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IMPLEMENTATION OF A BIM WORKFLOW FOR BUILDING PERMIT COORDINATION IN URBAN METRO PROJECTS

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Alon Urlainis, PhD
Department of Civil Engineering, Ariel University, Ariel 40700, Israel
ORCID: https://orcid.org/0000-0002-8125-1818
alonu@ariel.ac.il

Amichai Mitelman, PhD
Department of Civil Engineering, Ariel University, Ariel 40700, Israel
ORCID: https://orcid.org/0000-0003-0695-8853
amichaim@ariel.ac.il

SUMMARY: *Urban metro projects require managing vast amounts of information within highly dynamic environments. Building Information Modeling (BIM) workflows are increasingly integrated into traditional engineering tasks. This paper presents the implementation of a BIM workflow for a large underground metro project located in a densely populated area. The case study focuses on managing applications for new buildings that required assessing the potential interaction with the metro project plans. This case study required transitioning from a non-BIM environment and involved manually extracting data from numerous PDF documents, capturing key information such as parcellation ID, permitted building depth, ground level, building type, and statutory status. This data was used to create BIM objects for each lot, with extruded representations reflecting the permitted excavation depth. The BIM model proved to be beneficial for a number of key reasons. First, it facilitated better communication among stakeholders by visualizing permit impacts on the metro tunnels, crucial during the design stage. Second, once set up, the BIM model reduced drafting resources considerably. Third, it serves as an efficient tool for on-site supervision over conflicting building operations during the design phase, allowing for quick comparison between actual and permitted depths. Ultimately, the digitized model efficiently stores and manages data throughout the project life cycle, demonstrating the significant advantages of integrating BIM in large-scale infrastructure projects.*

KEYWORDS: *Metro, BIM, underground construction, tunneling-induced settlements, information management.*

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1. INTRODUCTION

Urban metro systems are vital infrastructure of modern cities, providing reliable transportation that reduces travel time, traffic congestion, and pollution (Derrible and Kennedy, 2010; Gao et al., 2018). Metro trains reduce carbon emissions per passenger compared to cars, thus providing an energy-efficient means of transportation (Al-Thawadi and Al-Ghamdi, 2019; Yu et al., 2020). Furthermore, urban metro systems support economic growth by facilitating access to employment opportunities and amenities, and significantly contributes to the urban gross domestic product (GDP), especially in larger cities (Zhang, 2020; Canitez et al., 2020).

The design, coordination, and execution of large-scale metro systems is a highly complex process, especially in dense modern cities (Ziv et al., 2021). These projects face unique challenges, where tunnels, stations, supporting structures, and systems, must interact with existing and planned infrastructure. The design and execution phases require thorough coordination and management of vast amounts of information across multiple stakeholders and disciplines. Therefore, innovative approaches are essential for the successful integration of these systems within dense and dynamic urban environments.

Building Information Modeling (BIM) is defined as a shared digital representation of a built asset, facilitating design, construction, and operation processes to form a reliable basis for decisions (ISO 19650/1). As BIM technology continues to evolve, the construction industry has shifted its focus from questioning the necessity of BIM adoption to exploring effective methods of its implementation (Deng et al., 2021). BIM has become a critical tool in the architecture, engineering, and construction (AEC) industries, offering a shared digital representation of a built asset throughout its life cycle, from design to construction and operation (Abbasnejad et al., 2020; Sacks et al., 2018). Public construction procurement agencies increasingly mandate the use of BIM, making it a central subject of research in construction management (Gurevich and Sacks, 2020). To support this transition, numerous BIM documents, guidelines, and standards have been developed by various construction organizations (Chae and Kang, 2015). These documents require organizations to create Organizational Information Requirements (OIR) and define the Level of Detail (LOD) and Level of Information (LOI) for projects, ensuring a comprehensive approach to BIM adoption (Abualdenien and Borrmann, 2022).

The adoption of BIM offers the potential for numerous advantages and capabilities throughout a building's life cycle, including 3D model visualization, clash detection, accurate cost estimates, quantity take-offs, and energy analysis (Fernández García et al., 2020; Nguyen et al., 2024; Shah et al., 2023). BIM provides a structured platform for managing, storing, and sharing information across the entire project life cycle, from design to operation. Storing information within a BIM environment allows for location-based indexing, which improves the understanding and management of data in large-scale infrastructure projects. In addition, BIM offers as a centralized, cloud-based source for information management (IM), enabling the integration of data from various sources and disciplines, which significantly enhances data accessibility and real-time collaboration among different consultants and stakeholders. While the known capabilities of BIM are widely recognized, it is likely that many benefits have yet to be fully realized or not implemented in practice. The growing interest within the tech community in BIM technology is expected to drive further technological advancements (Tang et al., 2019). These developments will likely enhance the cost-value proposition of BIM, particularly for IM applications.

Compared to the building industry, the application of BIM technology in large underground projects remains limited and is in the exploratory stage (Xing et al., 2020). Although there are significantly fewer tunneling projects compared to buildings, there is a wide diversity of characteristics within these projects (Hemphill, 2012). Tunnels can be constructed by excavating from the surface and building bottom-up, which is referred to as the Cut-and-Cover method. Alternatively, tunnels can be excavated horizontally, by either conventional excavation methods, or by fully mechanized operations via Tunnel Boring Machines (TBMs). Each construction method presents unique challenges and requires developing specialized BIM workflows that are tailored specifically to the project characteristics (Mitelman and Gurevich, 2021).

Despite the growing adoption of BIM in large-scale infrastructure projects, its application to managing building permits and resolving metro-building interactions remains underexplored. This paper addresses this gap by discussing the implementation of a novel BIM workflow within an underground metro system planned in the greater Tel-Aviv area, in Israel. This mega-project consists of 3 interconnected metro lines, totaling approximately 150 kilometers of twin tunnels, running through over 100 stations. The tunnels will be driven by TBMs, and almost all stations will be situated underground. The design and construction of metro systems is a lengthy process that regularly spans over a decade (Khosravi and Kähkönen, 2015). During this time, several new buildings and utilities that interact with the proposed metro lines and stations are often proposed. Metro designers must assess these applications and ensure that potential physical and functional conflicts are avoided. In this paper, we discuss in detail the transitioning of this process to a BIM workflow, and highlight the benefits demonstrated through its implementation. Our account is based on direct managerial involvement. Arguably, sharing lessons learned from real-world applications serves as an invaluable resource for researchers, engineers, managers and policy makers. While proposed methodologies may appear promising based on a-priori reasoning, testing these methodologies in actual case studies can help inform future projects.

Hereinafter, the paper is organized according to the following structure. First, we provide a review of the pertinent background information regarding metro projects. Second, we discuss the issues related to the permitting process for buildings that interact with the metro tunnels. Third, we outline the methodology and scope of analysis. Fourth, we describe the implementation of the BIM workflow and the transition process. Fifth, we provide a discussion on the case study, where we highlight the proven advantages of this implementation, and address the limitations of the study and suggest directions for future research. Finally, we present a summary of the key findings and conclusions.

2. URBAN METRO PROJECT DESIGN

As outlined by Khosravi and Kähkönen (2015), there are various unique challenges in the design of metro projects. One such key challenge is the interdependent nature of metro systems, where numerous disciplines and constraints must be coordinated. The limited experience of many designers in metro-specific projects, coupled with the rapid pace of technological advancement, further complicates this process. Additionally, metro projects demand high costs and risks, and mistakes in the design phase can lead to significant cost overruns. An example of a metro project with a flawed design process is the Hyderabad Metro in India. The project faced issues such as misalignments that necessitated expensive redesigns, underestimated soil conditions that caused delays, and the need to demolish and rebuild sections that had already been built (Dara and Vilventhan, 2023).

From a civil engineering perspective, two of the primary components of metro construction are the tunnels and stations. Stations must be designed to provide efficient passenger flow, as well as house various technical components, such as ventilation, power, fire safety systems, and more. The tunnels must be designed to ensure structural stability, accommodate the required train speeds, and allow for the installation of various utilities.

The depth of the metro line is a crucial design decision with many important implications. The advantages of a deep line include lesser probability of clashes with existing underground structures and utilities, as well as reduction of tunneling-induced surface settlements. The primary advantage of shallow lines is that passenger flow is improved, as station entrances and exits are closer to the surface, reducing the travel time via escalators and elevators. Additional factors influencing the choice of metro line depth include site-specific considerations that require careful geotechnical investigation to assess their impact.

The design process of a metro project typically includes a number of critical stages, each with its own set of challenges. The first stage is conceptual transport planning, which is based on a comprehensive analysis of key aspects of urban life and transportation needs. This second stage is basic design, where train routes and station locations are determined, and statutory processes are initiated. The third stage is tender design, where initial plans are progressed to a level that allows for tendering. Depending on the tendering strategy, a final stage may be included, where the winning contractors carry out the detailed design, thus allowing for optimizations based on their specific capabilities. After the completion of construction, systems are tested and handed over to operations and maintenance.

Considering that numerous stakeholders are involved throughout the design, construction, and operation of a metro system, effective IM is of utmost importance (Ghanbaripour et al., 2020). Metro systems are complex, they involve countless technical inputs from various parties, including engineers, architects, contractors, urban planners, government bodies, and operators. Each of these stakeholders must rely on accurate, up-to-date information to make decisions, coordinate efforts, and avoid costly errors or delays.

In the current era, many digital platforms are available for storing and sharing information. This includes cloud-based platform. Nevertheless, these solutions also introduce the risk of information overload, where engineers and contractors may become overwhelmed by the sheer volume of data transferred by other stakeholders. Moreover, the types of information generated throughout the project are often diverse in terms of file formats, quality, and relevance to specific aspects of the project, such as its location, phase, or stakeholder requirements. This variation in data can lead to inconsistencies in how information is shared and interpreted. Without a well-planned IM strategy, important details may be overlooked or misuses, consequently leading to poor decision-making, schedule delays, and rework.

In several countries, metro design tenders have already defined BIM as mandatory for traditional design processes. BIM software has evolved to address the challenges and requirements of such large-scale infrastructure projects (Domingo and Saurí, 2020; Kocakaya et al., 2019). Similarly, in our case study, a BIM policy has been mandated, including requirements for the LOD of the metro stations, the roles and responsibilities of BIM management, and the establishment of the environment for information sharing. Arguably, recognizing the advantages of BIM for broader tasks beyond mandatory requirements can significantly benefit such projects. The BIM model does not have to substitute sharing data via other IM tools. Rather, it can complement and enhance these tools by making data accessible across multiple platforms and allowing for BIM capabilities to be harnessed for additional tasks.

3. METRO INTERACTION WITH OTHER STRUCTURES

Urban metro lines are driven underneath many buildings. Figure 1 shows a 200 m segment of the twin tunnels from the Tel Aviv metro project, where the planned tunnels are situated directly under 12 buildings. Tunneling in such densely populated areas presents significant challenges due to the potential for clashes with existing underground structural components, such as pile foundations and basement walls. If a TBM clashes with these structures, there is a risk of damage to both the TBM and the structures. In turn, such events lead to delays and increased costs, which can severely impact project success.

Figure 1: A segment of 200 m of the planned Tel Aviv metro tunnels.

Even in the absence of direct clashes, tunneling-induced surface settlements can still pose risks to existing structures. Based on the example shown in Figure 1, the number of buildings physically affected by tunneling will be greater than the ones that are directly above it. Reasonable assessment of tunneling-induced surface settlements and their zone of influence is essential to avoid overly conservative decisions, such as unnecessary deepening of the tunnels, and underestimations that could result in structural damage.

Traditionally, the analysis of tunneling-induced surface settlements relies on predicting greenfield displacements, i.e. surface settlements without considering existing structures. Peck's (1969) simple empirical formula remains a widely used method for estimating such settlements. There are four inputs used for Peck's formula: tunnel depth, tunnel diameter, the percent of volume loss, and an empirical constant that represents the ground's strength. Volume loss in tunneling refers to the reduction in ground volume that occurs during the excavation of tunnels, often in the range of 1-5%, and depends primarily on the ground conditions and tunneling method. Peck's formula does not account for soil-structure interactions, as the building stiffness influences the ground response. To address this limitation, analytical solution which incorporates these interactions (e.g. Mair's et al., 1993), and guidelines that consider building conditions (e.g. Boscardin & Cording, 1989) have been developed.

Figure 2 illustrates twin tunnels and their associated greenfield displacement profile, highlighted in red and vertically exaggerated for clarity. Although the overall settlement beneath Building A is greater than that beneath Building B, Building B is more likely to experience damage. This is because differential settlements, which cause uneven ground movements, lead to more significant structural deformations and stresses.

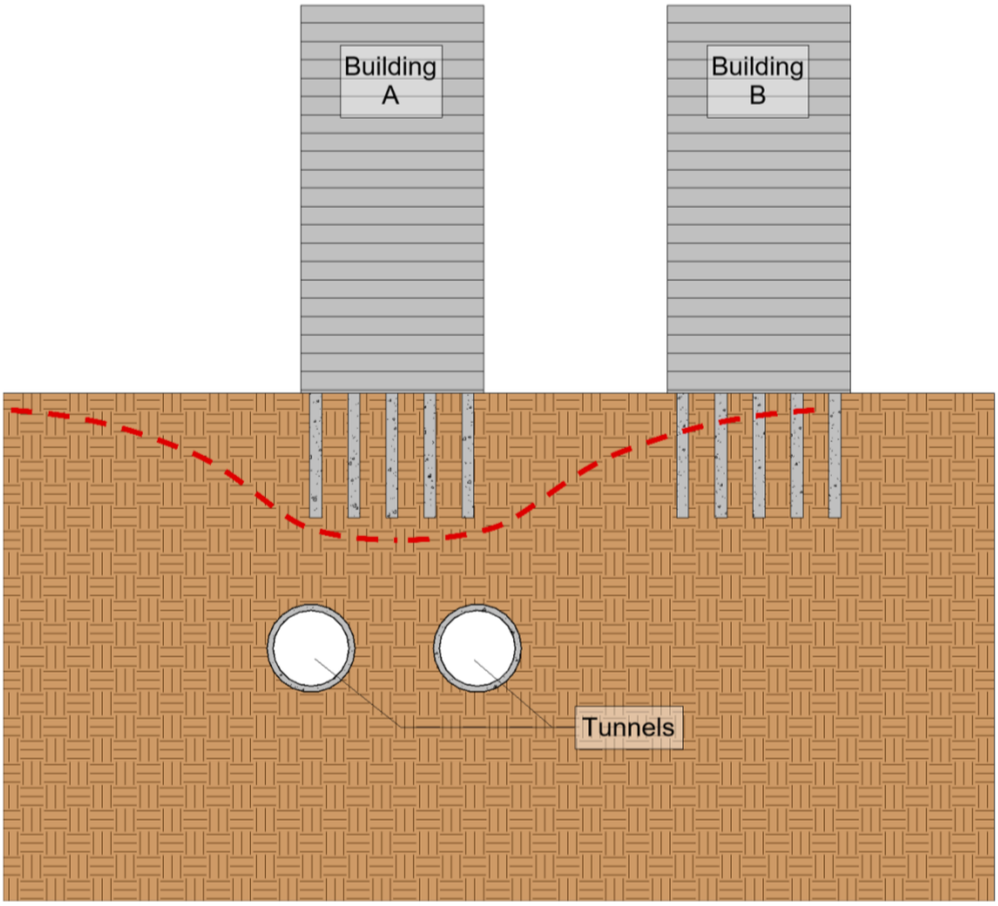

Figure 2: Illustration of a tunneling-induced displacement profile (in red).

The finite-element method (FEM) has further advanced this field by explicitly modeling soil-structure interactions via interconnected elements (Mitelman and Elmo, 2019). More sophisticated analyses can be achieved by coupling FEM with statistical and machine-learning tools to account for geotechnical uncertainties (McQuillan et al., 2023). Overall, soil-structure interactions problems are complex and require in-depth knowledge of geotechnical and civil-structural engineering. In the current state of practice, even in metro projects where BIM is utilized for station and tunnel design, geotechnical tasks like ground investigation, numerical analysis, and tunnel support design are typically conducted using separate software that is not integrated into the BIM platform. While different workflows have been proposed for this purpose, various challenges remain, such as achieving interoperability between BIM and geotechnical software, managing the complexities of cross-disciplinary data exchange, and ensuring that analysis outputs are consistently accurate and error-free across different platforms (Huang et al., 2022).

In the course of metro design, it is important to draw a distinction between existing structures and permits for new buildings. While the analysis of the physical interaction is identical, each requires a different managerial workflow. For existing buildings, a survey is regularly undertaken, where the existing buildings within the tunnel's zone of influence are mapped. Subsequently, structures at risk of clashes or settlement-induced damage must then be identified, as these constraints can impact the metro line's route and depth. For instance, if a building's foundations are found to intersect with the planned tunnel, the tunnels may need to be shifted horizontally to avoid the clash or deepened to pass beneath them. Each such decision carries significant implications for the metro system. In some cases, rather than repositioning the tunnels, remedial measures may be considered. For example, the ground beneath the building can be strengthened via grouting. In any case, wherever there is potential for structural damage, a monitoring plan must be implemented to ensure no damage occurs during tunneling operations, along with contingency plans to address any unexpected outcomes.

For new building permits, it is essential to establish a robust process for their assessment and approval. This necessitates a coordination system where public officials work with the metro design team. A safeguarding policy must be developed and publicly communicated to ensure that private owners and planners are aware of the constraints imposed by the future metro system. This policy should define rules for the exclusion zone around the tunnel, within which building is not permitted. One of the challenges in this process is that the metro line alignment is subject to changes as the design process progresses. The interest of the design team is to set forth a stringent safeguarding policy to allow for flexibility for changes, as well as applying geotechnical factors of safety. Nonetheless, the safeguarding policy must balance these needs while allowing urban development and the realization of private spaces.

Another issue related to building permits is safeguarding the functionality of the metro stations. For example, a new building may be positioned in a way that interferes with the escape route from a station exit. Similarly, a building may be located in a place that interferes with the flow of the metro station ventilation system. Hence, the safeguarding policy must define rules considering such issues, and such permits should be assessed by the relevant designers.

4. METHODOLOGY AND SCOPE OF ANALYSIS

This research adopted a direct observational case study approach to examine the transition from a CAD-based workflow to a BIM workflow during the tender design phase of a large urban metro project. Our study follows key phases of design science research, including problem identification, the iterative development of an artifact, demonstration through real-world application, and evaluation based on observed improvements (Peffers et al., 2007).

The motivations for this transition stemmed from the inefficiencies in processing permit-related information using traditional document-based workflows and the assumption that a centralized BIM model would enhance accessibility and decision-making. To evaluate the effectiveness of this transition, the investigation focused on three main aspects: (1) the process of migrating data from existing documents into a BIM environment; (2) the coordination enhancements facilitated by BIM across multiple design disciplines; and (3) the resulting improvements in accessibility and clarity. For this purpose, the study drew upon several key data sources:

- Project Documentation: Existing CAD drawings, PDF-based permit records, email correspondence, and other project records served as the baseline for understanding the initial, non-BIM workflow. These documents helped characterize pre-existing challenges and inefficiencies.
- BIM Model Development: A structured BIM model was created, incorporating key permit attributes such as lot boundaries, permitted excavation depths, and statutory constraints. This model functioned as an artifact for evaluating improvements in data integration, accessibility, and visualization.
- Observational Insights: The second author, serving as the project manager, was directly involved in the workflow transition, offering firsthand observations of key decision-making processes, challenges encountered, and iterative refinements made throughout implementation. Although no formal observational records were maintained, this direct involvement provided valuable qualitative insights into the adoption process.
- Design Management Input: Informal consultations with the design management team helped clarify roles, responsibilities, and anticipated benefits of the BIM transition. Their perspectives provided essential context, particularly in understanding how organizational structures influenced BIM adoption and its perceived value.
- Stakeholder Feedback: Throughout the implementation, input was gathered from BIM drafters, engineers, and other technical staff via regular coordination meetings and discussions. This feedback helped refine the workflow and assess its practical impact on project coordination and decision-making processes.

The findings of this case study contribute to the broader discourse on BIM implementation in infrastructure projects by demonstrating how workflows that run parallel to the design process can be integrated into BIM environment.

5. CASE STUDY: TRANSITION TO A BIM WORKFLOW

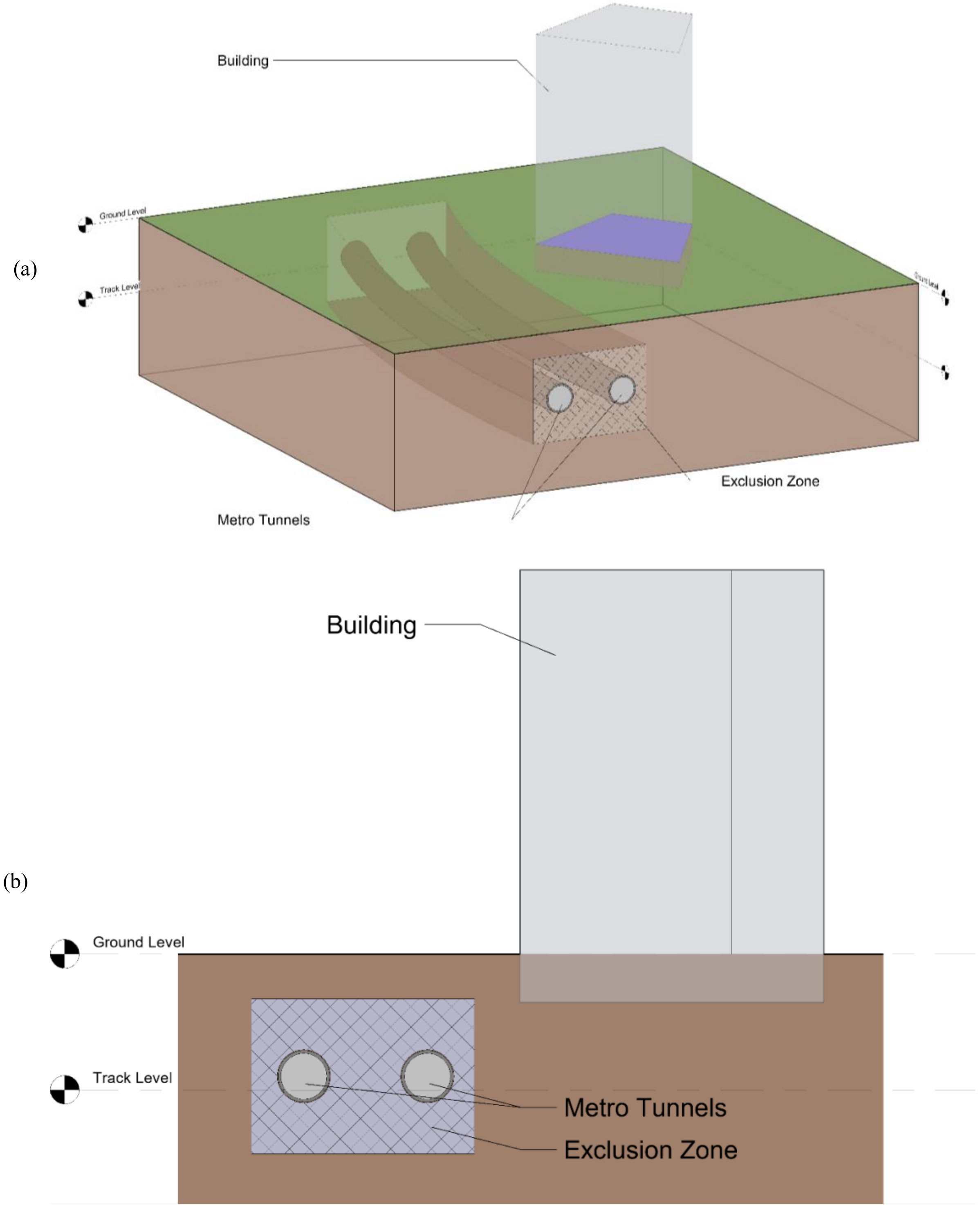

Figure 3: Illustration of (a) an isometric view and (b) a cross-section of the new building and tunnels with the exclusion zone.

In this case study, we examine the implementation of a novel BIM workflow during the tender design phase of one of the three lines of the underground metro system planned for the greater Tel Aviv area in Israel. The report on this case study relies on the direct involvement of the second author, who served as a project manager in this project. His role included overseeing the permit process on behalf of the metro tender design team and implementing BIM for this task. This involved active participation in managerial meetings, where critical decisions regarding the workflow were discussed and refined, as well as direct supervision of the BIM drafter during the model's development and data integration. Arguably, such first-hand involvement provides a distinctive advantage for the current study, offering a practical and nuanced understanding of the challenges, decision-making processes, and outcomes.

At the start of this phase, a new tender design team was tasked with taking over the basic design, which had already determined the tunnel routes and station locations. As the basic design team assumed a relatively large metro line depth, a critical task assigned to the tender design team (TDT) was to investigate the shallowest depth feasible. By this point, several metro-affected building applications had already been processed by the basic design team according to the initial depth. Thus, they imposed a major constraint upon the metro line depth. In addition, new applications were regularly submitted and required setting forth a workflow for their assessment by the tender design team.

Prior to the involvement of the TDT, the basic design team processed the metro-affected applications using computer-aided design (CAD). The building permits were received by the private architects in CAD and PDF formats, and the basic design team used these files to create plans and cross-sections with the new buildings and metro tunnels. These cross-sections showed the exclusion zone based on the safeguarding policy, thus defining the maximum allowable depth of excavation and building. Figure 3Figure 3 shows an illustration of the new building and tunnels with the exclusion zone. Note that the isometric view was added for clarity, whereas the basic design team used 2D CAD for this task. Based on this analysis, a reply with detailed instructions was sent back to the private applicants. Subsequently, the building structural plans were designed to conform to these instructions, with basements and foundations that would both not intrude into the tunnel exclusion zone.

After completing their private design, the plans were sent back to the basic design team for inspection. In addition to the construction plans, the building planners had to submit an analysis that demonstrated that the proposed structure could sustain the tunneling-induced settlements without damage. Once verified that the plans and calculations were in accordance with the safeguarding policy and instructions, the new building application could be approved by the metro planning authority. In some cases, the process outlined here included additional back-and-forth design iterations. Nonetheless, the process outlined here captures the primary essence of the workflow.

After the basic design was completed and handed to the TDT, it was proposed that the processing of new building permits should continue within a BIM environment managed via a cloud platform. Note that according to the owners' policies, the task of processing private applications was not mandated to be carried out in a BIM environment. Upon this proposal, design management officials were hesitant to transition this process to a BIM environment for a number of reasons. First, as the workflow had already been managed by the basic design team in CAD, and private planners largely work in CAD and submit their applications accordingly, transitioning was perceived to be a needless complication of the process. Second, from a resource perspective, BIM drafters are perceived to be more costly and less available than CAD drafters. Third, there was a concern that setting up this workflow would require time and effort that would cause delays.

On the other hand, there were compelling arguments in favor of transitioning to BIM. First, the capability of generating automated cross-sections in BIM offers a significant enhancement in accuracy, particularly for the twin tunnels that curve in 3D space. Traditional CAD methods often require manual adjustments to handle complex geometries, making it challenging to achieve the same level of precision. Second, BIM's location-based platform provides substantial advantages in organization and communication. For the metro designers who must evaluate these applications, having access to a single, integrated BIM model simplifies the process of understanding new building applications within the context of the overall project. The cloud platform established for the project further enhances this by allowing easy access and enabling different authorization levels tailored to the roles of various users. Third, the BIM model would include a topography layer imported and verified by the TDT, ensuring a higher level of accuracy. In contrast, the previous workflow relied heavily on private architectural plans for cross-section compilation, which could lead to inconsistencies and errors. Transitioning to BIM, therefore, not only improves precision and coordination but also ensures that all stakeholders are working on a consistent and verified dataset. Ultimately, it was decided to transition the new building permitting process to a BIM environment.

In order to set up the BIM model, three main components were necessary: (1) the 3D metro tunnels and station model, (2) the surface topography data, and (3) the cadastral parcellation. After setting up the model, the exercise of integrating the legacy applications processed by the basic design team into BIM began. Through this process, it quickly became apparent that the previous workflow did not provide a convenient means of interpretation for assessing the impact of the private building applications on the overall metro line. The data was stored in multiple folders, where the title of each folder was the address of the building application. Within these folders, it was necessary to search and read through multiple PDF files in order to understand the status of each application and its impact on the tunnel alignment.

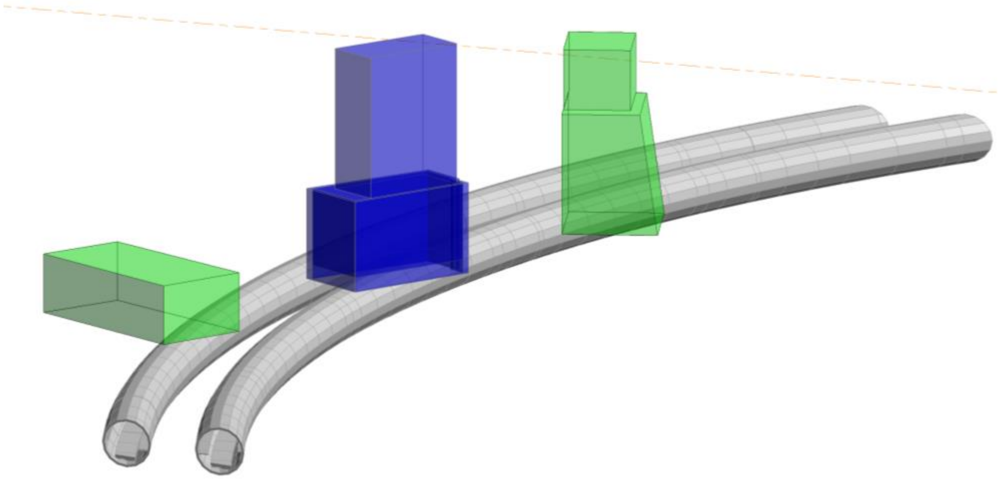

Figure 4: An illustration of the simplified 3D representation of building contours and tunnel alignment taken from the REVIT model.

In order to capture the crucial data and transfer it to the BIM model, the following methodology was applied. First, the crucial data was established, and included the parcellation ID, permitted building depth, building element type (i.e., piles, basement, ground anchors), and statutory status. Statutory process refers to whether the application was approved or only partially processed. For example, in some cases, the applicants have sent a request for information and have received initial guidance regarding the permissible depth but did not proceed to submit plans. These types of requests are important to distinguish from approved applications, as it is possible that, in some cases, the given instruction would be reversible, depending on the circumstances.

The second stage involved screening through all the files and building an Excel spreadsheet with the crucial data. An additional column was added with a link to the original folder so that the source documents could be quickly accessed when needed. In the third stage, a BIM drafter integrated the data from the Excel spreadsheet into the BIM model. In this stage, rather than attempting to build an accurate architectural model, the building contour was extruded from the surface level downwards to the permitted depth. Although inaccurate, this simplified approach was determined to be sufficient for preliminary analysis of tunnel-building interactions and allowed for rapid progress. Figure 4 shows an illustration of the BIM model with the tunnels and building representations. The additional information from the Excel spreadsheet, i.e., statutory status and building element type, was embedded as metadata within the extruded objects in the BIM model. Finally, the drafter measured the vertical distance from the tunnel roof to the bottom of the proposed building (as shown in Figure 5), and recorded this data back to the Excel spreadsheet.

The workflow described here was implemented by a single engineer and drafter, where over 100 applications were processed and completed in less than a week. Note that progress was made simultaneously, as all files were stored on a cloud-based collaborative platform, allowing for real-time updates. Note that although BIM is well-suited for computational automation via tools like Dynamo and Python, it is likely that this process, or aspects of it, could have been automated. However, it was decided to proceed manually to mitigate the risk of code errors and to ensure a thorough review and validation of all data. This approach allowed for greater control and precision, particularly in the context of handling diverse projects.

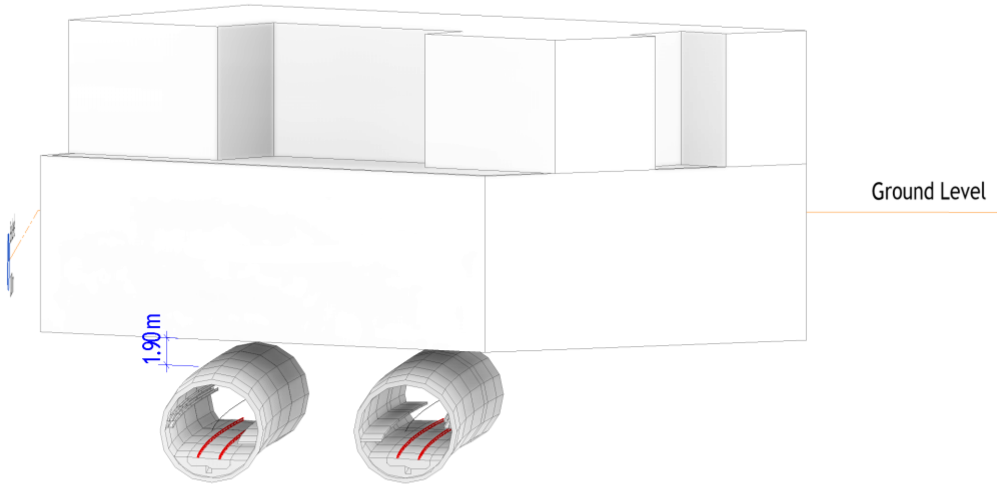

Figure 5: An illustration of a new building and tunnels in isometric views taken from the REVIT model.

Consultation with members of the previous basic design team, who were responsible for processing applications, revealed that it typically took between 3-5 hours using CAD to compile the plan view and cross sections of the new building and tunnels. Hence, contrary to initial concerns, the BIM workflow resulted in increased resource demands, but also demonstrated significant savings.

Upon the completion of transferring the crucial information into the BIM environment, the design teams were provided with convenient means, i.e., a REVIT model and Excel spreadsheet, for assessment of the impact of planned buildings on the tunnel alignment. This assessment primarily involves track alignment and geotechnical teams. The Revit model allowed for visually identifying which portions of the line already included future basements and piles that imposed a constraint on raising the alignment. For specific portions of the metro line where the alignment team deemed it critical to raise the tunnels, the geotechnical team could conduct an in-depth assessment of the minimal safe distance that would not risk the tunnels and building. The BIM model allowed for quick access to the additional information that consisted of the detailed architectural and construction plans of the building, so that each case could be studied using advanced tools if needed, such as 3D numerical models. In cases where it was identified that a building which was not fully approved created a significant constraint on raising the alignment, this issue was discussed with statutory and legal experts, as to whether the private owners could still be restricted to build according to initial guidance they have received from the basic design team.

6. DISCUSSION

6.1 Key Advantages and Future Potential of the BIM Workflow

The process described in the previous section demonstrated the significant advantages of using BIM as a tool for enhancing project outcomes. In contrast to traditional industry practices that often rely on fragmented 2D CAD documentation and multiple file repositories, the BIM-based workflow presented here aligns with acknowledged BIM benefits. BIM facilitated improved cross-disciplinary communication between consultants by providing a shared visual platform. The ability to visualize complex interactions in 3D allowed the design teams to better comprehend the spatial relationships and constraints, leading to more informed decision-making. In this context, the automated cross-section feature proved to be highly beneficial. Unlike architectural cross-sections, that often require manual adjustments, cross-sections for the current workflow are used for establishing distances and levels of tunnels and structures and required minimal adjustments.

In terms of working efficiency, the setup time for each permit application in the BIM environment was 1-2 hours, compared to 3-5 hours in the CAD environment. This difference is primarily due to the integration of essential project data, including metro tunnel layers, surface topography, and cadastral parcellation, directly within the BIM model. By extruding building volumes and utilizing automated cross-sections, the majority of the workflow was streamlined, significantly reducing manual effort. In contrast, the CAD-based approach required gathering information from multiple sources and manually constructing cross-sections for each application, making the process more time-consuming and less efficient.

The BIM environment offered an efficient means of IM by linking to other data and files and reduced the potential for errors. This represented a substantial improvement over the previous method of storing files in separate folders without connecting them to a unified 3D model. By embedding permit-related data as BIM objects rather than relying solely on generic reference files, this case study offers a tangible demonstration of BIM's potential in the context of underground metro design, a comparatively underexplored application area. The advantages of the BIM workflow in comparison to the CAD workflow are summarized in Table 1. Given these proven benefits, it became evident that the proposed BIM methodology should be adopted for processing new and ongoing building applications.

Table 1: Comparison of Traditional CAD Workflow and Implemented BIM Workflow in Metro Building Permit Assessment.

Aspect	Traditional CAD Workflow	Implemented BIM Workflow	Key Benefit
Data Management	Data scattered across multiple folders and files.	Centralized location-based model with links to all relevant project data.	Improved organization and convenient data retrieval.
Visualization	2D plans and cross-sections manually created for each building permit.	3D integrated model visualizing spatial relationships between buildings and tunnels.	Enhanced understanding of complex building-tunnel interactions.
Accuracy	Manual adjustments for complex geometries are less accurate and prone to errors.	Automated generation of cross-sections leads to accurate geometries.	Reduced potential for errors and higher precision.
Efficiency	Estimated 3–5 hours per application for CAD-based workflow.	Estimated 1-2 hours per application	Significant time savings, even when accounting for the initial setup time.
Collaboration	Limited cross-disciplinary communication due to fragmented data sources.	Cloud-based platform with real-time updates and role-based access for different stakeholders.	Improved coordination among designers and statutory teams.
Scalability	Workflow cannot readily accommodate additional data layers or advanced tools.	Ready for integration with emerging technologies (ML, IoT, etc.).	Future potential for enhanced analytics and decision-making.

In addition to these immediate advantages, additional benefits became apparent. One such example is related to the physical supervision along the future metro line throughout the design process. The supervision team's role was to ensure that any construction activities occurring near the future metro tunnels and stations were approved and would not impose any constraints on the planned tunnels and stations. The BIM model provided an efficient tool for quickly comparing on-site activities with the approved plans. For instance, if pile driving activities were observed at a specific location, the BIM model could instantly verify whether such work had been authorized and what depth had been permitted. This capability enhanced the supervision team's ability to monitor and manage construction activities, ensuring compliance and reducing the risk of unexpected complications.

The BIM model also offers substantial future benefits by enabling continuous inspection and updates throughout the project's life cycle. For example, monitoring plans can be integrated into the BIM model, showing where devices are installed, and linking to their readings. This is particularly important for sensitive structures, ensuring that any potential impacts are closely observed and managed. As the project progresses, updated as-built survey data can be incorporated into the model upon the completion of buildings, providing an accurate and current representation of the site conditions. Furthermore, the BIM model can be expanded to additional data, such as the installation of new private building utilities during the design process. Continuous updating and integration of data not only enhances project management but also allows for elegant transfer of data to future parties which will be handed responsibilities, such as contractors, on-site supervisors, and other stakeholders.

As BIM is fundamentally an object-oriented system, it allows for the integration of multiple layers of data and information within a cohesive framework. Hence, BIM is an ideal environment for coupling with rapidly advancing machine learning (ML) tools. ML algorithms can analyze various data layers to optimize design, provide real-time warnings during construction based on continuous analysis of as-built data and monitoring reports, and enhance maintenance processes. For example, in managing tunnel-building interactions, ML can predict potential conflicts between building foundations or underground utilities and metro tunnels, drawing on patterns identified from a wealth of historical data across similar projects. With techniques such as transfer learning, ML can overcome data limitations by adapting models trained on larger datasets to specific project conditions, improving the accuracy of predictions (Mitelman and Urlainis, 2023). This could include better prediction of the impact of new building applications on tunnel alignments, rather than relying on simplistic empirical methods that are based on limited data and few variables (Mitelman et al., 2023).

To fully realize these benefits, the construction industry must embrace a paradigm shift towards greater collaboration and knowledge-sharing across projects (Shi et al., 2022). While the industry has traditionally operated within a competitive environment, fostering a more cooperative approach would be essential for leveraging the collective power of BIM and ML. This shift could drive innovation and elevate the entire field, resulting in safer, more efficient, and sustainable infrastructure developments, ultimately benefiting all stakeholders involved.

Figure 6 shows an illustration of the BIM workflow implemented in our case study. To summarize, the BIM model serves as the central hub for managing the new building permits, linking to CAD files and other related data.

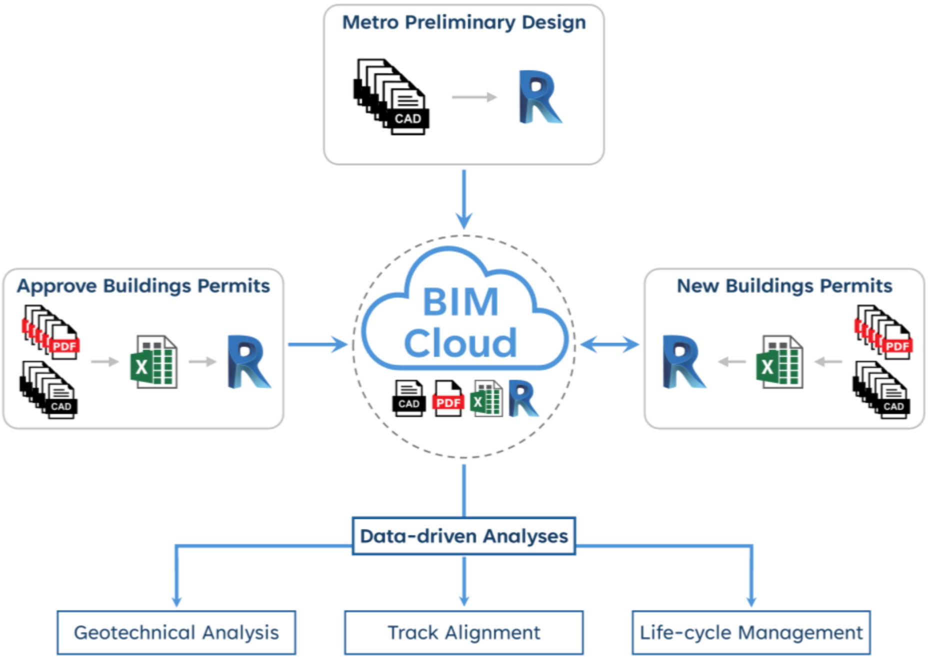

Figure 6: BIM Workflow for Information Management Process in Metro Project.

6.2 Limitations and Future Research

While the implementation of a BIM workflow in this case study demonstrated significant advantages, there are several limitations that should be considered. First, the study was conducted within the context of a single metro project in Tel Aviv, focusing on a certain aspect of new building permits. As such, the findings may not be fully representative of other infrastructure projects with different regulatory environments, construction methods, or stakeholder complexities.

Second, this study has been conducted during the tender design phase, therefore the full outcomes of the presented BIM-workflow across advanced stages of the project life cycle, such as construction, operation, and maintenance, have not been explored.

Third, while the case study highlights significant improvements in efficiency and accuracy, it is inherently challenging to precisely quantify these gains in terms of working rates and outcomes. Such measurements often rely on indirect indicators or subjective assessments, which may introduce some degree of uncertainty. In addition, no formal data collection methods, such as structured questionnaires, or time-measurement metrics, were employed. Future research could build on this groundwork by incorporating these methods to more accurately quantify improvements in drafting time, error reduction, and stakeholder satisfaction.

Finally, the study's reliance on the direct involvement of the second author as a project manager introduces the possibility of bias. However, this potential limitation has been mitigated through the oversight and critical evaluation provided by the lead author, ensuring a balanced and objective analysis.

Future research can build upon our findings by investigating the implementation of BIM in metro projects across different geographic locations and regulatory settings, allowing for a more comprehensive understanding of its adaptability. Other studies can focus on the application of BIM in later stages of the project lifecycle, particularly in the context of construction and asset management.

While emerging technologies such as ML, artificial intelligence (AI), and the Internet of Things (IoT), have the potential to be integrated into BIM environments and enhance metro projects, their actual implementation requires additional studies (Igwe et al., 2022; Pishdad and Onungwa, 2024).

7. SUMMARY AND CONCLUSIONS

This paper presents a detailed case study on the implementation of a BIM workflow during the tender design phase of an underground metro line in the greater Tel Aviv area. The focus was on managing metro-affected building applications, which played a critical role in determining the metro line depth. A substantial number of these applications had been managed using a CAD-based workflow by the basic design team. Crucial information was extracted into an Excel spreadsheet and used to construct a BIM model. Through this process, several benefits became apparent.

By providing a centralized location-based model, the BIM approach facilitated better coordination among different design disciplines. This included the ability to visualize the constraints imposed by future buildings on the metro tunnels and to evaluate different tunnel alignment options.

In addition, the BIM model served as a convenient repository of information, offering location-based links to additional information. By having all relevant project data, such as topographical maps, building plans, and cadastral data, integrated into a single model, team members across different disciplines were able to better communicate. Compared to the preceding workflow, where the materials for the building applications were scattered across multiple folders within a file sharing platform, the BIM environment facilitated faster retrieval of relevant information and ensured that all team members worked on the same data.

The BIM model also assisted with physical supervision along the future metro line, enabling building operations initiated by private parties to be readily checked and compared against approved permits.

Despite initial managerial concerns, the transition to BIM was completed without requiring significant resources. Moreover, BIM capabilities to generate automated cross-sections and accurately model 3D geometries allowed for reducing the time needed for creating plans and cross-sections and yielded more accurate results.

Looking to the future, BIM holds potential advantages for additional stages of the project life cycle. First and foremost, it can be transferred to future contractors, allowing them to efficiently track and monitor the interaction between tunneling operations and the buildings' responses. Second, as technology advances, future tools are likely to integrate with BIM, offering further benefits. In particular, ML tools are ideally suited for coupling with BIM's object-oriented system, improving predictive capabilities and enhancing IM tasks.

In conclusion, this case study advances the state of the art by demonstrating the significant advantages of adopting a BIM workflow in the design and management of underground projects in urban environments. Notably, the benefits realized in this project were achieved without the necessity for extensive development efforts. This underscores the value of localized initiatives that can be readily implemented and further advanced by others.

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