By enhancing visualisation, enabling iterative feedback, and fostering interdisciplinary collaboration, BIM has redefined engagement standards in complex infrastructure projects. However, the need for technical capacity building and the upfront costs of implementing advanced BIM strategies need to be addressed to ensure equitable access and broader adoption.

IV. Stakeholder Feedback Survey

A stakeholder survey was conducted to gather first-hand feedback on the perceived impact of BIM on engagement practices to supplement insights. The questionnaire was distributed to 32 participants involved in recent infrastructure projects, including project managers, community representatives and engineers.

The survey included both closed-ended and open-ended questions, focusing on key engagement dimensions: communication, visualisation, influence on design, and satisfaction with BIM-based processes. Respondents were asked to rate BIM's effectiveness and identify both benefits and barriers based on their project experience. Table 5 provide summary of BIM survey responses from infrastructure stakeholders.

Table 5: Summary of BIM Survey Responses from Infrastructure Stakeholders (n = 32)

Survey Indicator	**Response Summary**
BIM effectiveness in improving communication	60% Very Effective, 30% Somewhat Effective
Ability to visualise project impacts	80% agreed or strongly agreed
Influence of feedback on design	50% confirmed that feedback altered project design
Satisfaction with stakeholder engagement	65% reported being "Very Satisfied"
Recommendation for future use of BIM	70% "Very Likely" to recommend
Identified challenges	30% cited technical issues; 25% cited lack of training
BIM's role in reducing project delays	50% agreed it contributed to delay reduction
BIM usefulness in teamwork and collaboration	55% found it "Very Effective"
Confidence in BIM model accuracy	60% reported being "Very Confident"

Key Findings:

- Communication Enhancement: 60% of respondents rated BIM as "very effective" in improving communication with stakeholders. A further 30% described it as "somewhat effective," indicating broad approval of BIM's communicative value.

- Visualisation Impact: 80% agreed or strongly agreed that BIM helped visualise project impacts clearly, improving stakeholder understanding and enabling more productive dialogue.
- Design Influence: Half of respondents stated that stakeholder feedback—supported by BIM visualisations—led to meaningful changes in project design, demonstrating the role of BIM in participatory planning.
- Engagement Satisfaction: 65% of participants reported being "very satisfied" with the level of engagement supported by BIM tools. Only a small proportion cited dissatisfaction, primarily due to technical or training issues.
- Challenges Noted:
  - 30% reported technical barriers, such as software incompatibility.
  - 25% highlighted lack of training or familiarity among some stakeholders, particularly community participants.
- 70% indicated they would be "very likely" to recommend the use of BIM in future infrastructure projects, supporting the notion of its long-term relevance and applicability.

V. DISCUSSION AND IMPLICATIONS

The analysis of the three case studies reveals a progressive shift from traditional, hierarchical engagement approaches towards collaborative, data-driven practices facilitated by BIM. This transition reflects a broader transformation in infrastructure planning and delivery, with significant implications for design quality, project efficiency, and public trust.

Three principal insights emerge from the comparative evaluation: Firstly, across all projects, BIM's capacity to translate complex technical data into accessible, visual formats improved stakeholders' comprehension. In the Singapore case, 3D models and VR tools demystified engineering complexities, allowing non-expert stakeholders to engage with project designs. Secondly, BIM-enabled engagement has enhanced iterative feedback loops where public and technical inputs lead to concrete design changes. This was especially evident in Amsterdam, where community input influenced mobility policies, and in Singapore, where accessibility improvements were incorporated into station designs. Thirdly, the multidisciplinary collaboration supported by BIM tools allowed early identification of design conflicts, reducing the likelihood of costly changes during construction.

While BIM has delivered significant benefits, successful engagement often remains dependent on the ability of stakeholders to interpret BIM outputs. Projects such as Cancello–Benevento required training efforts for maintenance personnel and non-technical participants. Also, high initial costs for BIM adoption, software licensing and staff training may discourage organisations or projects with limited budgets. In addition, equity in participation: Without conscious strategies to include different voices of society, there is a risk that participation processes will be dominated by stakeholders with higher technical capacity or political influence. Based on the cross-case analysis, this paper proposes a structured framework for effective stakeholder engagement through BIM seen in Table 6. This model synthesises best practices observed in the case studies and addresses the identified limitations.

Table 3: Proposed Framework for BIM-Enabled Stakeholder Engagement

Phase	Key Actions	BIM Tools/Methods	Outcomes
Initiation	Identify stakeholder groups; define engagement objectives	Stakeholder mapping tools; project dashboards	Clear engagement strategy; inclusivity
Visualisation	Develop accessible visual materials	3D/4D BIM models; VR; GIS integration	Enhanced understanding; trust-building
Interaction	Conduct interactive sessions; solicit feedback	Digital workshops; online platforms	Dynamic feedback loops; informed design changes
Collaboration	Facilitate cross-disciplinary collaboration	Federated models; clash detection tools	Conflict reduction; efficiency improvements
Capacity Building	Train stakeholders in BIM literacy	Tutorials; user-friendly interfaces	Increased participation; equitable engagement
Evaluation	Monitor engagement outcomes and adapt strategies	Engagement analytics; change tracking	Continuous improvement; adaptive management

The proposed framework offers both practical and policy-level benefits:

- For Practitioners: The model provides a replicable process for integrating stakeholder engagement into BIM workflows, enhancing both project quality and community acceptance.
- For Policymakers: Findings underscore the need to institutionalise participatory planning processes supported by BIM, ensuring that public engagement is consultative and collaborative.
- For Academia: The cross-case synthesis contributes to the theoretical discourse on digital collaboration in the built environment, offering a basis for further empirical research and methodological refinement.

Further studies could examine:

- The scalability of BIM-enabled engagement frameworks in smaller or less digitally mature projects.
- Longitudinal impacts of BIM-based engagement on post-construction outcomes, such as user satisfaction and maintenance efficiency.
- The role of artificial intelligence and machine learning in enhancing stakeholder feedback analysis and design adaptation.

The transition from traditional to BIM-enabled stakeholder engagement represents a technological advancement and a fundamental rethinking of how infrastructure projects are conceived, designed, and delivered.

By advancing transparency, collaboration, and inclusivity, BIM potential to transform both project outcomes and public perceptions of infrastructure development.

VI. CONCLUSION

This paper has examined the role of BIM in enhancing stakeholder engagement across three diverse transport infrastructure projects (Singapore Downtown Line, Amsterdam initiatives, and Cancello–Benevento Railway Line in Italy). Through an analysis, the study has demonstrated that BIM serves as a design and coordination tool, and acts as a platform for transparent, participatory planning and decision-making.

Key findings indicate that BIM-enabled engagement strategies such as 3D/4D modelling, virtual reality experiences, real-time simulations, and federated models enhance stakeholders' understanding of complex technical information. This enhanced understanding encourages meaningful participation, which leads to better-informed design decisions, improved project efficiency and increased public trust.

The analysis highlighted three critical advantages of BIM-enabled stakeholder engagement over traditional methods: Enhanced visual communication, which demystifies complex technical designs for non-specialist stakeholders. And dynamic, iterative feedback processes that allow for design adaptations based on stakeholder input. In addition, interdisciplinary co-operation was improved, resulting in reduced conflicts, faster design solution and operational efficiency. However, the study also recognised limitations, including the need for technical literacy among stakeholders, the high upfront costs associated with BIM adoption, and the risk of excluding underrepresented groups if engagement processes are not deliberately inclusive. To address these challenges, the paper proposed a BIM-enabled stakeholder engagement. This model provides a phased approach encompassing initiation, visualisation, interaction, collaboration, capacity building, and evaluation. It offers a replicable structure for practitioners and policymakers aiming to integrate inclusive engagement practices into BIM workflows.

Implications for practice and policy suggest that adopting such models can improve project outcomes and the broader societal acceptance of infrastructure developments. For academics, the model provides a foundation for further research into the scalability of BIM-enabled engagement and the long-term impacts of participatory design approaches.

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