Integration of BIM and other Innovative Technologies to Enhance the Sustainable Design of Geotechnical Works

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ABSTRACT

Recent advancements in smart technologies, such as building information modeling (BIM) and digital twin systems, offer promising opportunities to enhance geotechnical practices. The integration of smart technology in geotechnical engineering has provided innovative and sustainable solutions to the challenges faced by engineers, geologists and construction professionals. For example, Dynamo visual programming is used to develop scripts within Civil 3D and Revit software for modeling subsurface conditions and proposed soil nailing works for slope upgrading projects, as well as to facilitate data exchange in tunnel projects. Handheld laser scanning devices are utilized to generate 3D point clouds of the existing conditions, which are then converted into BIM-compatible models through photogrammetry. The use of these tools and technologies provides many benefits, including improved accuracy and efficiency, as well as reduced costs. The integration of BIM, digital twins, and tools such as Dynamo scripts, handheld LiDAR scanning, and UAV photogrammetry has proven to be a game-changer in the field of geotechnical engineering, providing new and innovative solutions to the challenges faced by engineers, geologists and construction professionals.

Keywords: UAV LiDAR Photogrammetry, Parametric Geotechnical Design, BIM Digital Twin

1 Introduction

Building Information Modeling (BIM) has become a popular digital design and management tool in the construction industry, offering a unified platform for the design, construction, and maintenance of infrastructure assets. To improve the sustainability of geotechnical works, BIM can be integrated with other innovative technologies such as UAV photogrammetry, handheld LiDAR scanning, and automation tools with visual programming scripts for parametric design. These integrations can enhance the accuracy and efficiency of sustainable design for geotechnical works.

2 UAV Photogrammetry and Handheld LiDAR Scanning

UAV photogrammetry and handheld LiDAR scanning are two innovative technologies that can improve the accuracy and efficiency of geotechnical design and construction. UAV photogrammetry involves using unmanned aerial vehicles (UAV) to capture high-resolution images of the construction site, which can be used to create 3D models of the site. Handheld LiDAR scanning involves using a portable LiDAR scanner to capture accurate 3D data of the site. These technologies can be used to improve the accuracy of site surveys, reduce the risk of accidents and injuries, and enable more efficient and effective design and construction.

2.1 UAV Photogrammetry

Traditional topographic survey methods can be physically demanding and time-consuming when conducting topographic surveys at areas with steep slopes, dense vegetation, or areas obscured by debris. The process of setting up total stations and surveying points in such environments can be

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challenging, which can lead to errors and bias in manual processing. However, innovative technologies such as UAV photogrammetry can overcome these challenges and improve the accuracy and efficiency of topographic surveys.

UAV photogrammetry can be used to create a 3D model of the construction site that can be used for site analysis, visualization, and planning. UAV can quickly capture high-resolution aerial images and access hard-to-reach areas such as landslide scars, making it possible to create accurate 3D models of the terrain. These models can be used for a variety of purposes, including analyzing the site's topography, identifying potential hazards, and designing effective solutions for geotechnical engineering projects (Teppati Losè *et al.*, 2022).

Furthermore, UAV photogrammetry can be used to track changes in the construction site over time, enabling construction teams to monitor progress and identify potential issues before they become major problems. This can lead to more efficient and effective project management and ultimately result in cost savings. A typical UAV device equipped with LiDAR system is shown in Figure 1 below.

Figure 1: *Unmanned Aerial Vehicle (UAV) equipped with Light Detection and Ranging (LiDAR) systems for digital terrain modelling and landslide mapping applications*

2.2 Handheld LiDAR Scanning

Handheld LiDAR scanning technology can capture accurate data of existing structures, terrain, and underground utilities for more precise design and construction. A scan-to-BIM approach can be adopted for rapid and accurate on-site point cloud data capturing. Handheld LiDAR scanning captures and produces various types of data, including colorized point cloud data points, digital terrain model, and digital surface model.

The integrated scan-to-BIM approach offers several benefits, including better site characterization for hard-to-reach areas, enhanced safety for workers and the public, and reduced costs due to more efficient and accurate design and construction processes. In addition to landslip prevention and mitigation works, the scan-to-BIM approach can be used for digital terrain modeling, landslide debris mapping, and as-built modeling for heritage sites (Sammartano & Spanò, 2018).

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Utilizing handheld LiDAR scanning technology for geotechnical engineering works offers significant benefits in terms of efficiency, accuracy, cost savings, and safety. The technology can improve efficiency and accuracy by up to ten times compared to traditional surveying methods, while cutting the bulk of traditional surveying costs by around 80%. Moreover, using this technology can save up to 50% of staff hours and eliminate safety hazards associated with accessing challenging terrain. A point cloud model (left) generated from the handheld LiDAR scanner (right) is presented in Figure 2 below.

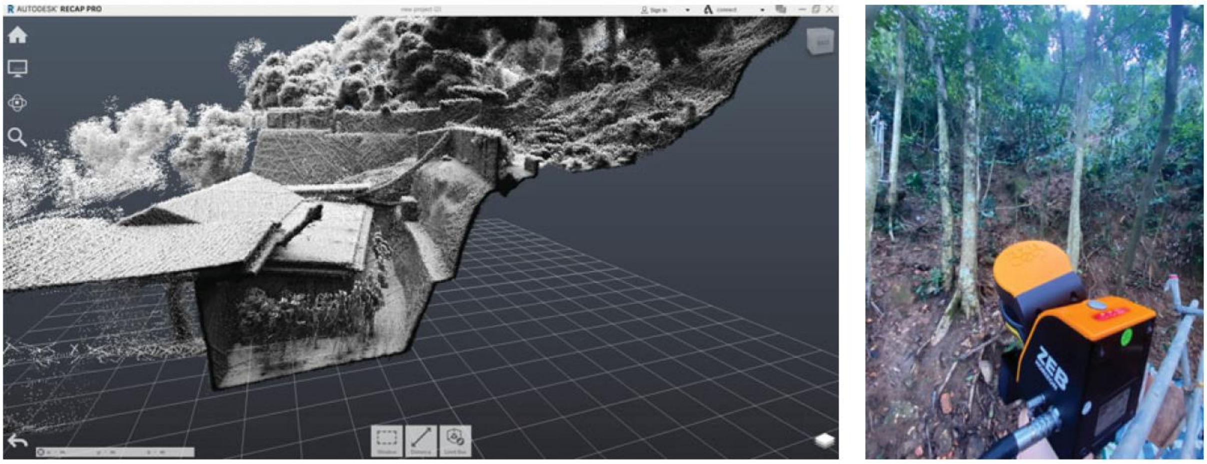

Figure 2: *Handheld LiDAR scanner for rapid generation of digital surface model with unprecedented level of details*

3 Building Information Modelling (BIM) and Dynamo Visual Programming

BIM and Dynamo visual programming are innovative technologies that can improve the accuracy and efficiency of geotechnical design and construction. BIM involves creating a digital 3D model of the construction project, which can be used to simulate construction activities, detect clashes, and optimize design and construction processes. Dynamo is a visual programming tool for BIM that enables the creation of custom scripts to automate design and construction tasks.

3.1 Dynamo scripts for slope upgrading works

Dynamo scripts can be used to automate geotechnical design and construction tasks such as slope upgrading works, site formation projects, and parametric design for tunnel projects. The benefits of using BIM and Dynamo for geotechnical design and construction include improved accuracy and efficiency of design and construction processes, reduced errors and rework, and more effective collaboration between stakeholders.

Designers can create parametric models that can be easily modified to test different design options and evaluate their impact on project objectives. This can help to identify the optimal design solution that best meets the project requirements. Moreover, the use of scripting can help to optimize the design process for factors such as time, cost, productivity, quality, safety, and sustainability. This can be achieved by creating scripts that automate repetitive tasks, enable faster iteration of design options, and provide real-time feedback on the impact of design changes.

One of the main advantages of using Dynamo is that it allows designers to easily include repetitive objects into the model. This can save time and reduce errors by automating tasks that would otherwise be done manually. For instance, scripts can be created to generate repetitive elements in slope upgrading work projects, such as the placement of soil nails, tree rings and hoarding layout as illustrated in Figure 3 below. This can help the designer to optimize the layout of the proposed slope upgrading works and avoid clashing of different objects on slope. By using this streamlined design workflow, the needs for future design review can be minimized and hence the time and cost required for the project can be reduced.

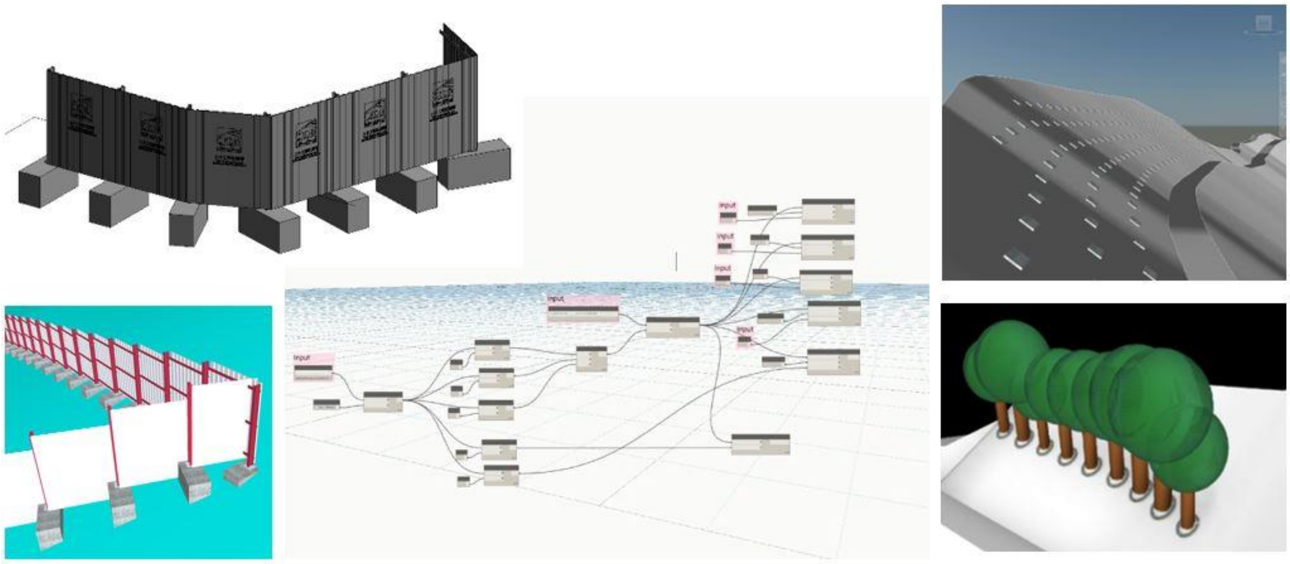

Figure 3: *Dynamo scripts developed to streamline the design workflow of slope upgrading works*

3.2 Automation for the design of site formation projects

Site formation projects can benefit significantly from the use of automation tools. In particular, LiDAR data can be used to create accurate terrain models that can help to plan and optimize the site formation level and platform area. Better coordination between different utility undertakers for underground utilities can also be achieved using automation tools to provide better integration between Geographic Information System (GIS) and BIM. This can help to reduce conflicts and rework. Real-time updating of 3D ground models and clear visualisation of soil-rock interface can help to identify potential adverse geological issues early on and allow for adjustments to be made quickly upon the completion of site-specific ground investigation works.

BIM models can be used to fine-tune and optimize the site formation level and platform area based on a pre-defined set of design criteria. Programming scripts such as Python can be used to quickly enhance the detailing of the site formation project such as adding retaining walls, soil nails, surface drainage channels and maintenance access, ensuring optimal design with minimal errors. Automation tools can also be used to measure and estimate the quantity of works required for a site formation project, as well as estimating cut-and-fill volume as shown in Figure 4 below. This can help to ensure completion on time and within budget.

Additionally, automation tools can produce design drawings quickly and accurately, reducing time and effort for the preparation of plans, cross-sections and elevations drawings. Effective communication with draughtsmen can also be facilitated using automation tools, minimizing revisions and ensuring everyone understands the project requirements. Overall, the use of automation in site formation projects can improve efficiency, accuracy, and quality, while reducing waste and costs.

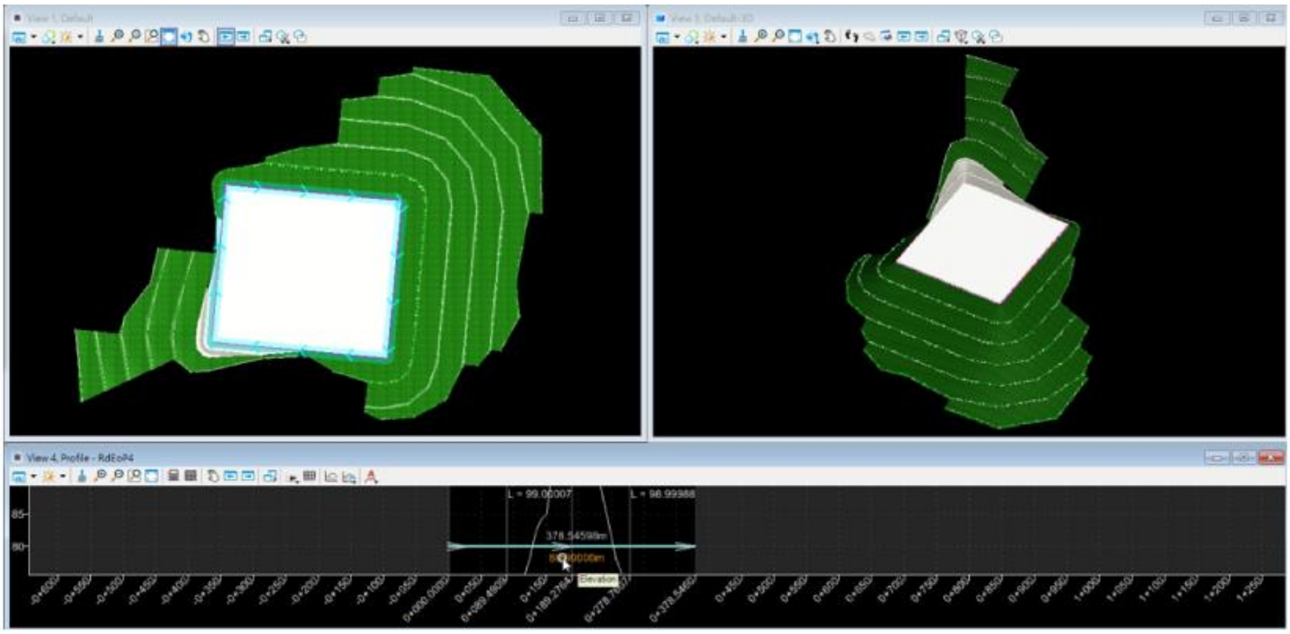

Figure 4: *Use of BIM model to fine-tune and optimize the site formation level and platform area*

3.3 Parametric design for tunnel projects

Parametric design is a method of design that uses a set of defined parameters to generate a range of design options. In the context of tunnel projects, parametric design can be used to generate multiple design options for tunnel alignments, segment arrangements for the linings of TBM tunnels, cross-sections and MEP arrangements as shown in Figures 5 and 6. This can help to optimize the design for a range of factors such as cost, constructability, safety, and environmental impact.

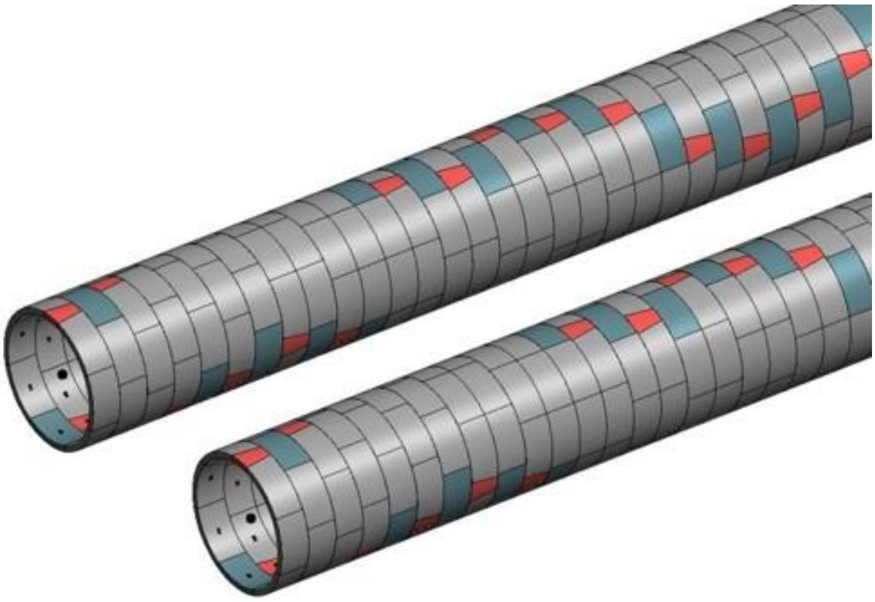

Figure 5: *Parametric design for TBM tunnel segment arrangement*

One of the main benefits of parametric design for tunnel projects is that it enables rapid iteration and evaluation of design options. By adjusting the defined parameters, designers can generate a range of design options and evaluate them against a set of criteria such as cost, constructability, safety, and environmental impact. This can help to identify the optimal design option that best meets the project requirements.

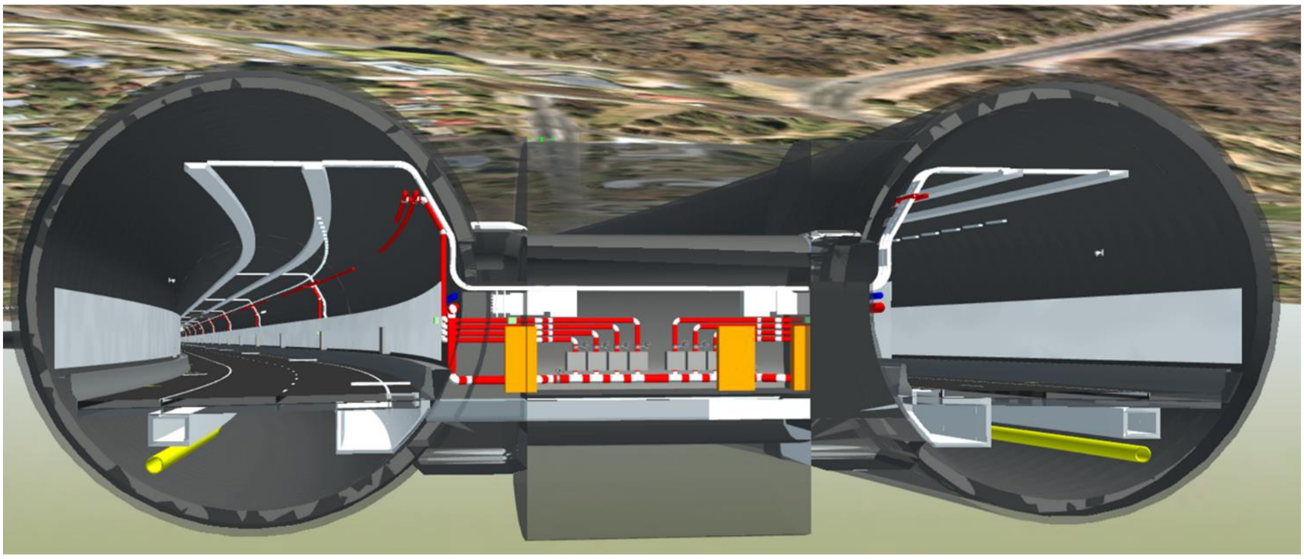

Figure 6: *Semi-automation of tunnel MEP element arrangement*

Parametric design can also help to improve the efficiency of the design process by automating repetitive tasks such as generating cross-sections and performing finite element analysis for different configurations as demonstrated in Figure 7. This can reduce design time, minimize errors, and improve the accuracy and consistency of the design. Furthermore, parametric design can enhance collaboration and communication between different stakeholders involved in the design process.

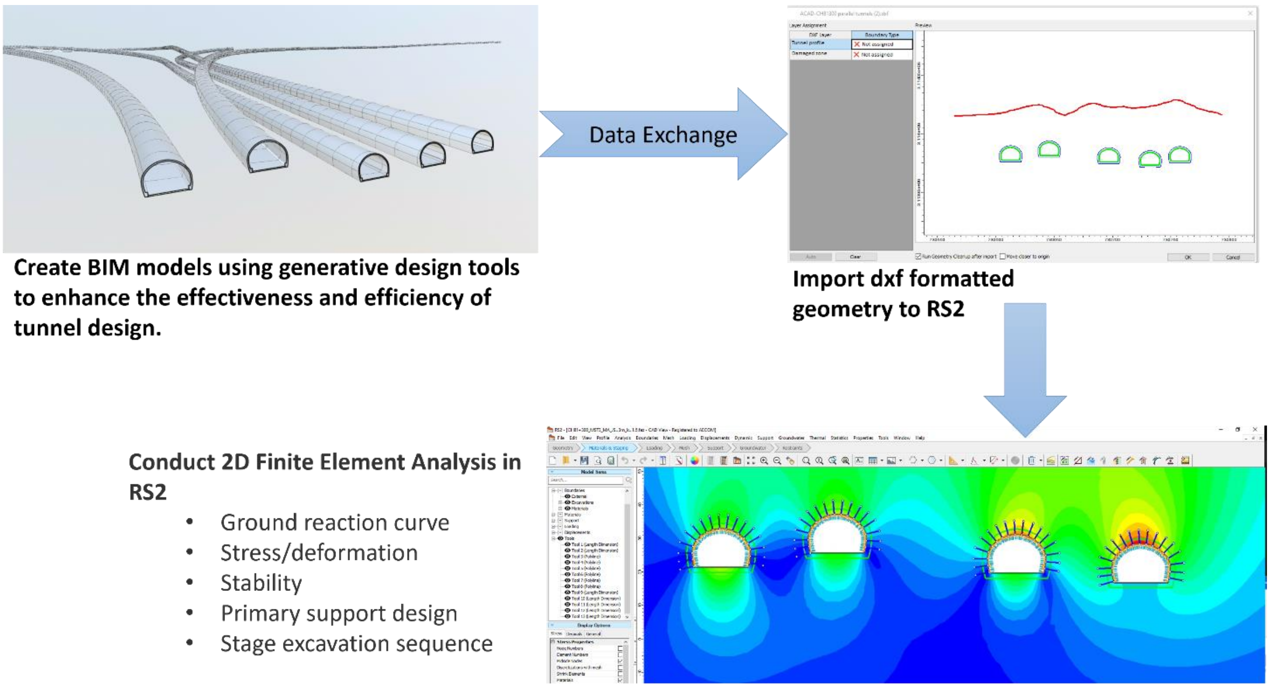

Figure 7: *Sample workflow of using BIM models as generative design tools in a tunnel project*

Dynamo scripts can be used to create data exchange workflows, which can be implemented into the project management plan. The workflows can include importing and exporting data between different software applications between commonly used BIM software. These data exchange workflows can be tested and refined to ensure that they are working correctly. The use of Dynamo scripts to automate data

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exchange workflows can save time and reduce errors associated with manual data exchange as shown in Figure 8 below. It also ensures that all stakeholders have access to the most up-to-date information, enabling effective decision-making.

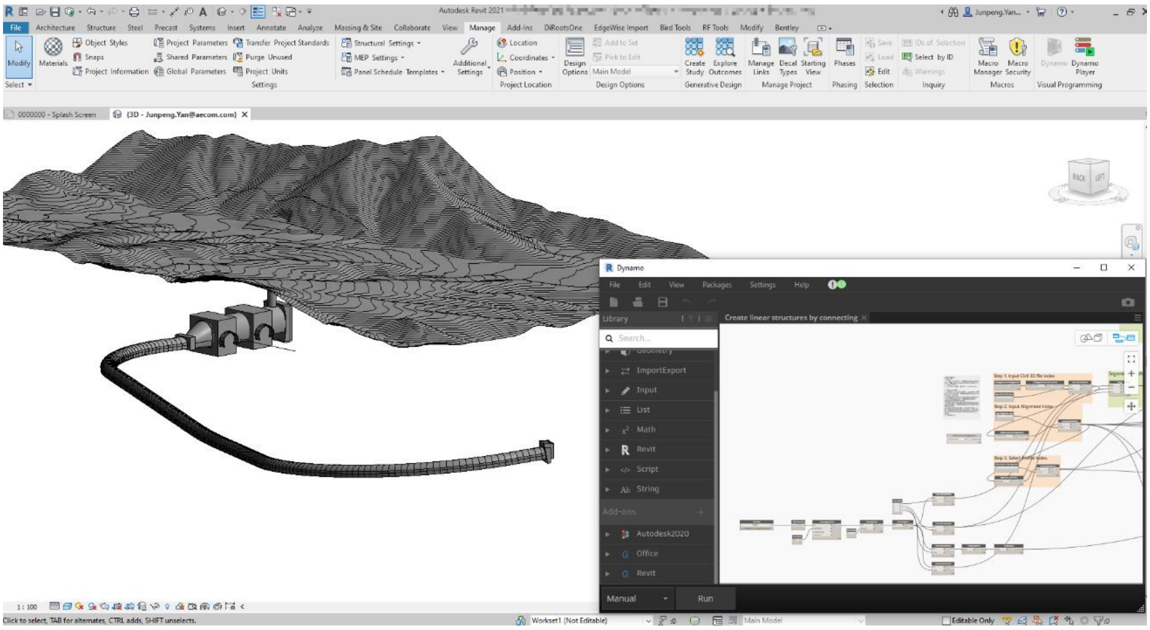

Figure 8: *Use of Dynamo scripts to facilitate data exchange in a tunnel project*

4 Digital Twin Systems and As-constructed BIM Models

Digital twin systems and as-constructed BIM models are innovative technologies that can improve the accuracy and efficiency of maintenance and repair tasks, reduce downtime and costs, and enable more effective collaboration between stakeholders. As-constructed BIM models involve creating a digital model of the construction project that accurately reflects its as-built condition.

4.1 As-constructed BIM Models using openBIM

Digital twin systems and as-constructed BIM models using openBIM can provide a comprehensive and accurate representation of geotechnical works, enable real-time monitoring and analysis of their performance. As-constructed BIM models can be used as the basis for creating digital twins of geotechnical works, providing a detailed and accurate representation of the physical asset. The use of openBIM format ensures that the as-constructed BIM models can be easily integrated with other data sources, such as sensor data, to create a digital twin that accurately reflects the current state of the asset (Building Smart, 2020).

Digital twin systems and as-constructed BIM models using openBIM can also help to streamline the design review process for geotechnical works. The use of digital twin systems and as-constructed BIM models can also enhance collaboration and communication between different stakeholders involved in the design review process. The 3D models and simulations, such as the one as illustrated in Figure 9, can be easily shared and reviewed by all stakeholders, which can help to identify potential issues and enable timely and effective decision-making (Construction Industry Council, 2021a).

The as-constructed BIM models can be used to compare the design intent with the actual construction and identify any discrepancies or issues that need to be addressed. This helps to improve the accuracy and completeness of the design and ensures that the constructed asset meets the design intent. Furthermore, digital twin systems can be used to simulate the performance of the geotechnical works under different conditions, such as changes in loading or environmental factors. This can help to identify potential issues and optimize the design to ensure that the asset meets the required performance criteria.

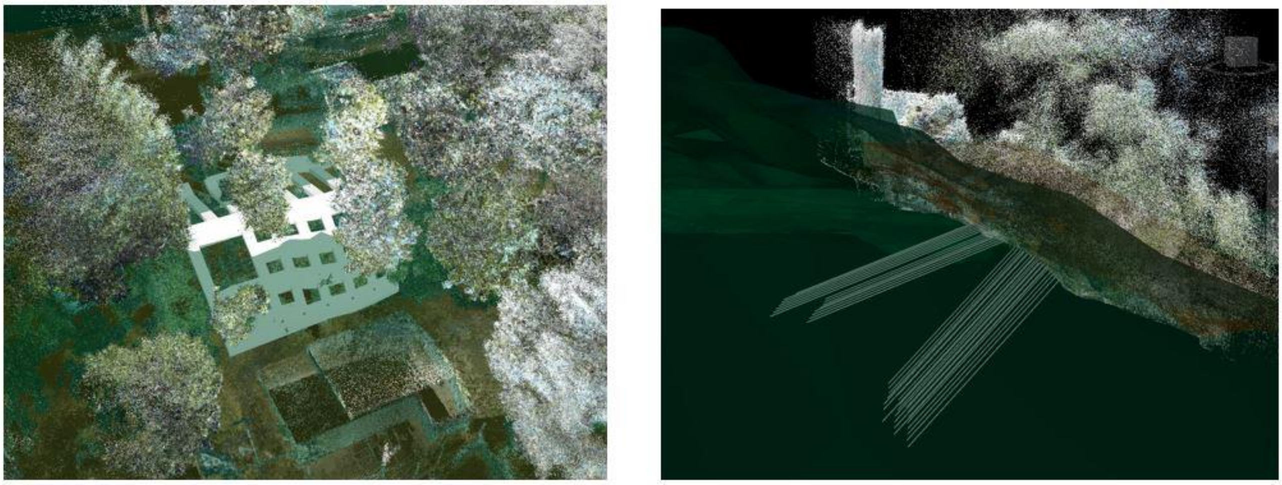

Figure 9: *BIM models created using point cloud data from handheld LiDAR scanner to facilitate the design review process and production of as-built drawings*

4.2 Data exchange and asset management

As-constructed BIM models created in openBIM format can facilitate information exchange in Common Spatial Data Infrastructure (CSDI) and future asset management by maintenance departments. CSDI is a platform for sharing spatial information across different organizations and government departments. It is crucial for effective asset management and maintenance of geotechnical works. As-constructed BIM models in openBIM format can provide a standardized and interoperable platform for sharing spatial information between different organizations and government departments (Yiu *et al.*, 2021).

The use of openBIM format ensures that information can be easily exchanged between different software programs and platforms, regardless of their proprietary formats. This means that maintenance departments can access and use the information from the as-constructed BIM models without the need for specialized software or data conversion. The openBIM format also enables the integration of other relevant data such as geospatial and environmental information, which can enhance the accuracy and completeness of the asset management system.

The as-constructed BIM models, such as the one as shown in Figure 10, can provide a comprehensive and accurate representation of the geotechnical works, including their location, shape, size, and condition. This information can be used for a range of asset management activities such as condition assessment, maintenance planning, and cost estimation. The use of BIM-based asset management can also help to improve the efficiency and effectiveness of maintenance operations by providing timely and accurate information to the maintenance agencies for better planning and prioritization of resources (HKSAR Development Bureau, 2023).

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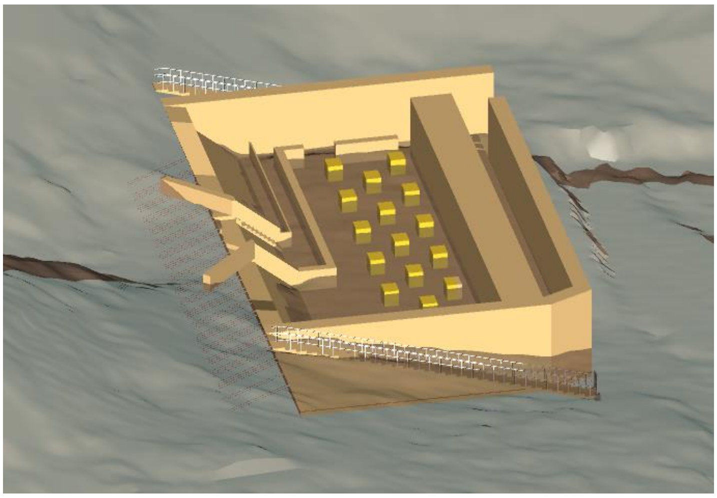

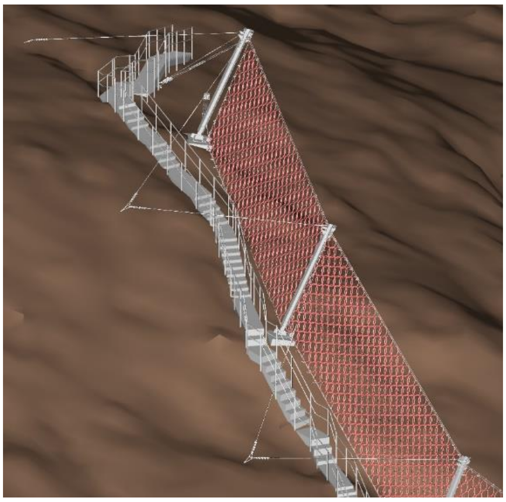

Figure 10: *As-constructed BIM models created in openBIM format to facilitate information exchange in Common Spatial Data Infrastructure (CSDI) and future asset management by maintenance department*

5 Sustainable design of geotechnical works

5.1 Design for safety

Design for safety is a method of designing products, systems, or structures with the goal of minimizing or eliminating safety hazards. It involves considering potential safety hazards during the design process and implementing measures to prevent or mitigate those hazards. The design for safety approach is based on the principle that it is easier and more cost-effective to design safety features into a product or system from the beginning rather than trying to address safety concerns after the design is completed. The goal of design for safety is to ensure the safety of workers and the public, reduce the risk of accidents and injuries, and comply with safety standards and regulations.

BIM models and automated scripts can improve the design for safety of geotechnical works by providing a more accurate and detailed representation of the construction site, identifying potential safety hazards, and developing effective solutions to mitigate these risks. Comprehensive site analysis is possible using BIM models, incorporating data on the site's topography, geology, and other features. This allows engineers and construction teams to identify potential safety hazards and problematic areas in the early stage of the project and develop effective solutions to mitigate these risks. Automated scripts can be used to analyze complex data quickly and accurately, reducing the risk of errors and improving the efficiency of the design process.

Simulating construction processes is another application of BIM models. These models can be used to simulate the construction process, identifying potential safety hazards and developing effective solutions to mitigate these risks. Real-time monitoring is also possible with BIM models and automated scripts. These technologies can be used to monitor the construction site in real-time, identifying potential safety hazards and taking action to prevent accidents and injuries. This can include using sensors to monitor the stability of excavations and temporary slope cuttings, detecting the presence of hazardous materials, and alerting workers to potential hazards.

5.2 Enhanced sustainability

Sustainable design is an important aspect of geotechnical works, and BIM and other innovative technologies can be utilized to promote sustainable design by enabling more accurate and efficient design and construction processes. For example, BIM can simulate construction activities and optimize design and construction processes, which can help reduce waste and energy consumption. Other innovative technologies, such as UAV photogrammetry, handheld LiDAR scanning, and digital twin systems, can also enhance the accuracy and efficiency of sustainable design for geotechnical works.

In addition to BIM and other technologies, parametric and generative design can be utilized to explore a wide range of design options quickly and efficiently, thus promoting sustainability in geotechnical design. Generative design has several benefits, including optimizing material usage, reducing energy consumption, enhancing safety, improving resilience, and reducing carbon footprint. By using generative design, engineers and geologists can identify optimal solutions that are not only safe and efficient but also sustainable, contributing to the achievement of the United Nations Sustainable Development Goals (UNSDGs). Generative design can help optimize the placement of structures and infrastructure, reduce the amount of material used in construction projects, design infrastructure that is more resilient to natural disasters and climate change, and identify solutions with a lower carbon footprint (Fei *et al.*, 2021).

5.3 Promoting the use of BIM within the company

Promoting the use of BIM and other innovative technologies within the company is essential to promote digital transformation within a company and thus achieving sustainable design for geotechnical works. Strategies for promoting the use of BIM and other innovative technologies include training and education, collaboration with stakeholders, and integration of BIM into company standards and procedures.

To foster a BIM culture within the company, it is important to provide training and education on BIM and other innovative technologies. This can be achieved through various methods, such as promoting in-house BIM training programmes, webinars, and technical knowledge sharing sessions. By providing these training opportunities, engineers and geologists can become more familiar with BIM and its applications, leading to increased adoption of BIM technologies and embedded design for safety and sustainability from the preliminary design process. Providing basic training to graduates and developing Dynamo scripts for BIM applications can also help reduce the learning curve of preparing BIM models, encouraging more engineers and geologists to use BIM in their work.

Another way to promote the use of BIM within the company is to integrate BIM into company standards and procedures. This can help ensure that BIM is used consistently and effectively across projects, leading to improved collaboration and efficiency.

Finally, it is important to collaborate with stakeholders, such as contractors, consultants, and clients, to promote the use of BIM and other innovative technologies throughout the project lifecycle. This can help ensure that BIM is used effectively and efficiently, leading to more sustainable geotechnical design and construction. Accreditation and certification of training programs such as Construction Industry Council's (CIC) Certified BIM Managers (CCBM) and BIM Coordinators (CCBC) also help promote the use of BIM and other innovative technologies among stakeholders, leading to increased collaboration and a more sustainable design process (HKSAR Development Bureau, 2023).

5.4 Potential areas for further development

Digital transformation can enhance workflows, promote automation, handle repeatability, improve collaboration, and support knowledge transfer. The shortage of resources, such as geotechnical engineers, geologists, and BIM modellers, can be addressed through investment in BIM education and training programmes.

The design process can be optimized using tools and techniques to ensure cost-effectiveness, buildability and constructability, sustainability, and compliance with relevant codes and standards. Pre-

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fabrication and modular construction, including 3D printing, offer opportunities for greater efficiency and cost savings. The development of advanced materials can improve the sustainability, durability, and performance of geotechnical engineering projects, while also reducing their environmental impact.

The use of autonomous construction technologies, such as drones and robots, can improve efficiency and safety. Augmented reality and virtualization technologies can improve visualization, communication, and collaboration. Big data and predictive analytics, including AI, can enable more accurate and efficient decision-making. Wireless monitoring and IoT sensors can improve safety, efficiency, and maintenance (Construction Industry Council, 2021b).

Cloud-based tools and real-time collaboration can improve communication and coordination between different stakeholders. Overall, the use of automation tools and digital technologies can improve the efficiency, quality, and sustainability of geotechnical engineering projects.

6 Conclusion

BIM and other innovative technologies have the potential to enhance sustainability and promote design for safety right from the preliminary design process, thus contributing to the achievement of the UNSDGs. For instance, the use of UAV photogrammetry and handheld LiDAR scanning can improve the accuracy and efficiency of topographic surveys, which can help reduce the environmental impact of construction activities. BIM and Dynamo visual programming can automate design and help to visualize complex site settings, which can enhance safety and improve the efficiency of construction activities. Digital twin systems and as-constructed BIM models can improve the effectiveness of design review and scheduled maintenance for asset management, which can contribute to the sustainability and lower long-term recurrent costs of the projects.

The use of generative design and machine learning algorithms can be explored in the design of geotechnical works. For instance, machine learning algorithms can be used to optimize the design of soil nailing works, which can help reduce material waste and energy consumption. Generative design can be used to explore a wide range of design options quickly and efficiently, which can help identify optimal solutions that are safe, efficient, and sustainable.

To achieve these sustainability goals, companies can adopt Industry 4.0 and Construction 2.0 strategies that leverage the power of digital technologies such as BIM, IoT, and AI. These strategies can enhance collaboration, improve efficiency, reduce waste, and promote sustainability in the design and construction of geotechnical projects, contributing to a more sustainable and resilient future.

7 Publisher's Note

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