19th Australasian Tunnelling Conference – Acosta-Martínez, Stewart and Hudson-Smith (Eds.)
© 2025 Australian Tunnelling Society, ISBN 978-0-85825-002-4

Enhancing tunnel design and construction through Building Information Modeling (BIM): A case study approach

A. Rajesh & M. Mohandas
PINI Australia Pty Ltd, Melbourne, Australia

ABSTRACT: Building Information Modeling (BIM) is a transformative methodology for the construction industry, yet its adoption in tunnelling has lagged behind other sectors due to unique challenges including geological complexity, stringent safety requirements, and intricate multidisciplinary coordination. This paper examines the practical application of BIM to overcome these hurdles through a case study analysis of international and Australian tunnelling projects. The analysis demonstrates that BIM implementation yields significant benefits, including enhanced clash detection, optimized construction sequencing, and improved stakeholder collaboration through a single source of truth. The study also identifies critical barriers to adoption, such as data interoperability issues and a shortage of digital skills and proposes practical strategies to address them. By synthesizing lessons from successful implementations, this research provides a valuable roadmap for advancing BIM adoption in the tunnelling industry, promising greater efficiency, cost certainty, and safety in future underground infrastructure development.

1 INTRODUCTION

Tunnel construction represents one of the most complex and high-risk domains of civil engineering, traditionally constrained by reliance on 2D drawings and fragmented communication methods. As urbanization intensifies the demand for underground transport and utility networks, these conventional approaches struggle to address the critical needs for precision, safety and interdisciplinary collaboration in geotechnically uncertain environments. Building Information Modeling (BIM) offers a transformative and alternative solution through data-rich 3D models that integrate design, construction and lifecycle management. However, despite its proven success in building construction, the adoption of BIM in tunneling remains limited due to the sector's unique challenges including the variable ground conditions, linear project nature and a lack of standardized digital workflows (Zhou et al., 2017).

This paper investigates the practical application of BIM to overcome these tunneling-specific challenges. Through a detailed case study analysis of major Australian projects alongside international benchmarks, we examine how advanced BIM processes enhance design coordination, construction sequencing and stakeholder engagement. The research aims to identify key success factors and methodologies that demonstrate BIM's value in managing complexity, ultimately providing an actionable framework for its effective implementation in future underground infrastructure projects.

2 BIM IN TUNNEL ENGINEERING: CURRENT STATE AND EVOLUTION

2.1 *Evolution of BIM in Infrastructure Projects*

The global push for infrastructure development has significantly increased the complexity and scale of tunneling projects for railways, highways and urban utilities (Lai et al., 2018). In parallel, Building Information Modeling (BIM) has evolved from a basic design tool into a comprehensive lifecycle management platform, integral to the architecture, engineering, and construction (AEC) industry (Howard & Björk, 2008; Bradley et al., 2016). This evolution is marked by the expansion from 3D modeling to multi-dimensional applications, including time (4D), cost (5D) and facility management (7D), which are critical for the long-term planning and operation of major infrastructure (Smith, 2014).

Despite its proven value in building construction, the adoption of BIM in the tunneling sector is still young. The linear nature of tunnels, coupled with unpredictable geological conditions and complex ground structure interactions presents unique challenges not adequately addressed by standard BIM tools (Zhou et al., 2017). A significant barrier is the lack of specialized component libraries because most BIM software families are designed for above-ground buildings, creating difficulties in accurately modeling tunnel-specific elements like segments, portals and lining systems (Song et al., 2019). These fundamental modeling issues are compounded by the risks of underground construction such as geological uncertainty and spatial constraints.

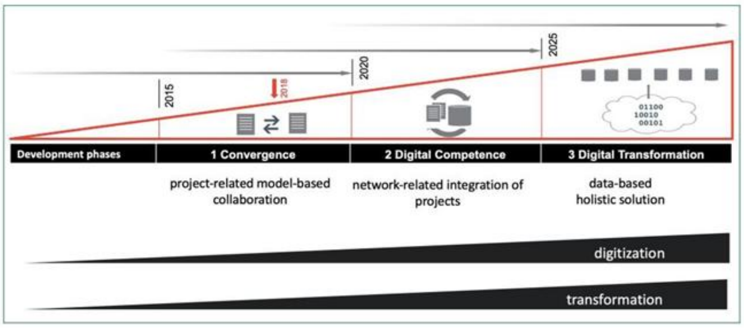

Figure 1. Development stages into the digital world (Digital Design, Building and Operation of Underground Structures-BIM in Tunnelling, DAUB

In response to these challenges, the industry is developing tailored methodologies. Researchers have proposed specialized Tunnel Information Modeling (TIM) frameworks, such as interconnected subdomain models (Koch et al., 2017) and standards for drill-and-blast tunneling (Sharafat et al., 2021). Concurrently, committees like the German Tunnelling Committee (DAUB) have published guidelines to standardize BIM application underground. These efforts collectively aim to establish consistent, effective practices for leveraging BIM in tunneling, moving the industry toward full digital integration (DAUB, 2021).

2.2 *Global Implementation Trends*

International adoption of BIM varies significantly by region. European countries particularly the UK, Germany, Norway, Switzerland and Austria lead in BIM integration due to digital transformation mandates and infrastructure modernization programs (Shivasami et al., 2019). The UK's 2016 BIM mandate for public projects catalyzed adoption in major infrastructure including crossrail and HS2. Australia's BIM adoption has progressed more slowly, with the "Australia BIM Strategic Framework" released only in 2019. Although not yet mandated, projects like Sydney Metro & Melbourne Metro have pioneered BIM use in design and delivery showcasing benefits in managing complex designs and enhancing coordination. However, challenges persist including the lack of tunnel-specific BIM libraries, inconsistent standards, limited GIS integration and the need for workforce training. Government initiatives like the Transport for NSW Digital Engineering Framework and the National Digital Engineering Policy are working to address these issues and promote BIM across the full asset lifecycle.

3 STRATEGIC BIM WORKFLOWS IN TUNNEL PROJECTS

3.1 *Level of Development (LOD) Frameworks for Tunneling*

While conventional LOD frameworks (e.g., AIA E203-2013) define geometric and semantic granularity for building projects, tunneling demands specialized adaptations due to geological variability and linear infrastructure complexity. Sharafat et al. (2021) proposed a five-stage LOD framework tailored to tunneling:

LOD 100 (Conceptual):
Basic alignment and cross-sectional geometry and geotechnical profiles.
LOD 200 (Design Development):
Parametric lining segments, temporary support systems and probabilistic ground models.
LOD 300 (Construction-Ready):
Machine-readable TBM specifications, construction sequencing logic, and clash-resolved utility corridors.
LOD 400 (Fabrication/Assembly):
As drilled rock bolt patterns, grouting and precast segment tolerances.
LOD 500 (Operational):
Asset metadata (e.g., MEP component lifespans) linked to facility management systems.

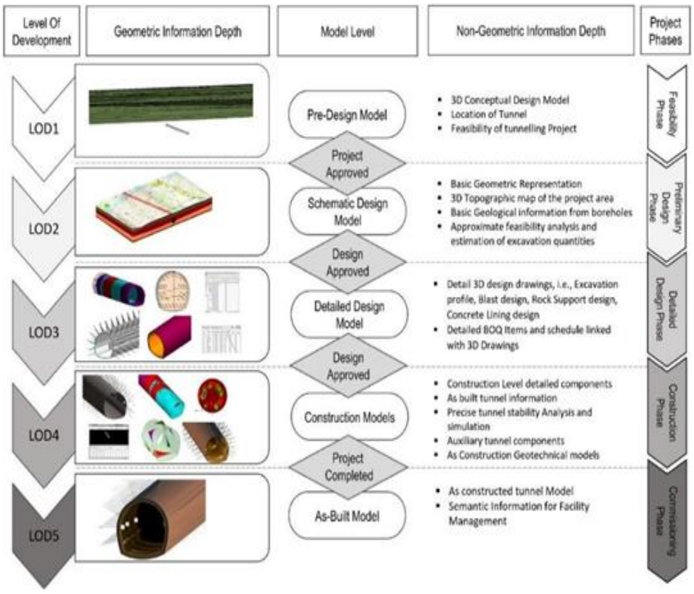

Figure 2. LOD for BIM-Based Tunnel Information Modelling *(Sharafat, A., et al. (2021). Journal of Computing in Civil Engineering, Volume 35, Issue 2)*

This framework explicitly addresses geological uncertainties through probabilistic modeling, where ground parameters are represented as distributions rather than deterministic values, enabling risk-adjusted decision-making (Zhang & Liu, 2020).

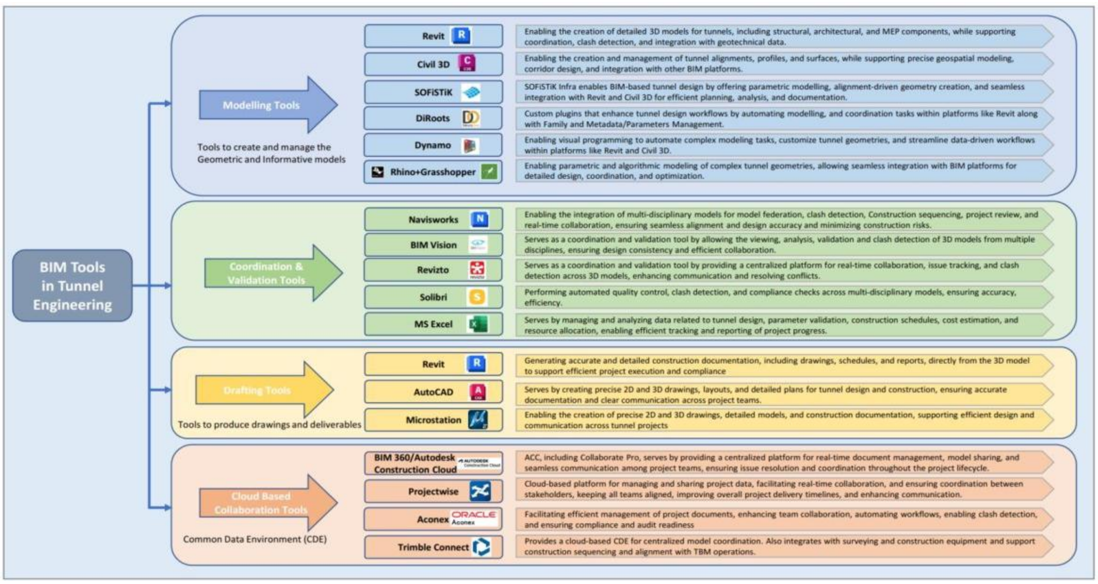

Figure 3. Tools in Tunnel BIM.

Autodesk Revit can be adapted for tunnels while Civil 3D is better for linear modeling. Bentley's suite offers integrated tools for tunnel design and structural detailing. Specialized software like Plaxis and RIB iTWO add critical geotechnical analysis and construction simulation capabilities. Together, these platforms form a robust digital toolkit, allowing engineers to manage the geometric, structural, and geotechnical complexities of tunnel projects more effectively.

3.2 *Geospatial Foundation and Coordinate Systems*

The initial and most critical step in the BIM process was the establishment of a unified geospatial framework to ensure all discipline models were aligned within a single, accurate coordinate system. This was of paramount importance for a project of this linear scale and complexity. A project wide coordinate system was defined based on the national geodetic grid (GDA2020/ MGA Zone 55 for Australia) to ensure accuracy across all software platforms (Civil3D, Revit, Navisworks, etc). This guaranteed that the tunnel alignments, surface features and subsurface models were all geospatially coherent.

3.3 *Input Data and Pre-processing*

With the coordinate system established, geological, geotechnical and structural inputs formed the basis of the models. Geological data such as rock mass rating and fault zones were processed to define the rock classes along the tunnel alignment. This data was interpolated to create 3D geological models that could be referenced within the BIM environment. Geotechnical inputs encompassed the designs for rockbolts, shotcrete, and lattice girders, while structural inputs included concrete linings and portal structures based on load assumptions. All these data are pre-processed into standardized formats (IFC for model elements, DWG for base geometry and XLSX for chainage-based data like rock class) to be efficiently consumed by BIM authoring tools for subsequent modelling and coordination activities

3.4 *Modelling Tunnels and Stations – A Multi-Model Approach*

With the geospatial framework and input data established, the modelling of primary structures commenced. This process was not monolithic but was strategically divided into distinct model types to manage complexity, enable parallel workstreams and maintain performance.

3.4.1 *Tunnel Modelling: Corridor based Parametric design*

The linear nature of the tunnel drives demanded a corridor-based modelling approach, diverging from standard building techniques. The tunnel alignment and profile defined within AutoCAD Civil 3D served as the digital "backbone". This corridor was then leveraged to generate the primary tunnel void. Two primary methods were employed. The first one using the Civil 3D corridor was imported in Revit as a reference. Using Dynamo scripts, the tunnel's internal lining was automatically generated by extruding a parametrically defined cross section (eg, horseshoe, circular) along the imported alignment. This created a native Revit element that could be scheduled and tagged; however, this geometric translation often introduces inaccuracies and tessellation errors. Any design change forces a slow and manual update of the entire process which may hinder performance through these heavy Revit models.

An alternative solution for this is using Sofistik, which uses a unified model environment where the tunnel is an intelligent, parametric object. The tunnel lining is defined by a parametric cross section that is associatively extruded along the alignment. If you change the alignment or lining thickness, the tunnel updates automatically throughout its length. You get a light, native and schedulable Revit model without writing a single line of Dynamo code. The link remains bidirectional which allows to update the Revit model if the Sofistik design changes.

As detailed in section 3.3, rock support classes were applied parametrically along the alignment based on chainage-specific rock class data. Dynamo scripts automated the placement of rock bolt families and defined shotcrete thickness zones, transforming geotechnical design into a constructible 3D model.

3.4.2 *Station Modelling: Building-like complexity Underground*

Stations with their large caverns, multiple levels and dense mechanical, electrical and plumbing (MEP) requirements were modelled using a more traditional building BIM approach within the established project coordinate system.These stations were developed as separate Revit models, with their locations precisely georeferenced using the project's shared coordinates to ensure alignment with the connecting tunnels. To manage complexity and enable concurrent workflows, each station model was subdivided into discipline-specific models. The Structural models defined the cavern and entrance layouts, framing, walls, and slabs, while the MEP models contained all ventilation, fire protection, cable management, and piping systems. This model separation prevented single-file overload and facilitated specialized development, with all data preprocessed into standardized formats (IFC, DWG, XLSX) to be efficiently consumed by BIM authoring tools for subsequent modeling and coordination activities.

3.5 *Federation into the Coordination Model*

The various container models (tunnels, station structures, station MEP, surface utilities) were not designed in isolation. They were periodically published to the Common Data Environment (CDE) and federated within coordination software like Navisworks Manage or BIMCollab to create an overarching Coordination Model – a single, comprehensive digital prototype of the entire project. Within this federated model, automated clash detection routines were run. The rules were sophisticated, checking not only for "hard clashes" (e.g., a pipe intersecting with a beam) but also for "soft clashes" (e.g., breaches of maintenance clearance zones around equipment). The CDE tracked identified clashes, assigned them to the relevant design team for resolution, and verified the solutions, ensuring all interdisciplinary interfaces were meticulously coordinated before construction commenced.

3.6 *Creation of the Documentation Model*

A core principle of BIM is that construction documents (drawings, schedules, quantities) are outputs or views of the model, not separate entities. The Documentation Model is the managed set of these extracted views, ensuring consistency and eliminating redundancy. Within each Revit container model (e.g., Tunnel A02, Station MEP), dedicated sheets were created for plans, sections, elevations, and details. Views on these sheets were generated directly from the 3D model. Sections and callouts were "live," meaning any change in the 3D model automatically updated all associated drawings. Annotations (dimensions, tags) were linked to model elements via shared parameters. Schedules for quantities (e.g., concrete volume, rock bolt count, rebar tonnage) were generated directly from the model database. This ensured that the Bill of Quantities was inherently tied to the design model, drastically reducing manual takeoff errors and ensuring cost certainty. The Solibri model checker was used to validate the documentation model itself, running rules to ensure that every element tagged in a drawing was present in the model, that all sheets contained the required views, and that the project's naming and numbering standards were consistently applied across all documents.

4 CASE STUDY ANALYSIS – EMERGING PATTERNS & LESSONS LEARNED

4.1 *Case Study A: Urbania Tunnel*

The complexity of the 28-kilometer Urbania Tunnel Project, with its four natural tunnels and seven bridges presented significant BIM modelling challenges particularly in accurately representing the complex, curved geometry of the tunnel bores and their interfaces with other structures. To overcome this, the team moved beyond standard modelling techniques by developing parametric Revit families with adaptive points linked directly to the Civil 3D alignment. This crucial technique ensured the tunnel lining and internal components dynamically updated with design changes. Furthermore, specific challenges like clash detection between temporary and permanent works were addressed by creating separate worksets in Navisworks, while initial inconsistencies in model detail from subcontractors were resolved by implementing a strict BIM

Execution Plan and automated validation scripts within the Common Data Environment to ensure model integrity.

This refined clash detection process resolved over 80 major interferences before construction, while the accurate 4D sequencing of activities in high risk geological and traffic sensitive areas prevented delays. The precise modelling of complex geometries combined with immersive walkthroughs for stakeholders, not only provided a superior understanding of the project but also streamlined planning approvals reducing lead times by an estimated 30%. The project establishes a benchmark for BIM implementation in complex infrastructure projects, particularly those involving multiple tunnels, bridges, and road alignments in challenging topography.

4.2 *Case Study B: A major orbital rail infrastructure in Melbourne*

The Orbital Rail Project, a metropolitan-scale underground rail system in Victoria, Australia, exemplifies the application of advanced BIM to overcome the profound complexities of building in a dense urban environment. The integration of dozens of discipline-specific models for stations which consists of complex architectural, structural, and MEP systems posed a significant coordination challenge. Instead of relying solely on post-design clash detection, the team implemented a strategy of "Federated Model Zones" within Navisworks. This involved creating rule-based filters to isolate coordination tasks by specific station areas (e.g., concourse level, platform level), significantly streamlining the clash detection process and aligning with the zone-based coordination frameworks discussed by Kassem et al. (2015) in their analysis of BIM maturity in large projects.

The project faced significant secondary challenges in data handover and logistical planning. The goal of using the digital model for future asset management was hindered by inconsistent data formats and varying Levels of Detail (LOD) from different contractors. The solution was the implementation of a Model-Based Delivery requirement, mandating COBie data drops at key milestones. This ensured that critical asset information was structured and embedded within model elements from the outset, creating a reliable digital twin for facilities management as suggested by NBS (2019). For logistical planning within a constrained right-of-way, sequencing complex construction without disrupting surface traffic required advanced analysis. The team utilized 4D BIM (Synchro 4D) to conduct "what-if" scenarios, optimizing Tunnel Boring Machine (TBM) deployment and evaluating procurement strategies. This application of 4D BIM for strategic decision-making, rather than mere visualization, is a key indicator of high BIM maturity, as noted by Heigermoser et al. (2019).

4.3 *Case Study C: Sydney Metro West – Eastern Tunneling package, Australia*

The Sydney Metro West – Eastern Tunnelling Package serves as a seminal case study on the strategic value of implementing BIM from the conceptual design phase to manage complex interfaces in dense urban area. To navigate the impossible web of existing subsurface utilities and foundations, the project established a federated model as a "single source of truth." This integrated platform consolidated geospatial, geotechnical, and existing asset data, which enabled continuous, automated clash detection and provided designers with direct feedback capabilities. This allowed for the real-time iteration and optimization of alignments and structural solutions, efficiently mitigating interface risks during design development. The benefits of this early BIM adoption extended into procurement and stakeholder engagement by providing tenderers with the comprehensive concept model, the project transformed the tender phase into a collaborative, model-based assessment. This dramatically accelerated the understanding of project constraints which prevented an estimated $15M in rework and 6 months of delays. This centralized digital environment helped facilitate consensus among diverse parties is a hallmark of mature BIM implementation, a principle strongly supported by the ISO 19650 standard on information management. The project demonstrated that embedding a digital culture from the outset creates a robust backbone for data-driven decision-making, confirming that the value of BIM in managing subsurface risks (Shivasami et al., 2019) far outweighs the initial modeling effort and secures a digital foundation for the entire project lifecycle.

4.4 *Discussions And Future Trends in Tunnel BIM*

Future advancements in BIM for tunneling are emerging through projects like Sydney Metro and Melbourne's ongoing "Mammoth Rail Project," which utilize sensor-based "live digital twins" to monitor ground movements in sensitive urban areas. These IoT-enabled BIM models integrate data from LiDAR and fiber optics to track deformation at a millimeter scale, a capability demonstrated on projects like Norway's Follo Line. Looking ahead, machine learning is poised to predict Tunnel Boring Machine (TBM) performance in varying ground conditions, thereby reducing project uncertainty. Concurrently, cross-border collaborations, such as knowledge-sharing initiatives between Australia and Singapore, aim to enhance geological models for challenging environments like tropical soils and karst. These technical efforts are supported by evolving BIM guidelines and IFC extensions, which are critical for improving software interoperability, while Augmented Reality (AR) tools are increasingly being deployed to help technicians visualize utilities and defects on-site. Ultimately, the future of BIM in tunneling will focus on the seamless integration of real-time data, AI-driven insights, and the development of global standards to de-risk megaprojects.

5 BENEFITS OF BIM IN TUNNELLING

Building Information Modeling (BIM) has revolutionized tunneling projects by enhancing precision, collaboration, and lifecycle management. BIM's 3D models surpass traditional 2D drawings by integrating geometric and non-geometric data, offering stakeholders unparalleled clarity of complex underground spaces. For instance, Sydney's West Connex project utilized BIM to detect spatial conflicts early, improving stakeholder alignment and reducing costly rework (Roads and Maritime Services, 2019). Virtual Reality (VR) further aids spatial comprehension, as seen in Crossrail's design reviews, minimizing errors in confined environments. (Dogan et al., 2022).

BIM integrates geotechnical data, enabling 3D stratigraphic models from borehole and geophysical surveys (Wang et al., 2021). This integration allows engineers to analyze how geological conditions might affect construction methods and structural designs (Hoek et al., 2019). The Melbourne Metro Tunnel project demonstrated this capability by incorporating borehole data and geotechnical surveys into the BIM environment, enabling more accurate risk assessment and construction planning (Rail Projects Victoria, 2020). Parametric modeling allows tunnel lining and reinforcement designs to be dynamically adapted to variable ground conditions. This process integrates geotechnical data directly into the structural model, embodying the "geotechnical BIM" concept where soil-structure interaction directly informs design. This is crucial for coordinating multiple systems within the confined space of underground construction.

BIM enables automated clash detection between these systems, helping to identify and resolve conflicts before construction begins. The North Connex tunnel in Sydney employed BIM-based clash detection to coordinate mechanical, electrical, and plumbing systems with the tunnel struc- ture, resulting in fewer on-site conflicts and associated delays (Transurban, 2021). As observed in the Crossrail project (Barton et al., 2016), such prioritization reduces false positives in clash detection, which are prevalent in complex infrastructure models. Federated models are systematically updated through defined cycles with version control protocols ensuring traceability - a practice shown to reduce rework by 15–20% in large-scale projects (Zou et al., 2019). BIM ex- tends beyond static 3D models to include the time dimension (4D), allowing for the simulation of construction sequences to optimize the construction schedule and identify potential logistical challenges. The Cross River Rail project in Brisbane utilized 4D BIM to plan the tunnel boring machine operations and coordinate associated activities improving resource allocation and sched- ule reliability (Cross River Rail Delivery Authority, 2021). The Sydney Metro Northwest project implemented a BIM- based asset management system that facilitated more efficient maintenance planning and reduced lifecycle costs (Sydney Metro, 2022).

6 CHALLENGES AND BARRIERS IN BIM IMPLEMENTATION FOR TUNNELING

A significant barrier to BIM implementation in tunnel engineering lies in the inherent limitations of the software and data environment. Most pre-built family components in BIM platforms are designed for general construction rather than tunnel applications, creating difficulties in foundational modeling processes (Song et al., 2015). This issue is compounded by significant software interoperability challenges, a barrier identified by Zhou et al. (2017) in the context of Chinese tunnel engineering, which reflects the broader difficulty of integrating specialized tunneling software with general BIM platforms. Furthermore, the volume, velocity, and variety of data generated throughout a tunnel's lifecycle from prospecting to structural monitoring exceed the capabilities of traditional analysis methods, necessitating advanced computational approaches like machine learning (Huang, 2019).

Beyond technical hurdles, organizational and procedural factors also impede adoption. Zhou et al. (2017) further identified disorganized management as a critical challenge, where traditional design and construction approaches often create resistance to new digital methodologies. The specialized nature of tunnel BIM also demands new skills not widely available in the existing workforce (Sulankivi et al., 2020), and the substantial investment required for hardware, software, and training can be a deterrent, especially without a clearly quantified return on investment. A root cause of many interoperability issues is the absence of standardized protocols. Current Industry Foundation Classes (IFC) standards do not fully encapsulate the unique elements of tunnel engineering. In response, researchers like Sharafat et al. (2020) have proposed an extended IFC schema to represent tunnel-specific components not yet covered by buildingSMART international definitions.

7 PROPOSED STRATEGIC FRAMEWORKS FOR BIM ENHANCEMENT

Australia requires a cohesive national BIM strategy to overcome current fragmentation across jurisdictions and sectors. Research suggests a three-tiered framework addressing critical gaps in current implementation (Succar & Sher, 2014). First, establish a federally endorsed National BIM Authority with state implementation committees to develop consistent standards while respecting regional differences (Hampson et al., 2018). Second, develop specialized technical extensions for underground infrastructure that address geological data integration challenges identified in recent studies (Newman et al., 2020). Third, implement a national BIM accreditation program addressing the skills shortage documented by Consult Australia (2021). Infrastructure Australia's research (2023) demonstrates potential productivity improvements of 15-20% through consistent BIM implementation, particularly valuable for complex underground projects. Critical to success is reforming procurement models to support collaborative digital delivery, with standardized contractual provisions addressing intellectual property and data exchange (Australian Procurement and Construction Council, 2022). This framework aligns with international best practices while addressing Australia's unique federal structure and infrastructure needs.

8 RECOMMENDATIONS

Based on the case studies and industry best practices, the following recommendations are proposed.

- Early BIM adoption: Integrate BIM from the feasibility and conceptual design stages.
- Training, Standards and Continuous feedback: Establish BIM standards and train personnel across disciplines using project lessons.
- Data Integration: Ensure interoperability with GIS, geotechnical databases and FM
- systems.
- Leadership and Governance: Assign BIM managers to lead coordination and enforce model integrity.
- Interoperability between FEM and BIM is important in civil infrastructure design, as including ground conditions and geotechnical data in the BIM model improves its quality and use-

fulness not just in design, but also during construction and lifecycle management, especially for decision-making in urban areas.

— Although BIM use in Australian tunnelling is growing, it is still inconsistent. To maximize its benefits, Australia needs to standardize practices, build skills, and support policies. Collaboration between industry and government is key to advancing digital engineering in tunnel projects.

9 CONCLUSIONS

The findings indicate that while BIM adoption in tunneling remains less advanced than in general building construction, significant progress has been made through the development of specialized Tunnel Information Modeling frameworks, adaptation of LOD concepts to tunneling contexts, and successful implementation in major infrastructure projects worldwide. Key challenges identified include the lack of specialized component libraries, integration complexities with geological data, software incompatibility issues, and the absence of standardized protocols. These challenges are being addressed through ongoing research and development efforts, including the extension of IFC schemas to incorporate tunnel-specific elements and the creation of collaborative platforms tailored to tunnel engineering requirements. Future directions for BIM implementation in tunneling include integration with emerging technologies such as digital twins, machine learning, and robotics; continued development of tunneling-specific standards; and enhanced collaborative platforms that facilitate real-time data integration and cross-disciplinary collaboration. The global implementation of BIM in tunneling represents a crucial frontier in digital transformation for underground infrastructure development.

10 REFERENCES

Australian Constructors Association. (2022). constructors.com.au/wp-content/uploads/2020/09/ACA-IA- Response-Final-Version.pdf

Australian Cyber Security Centre. (2023). Protecting critical infrastructure information systems. Canberra: Australian Government.Critical Infrastructure | Cyber.gov.au

Bradley, A., Li, H., Lark, R. and Dunn, S., 2016. BIM for infrastructure: An overall review and constructor perspective. *Automation in construction*, *71*, pp.139-152

Bui, H.G., Trung Cao, B., Ninić, J., Nösges, M. and Meschke, G., Automatic Integration of Building Data into Large-Scale Numerical Simulations. *J. and Nösges, Markus and Meschke, Günther, Automatic Inte- gration of Building Data into Large-Scale Numerical Simulations*.

BuildingSMART Australia. (2021). Interoperability challenges in Australian construction. Sydney: BSA Publications.

Chen, L., et al. (2023). Blockchain for BIM Version Control in Megaprojects. Automation in Construction, 145, 104623.

Chow, L., Kuang, Z., & Baker, M. (2019). Representing geological uncertainty in BIM for underground construction. Automation in Construction, 97, 40 -53.

Consult Australia. (2020). Digital engineering skills gap analysis. Melbourne: CA Reports. digital.tas.gov.au/data/assets/pdf_file/0019/408331/ACS-DigitalPulse-2024_digital

Cross River Rail Delivery Authority. (2023). Digital delivery strategy outcomes report. Brisbane: Queens- land Government. Home - Cross River Rail

Critical Infrastructure Centre. (2022). Security guidelines for digital infrastructure models. Canberra: Australian Government.

Deartment of Home Affairs.Cyber and Infrastructure Security CentreDigital Design, Building and Operation of Underground Structures-BIM in Tunnelling, DAUBdaub-ita.de/fileadmin/documents/daub/gtcrec5/2019-05_DAUB_BIM_im_Untertagebau_EN.pdf

Engineers Australia. (2023). Professional development framework for digital engineering in underground construction. Sydney: EA Publications.

Howard, R. and Björk, B.C., 2008. Building information modelling–Experts' views on standardisation and industry deployment. *Advanced engineering informatics*, *22*(2), pp.271-280.

Infrastructure Australia. (2024). National digital engineering policy for infrastructure. Canberra: Australian Government.

Infrastructure Australia. (2021). Data management in major infrastructure projects. Canberra: Australian Government.

Infrastructure Australia. (2023). Digital transformation of infrastructure delivery. Canberra: Australian Government.

Koch, C., Vonthron, A. and König, M., 2017. A tunnel information modelling framework to support man- agement, simulations and visualisations in mechanised tunnelling projects. *Automation in Construction*, *83*, pp.78-90.

Lee, P.C., Wang, Y., Lo, T.P. and Long, D., 2018. An integrated system framework of building information modelling and geographical information system for utility tunnel maintenance management. *Tunnelling and Underground Space Technology*, *79*, pp.263-273.

Liu, Z., Lu, Y. and Peh, L.C., 2019. A review and scientometric analysis of global building information modeling (BIM) research in the architecture, engineering, and construction (AEC) industry. *Buildings*, *9*(10), p.210.Mao, J., Wang, Q., & Li, J. (2022). Integration of geotechnical and BIM systems for tunnel projects. Journal of Computing in Civil Engineering, 36(3), 04022008.

Rail Projects Victoria. (2020). Melbourne Metro Tunnel: Geotechnical BIM integration report. Melbourne: Victorian Government.

Roads and Maritime Services. (2019). WestConnex M4 East: BIM implementation case study. Sydney: NSW Government.treasury.nsw.gov.au/sites/default/files/2020-11/0023_westconnex_summary.pdf

Royal Institution of Chartered Surveyors. (2021). Measuring the benefits of BIM in infrastructure projects. London: RICS.BIM and the power of data in construction

Sacks, R., Eastman, C., Lee, G. and Teicholz, P., 2018. *BIM handbook: A guide to building information modeling for owners, designers, engineers, contractors, and facility managers*. John Wiley & Sons.

Sharafat, A., et al. (2021). Tunnel Information Modeling (TIM) for Risk-Driven Delivery. Journal of Con- struction Engineering, 147(8).

Shivasami, A., Lai, D., Dowdell, S., Gklotsos, N., Clifton, G. and Thorin, S., 2023. Early implementation of BIM in large infrastructure projects to manage complex interfaces in a dense urban environment. In *Expanding Underground-Knowledgeand Passion to Make a Positive Impact on the World* (pp. 2893-2901). CRC Press.

Smart Cities Council Australia New Zealand. (2022). Digital twins for underground infrastructure manage- ment. Sydney: SCCANZ.Harnessing AI and Digital Twins for Transformative Urban Asset Management | Smart Cities Council

Song, Z., Shi, G., Wang, J., Wei, H., Wang, T. and Zhou, G., 2019. Research on management and applica- tion of tunnel engineering based on BIM technology. *Journal of Civil Engineering and Management*, *25*(8), pp.785-797.

Standards Australia. (2023). Framework for performance-based BIM requirements. Sydney: SA.

Wang, L., Huang, M., Zhang, X., Jin, R. and Yang, T., 2020. Review of BIM adoption in the higher education of AEC disciplines. *Journal of Civil Engineering Education*, *146*(3), p.06020001.

Victorian Auditor-General's Office. (2022). West Gate Tunnel Project: Digital delivery assessment. Melbourne: Victorian Government.bigbuild.vic.gov.au/ data/assets/pdf_file/0006/787407/Audit-report,-September-2022-to-February-2023.pdf

Zhang, Y., & Liu, X. (2020). Probabilistic Geotechnical BIM for Underground Construction. Tunneling and Underground Space Technology, 98, 103354.

Zhou, Y., Wang, C., Yuan, B., Chen, M. and Lv, J., 2021. Research on visual management technology of tunnel construction process based on bim technology. Advances in civil engineering, 2021(1), p.9738820.

https://infrastructuremagazine.com.au/tunnel-vision/

https://www.sydneymetro.info/

http://westgatetunnelproject.vic.gov.au/about/keytopics/open-space

https://crossriverrail.qld.gov.au/info/benefits-for-all-of-seq/