GIS-BIM Adoption for Construction Digitalization

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ABSTRACT

GIS is assisting architecture, engineering, and construction (AEC) companies build smart assets and communities for the future. The fusion of GIS and BIM enables stakeholders to put their projects, issues, and assets on a map, while gaining a deeper understanding of their interaction within the geographic context. Cited with examples and applications of adopting GIS-BIM integration technology in Hong Kong, we will examine how construction digitalization can supercharge projects collaboration and to build smarter, more resilient infrastructure for our city. It is worth taking an in-depth look at the GIS-BIM integration in geotechnical engineering in Hong Kong, 3D voxel for visualization of the geological condition underground, and other latest development in construction digitalization.

Keywords: Geographic Information Systems (GIS), GIS and BIM Integration, Construction Digitalization

1 Introduction

The integration of Geographic Information Systems (GIS) and Building Information Modeling (BIM) has led to a transformative technological advancement in the architecture, engineering, and construction (AEC) industry, including geotechnical engineering projects. GIS and BIM have a beneficial relationship that complements one another. GIS offers a geographical context that supports geospatial visualization-based decision making and geospatial modeling in a geographical context, while BIM provides rich geometric with semantic information through the construction life cycle (Song et al. 2017). Both GIS and BIM offer unique and essential roles in every phase of the life cycle of construction projects. However, there are significant needs for GIS and BIM integration to maximize their capabilities and benefits.

The capabilities of GIS allow users to create, manage, analyze and map many different types of geospatial data, including but not limited to raster data from imagery, vector data like point, line, and polygon, and 3D data such as point cloud, 3D mesh model and BIM data. The integration of GIS and BIM is an emerging research area (Ma and Ren, 2017). In Hong Kong, such integration has been gradually applied in different stages of the project life cycle, from planning and design, and construction, to operation and maintenance phases.

The objective of this paper is to illustrate the conceptual framework of GIS and to discuss the latest technological development of GIS and BIM applications supported by six Hong Kong examples. These examples are 3D slope visualization, GIS-BIM integration for Smart Barrier System, 3D GIS voxel for geological condition visualization, GIS-BIM-IoT integration for real-time slope safety monitoring, 3D landslide simulation, and Common Operational Picture.

2 Conceptual Framework of GIS

2.1 What is GIS?

In a classic definition, GIS is a computer system with a graphical user interface software for capturing, storing, querying, analyzing, and visualizing geographically referenced data. Geographically referenced data also called geospatial data, which describes the location and characteristics of spatial features such as a house, street, road, vegetation, or forest (Chang, 2006).

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From a system perspective, GIS supports three fundamental systems: a system of record for transactional data management, a system of insight for analytics, and a system of engagement through apps and maps that connect people to the organization's project and help them communicate and share information.

System of record is the foundation of GIS. Analysis and engagement cannot be done without the system of record. The ability of GIS to store and process spatiotemporal data with other 2D and 3D datasets distinguishes GIS from other systems. It makes GIS imperative for a broad-range variety of applications. Spatial statistical analysis, GeoAI or open-science AI algorithms can be applied to the data to find insightful results. Users can share the findings with stakeholders, colleagues, or the public via GIS.

From an application perspective, GIS provides tools for mapping, measurement, geospatial data visualization, modeling and analysis, planning and design. Therefore, an action plan can be generated through a geographic approach with location intelligence.

Nowadays, the capability of GIS is expanding. The modern GIS platform can process a large amount of heterogeneous spatial data from different technologies, such as orthophoto map and 3D Mesh from drone mapping, Lidar point cloud, real-time data from IoT sensors, CCTV feed, BIM models, CAD drawings, 3D map, etc. GIS can integrate all these data in a unified platform.

For the platform choices, traditionally, GIS is a desktop-based system for storing and analyzing geospatial data. Over the past decade, mobile devices are becoming more and more popular. Meanwhile, cloud platforms are playing a significant role in boosting this transformation. Hence, GIS platforms are developed and deployed on computers, servers, mobile phones, and tablets for various purposes.

2.2 GIS BIM Integration

As discussed in the previous sessions, GIS allows many different types of data to be integrated with various operation systems. BIM is one of the data types that can be integrated with GIS.

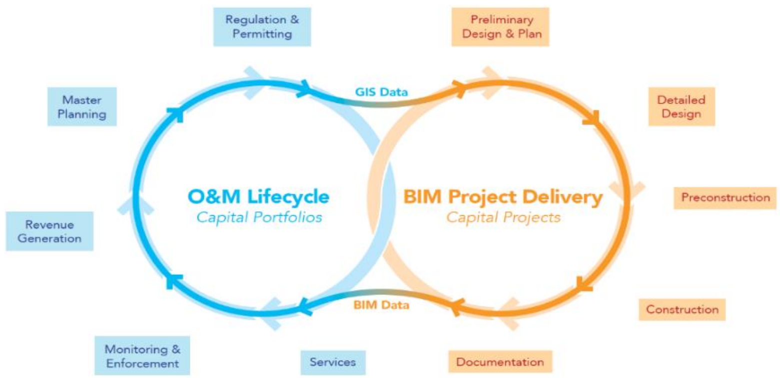

Figure 1: The GIS and BIM workflows (Andrews, 2018).

In a construction project life cycle, BIM supplies detailed information about assets, while GIS provides information about assets in the context of the built and natural environment. GIS and BIM workflows are happening continuously and complement each other perfectly. Figure 1 shows that GIS focuses on master planning, regulation and permitting, monitoring and enforcement, and revenue generation. BIM, on the other hand, plays a role in the preliminary design and plan, detailed design, preconstruction, construction, and documentation.

The Construction Industry Council released the "Construction Digitalisation Roadmap for Hong Kong" in November 2021. The roadmap emphasized the integration of GIS and BIM, Common Spatial Data Infrastructure and Common Data Environment, form the core of construction digitalization for smart data sharing, "which can facilitate collaboration among all stakeholders on a city or project level" (Construction Industry Council, 2021).

Furthermore, there are enormous advantages from the GIS-BIM integration in every phase of the construction project life cycle. 3D geospatial and BIM data can leverage the digital planning and design phase through a series of environmental and engineering analysis tools. Better situational awareness can be provided with the use of design and construction data under a geographical context. More efficient planning can be achieved through a broader analysis of environmental, demographic, and economic factors surrounding the new development areas. (Construction Industry Council, 2021). In the construction phase, the GIS-BIM integration provided a modernized project delivery that enables collaborative workflows. A Common Data Environment (CDE) supported by web GIS technology also serves as a common platform for the project stakeholders to collaborate and communicate with each other securely. Hence, AEC companies can make well-informed decisions to speed up project delivery.

2.3 Digital Twin

GIS builds digital twins of both the natural and built environments. A digital twin is a virtual representation of physical objects, processes, relationships, and behaviors. A digital twin can be created with the integration of Landscape Information Modeling (LIM), Building Information Modeling (BIM), Network Information Modeling (NIM), and Cities Information Modeling (CIM). It is abstracting and modeling everything. Digital twin provides a framework for real-time visualization, analysis for future prediction, and information sharing and collaboration for solving real-world challenges.

3 Hong Kong Examples of Geotechnical Engineering Projects with GIS and BIM integration

3.1 PoC Study of 3D Web GIS for Slope Visualization and Analysis

To grasp the trend of 3D GIS development, a Proof of Concept (PoC) study was carried out to develop a 3D Web GIS for slope visualization and analysis. It was a feasibility study of turning a 2D slope information system into a 3D GIS web platform. The 3D GIS web platform was constructed with two major components – 3D slope visualization and a landslide detection system for smart barriers. In this project, the study area was located at the western part of Hong Kong Island, approximately 5km x 5km in a 3D scene. The platform provided visualization of the 3D boundary of not more than 600 nos. of man-made slope features with the labeling of their feature numbers. The slope data are provided by the Geotechnical Engineering Office (GEO) of Civil Engineering and Development Department (CEDD).

This 3D slope visualization was integrated with layers of a 3D mesh model, a 3D digital terrain model with 3D building and infrastructure objects in a 3D scene. Three types of data have been applied (Table 1), and each data is converted to GIS format and integrated into the 3D GIS web platform with World Geodetic System 1984 (WGS 84) coordinate system. All converted data are uploaded and integrated into the 3D GIS web platform for assessment.

Table 1: Three Types of Data Applied for the 3D Slope Visualization

Data Type	Extension	Area	Usage
Mesh Data	.osgb	Conduit Road Victoria Road Queen Mary Hospital	Mesh data in tiles to be converted to Integrated Mesh Scene Layer and modified by the footprint of the BIM data.
Lidar data	.las		Provides elevation information is converted to Raster for ArcGIS to custom an Elevation Service.
3DS data	.3DS	Conduit Road Victoria Road Queen Mary Hospital Tung Chung	Provides 3D spatial data of Digital Terrain Model (DTM) and buildings and is converted to ArcGIS 3D model, that is the Multipatch feature layer.

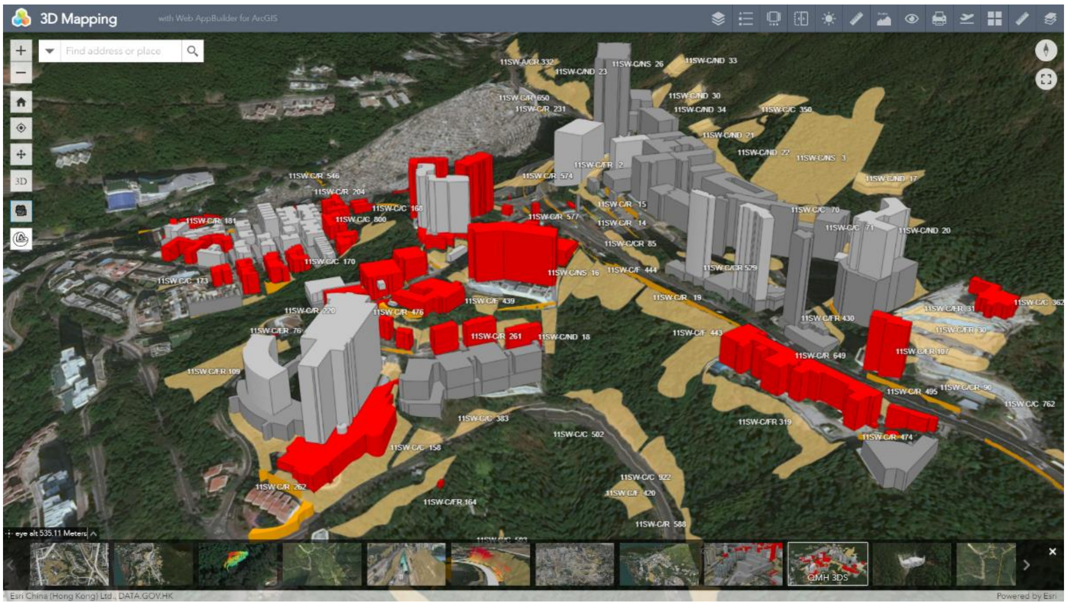

Plate 1: In the PoC study, the 3D visualization of the slope data and 3D buildings are shown in the study area.

In plate 1, the 3D GIS Web Platform using ArcGIS Pro and ArcGIS Enterprise was established, which offers a visualization of 3D slope and landslide data. The platform allowed an effective, efficient, and user-friendly storage, retrieval and update of slope data, GIS data, BIM model data, satellite images, 3D spatial data, 3D mesh models, and laser scanning point cloud data in one single platform.

ArcGIS Pro, ArcGIS Online, and ArcGIS Enterprise have been adopted in the project.

3.2 GIS-BIM-IoT Integrated Smart Barrier System

CEDD developed the Smart Barrier System with BIM and GIS integration and an internet-of-things (IoT) sensor system, to detect the impact of landslide debris on debris-resisting barriers to transmit real-time alerts to relevant officers for immediate follow-up (Civil Engineering and Development Department, 2019).

To construct the Smart Barrier system, the BIM model data (Table 2) representing the smart barriers is imported to the GIS platform together with other 3D geospatial data mentioned in Table 1. The smart barriers are located in the western part of Hong Kong Island. The point data of its IoT sensors includes two depth gauge sensors, three impact switches, and two cameras.

Table 2: Data Applied for the Smart Barriers

Data Type	Extension	Area	Usage
BIM Model Data (Revit)	.rvt	Conduit Road Victoria Road Queen Mary Hospital	Representing the smart barriers converted to 3D format

The Smart Barrier System integrated with a 3D mesh model, 3D digital terrain model, 3D building, and infrastructure objects in a 3D scene, which formed the landscape information model. The Smart Barrier System displays the real-time and dynamic monitoring data captured from the smart barriers, including numeric data of debris depth in graphical format and photos captured for a specified period by connecting to on-premises SQL Server databases. Conspicuous alert signals such as flash warning symbols will be popped up when the impact switches detect impact from landslide debris.

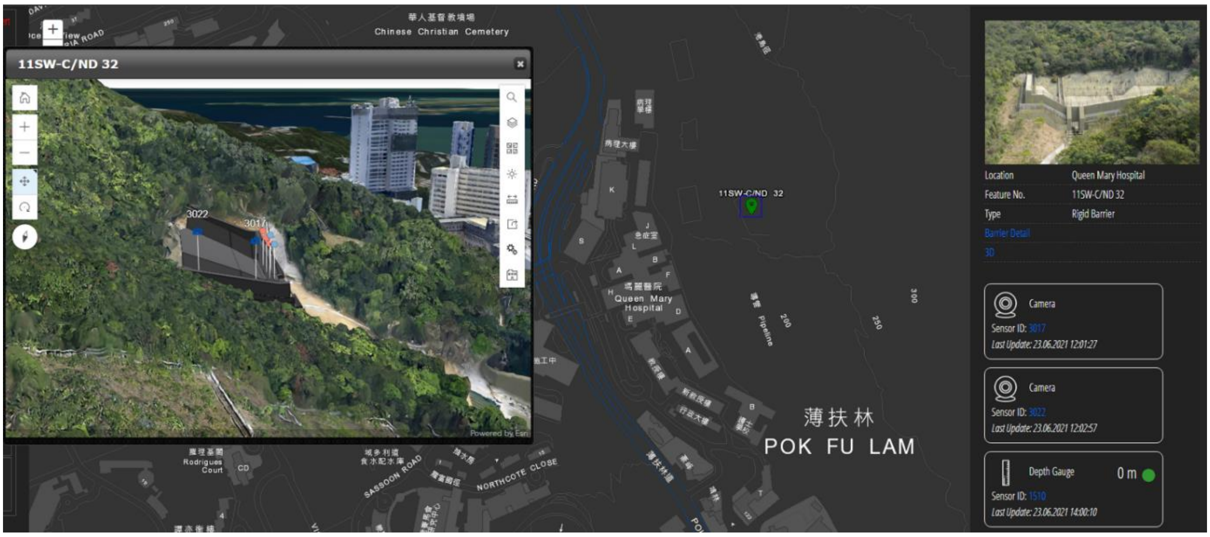

Plate 2: Integrated with BIM data, IoT sensors, 3D mesh model, and 3D digital terrain model with 3D building and infrastructure objects, the smart barrier 11SW-C/ND 32 was shown in the Smart Barriers System.

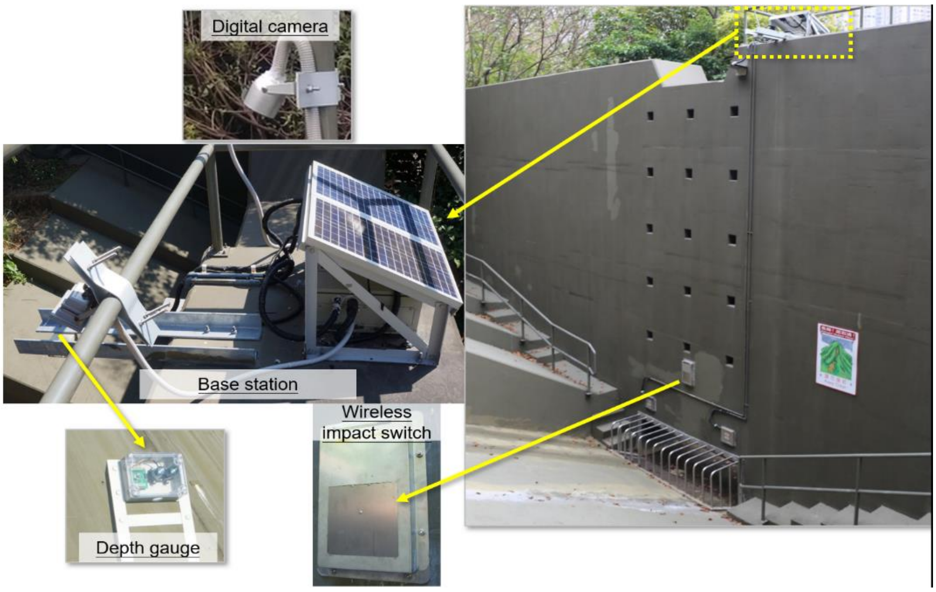

Plate 3: The smart barrier 11SW-C/ND 32 was installed with the depth gauge sensors, impact switches, and cameras. All sensors and cameras were connected to the Smart Barrier System for real-time monitoring.

ArcGIS Pro, ArcGIS Online and ArcGIS Enterprise have been implemented in the Smart Barriers System.

3.3 GIS Voxel for Geological Condition Visualization

The 3D GIS voxel layer for the visualization of the geological condition is an enhancement project based on the demo 3D GIS Web Platform discussed in sessions 4.1 and 4.2. Voxel is a 3D visualization of an objection constructed by 3D pixel cubes representing its characteristics. In the following PoC, the study area was a 59,000m^2 site area in Tung Chung.

To establish a GIS voxel layer for the 3D geological underground model, different types of data were integrated including six main geological layers of superficial deposits and in situ weathered materials which are stored in TIN format.

The geological layers will be geo-referenced and converted to a netCDF layer through a data conversion process in GIS. Based on the spatial information (X, Y, Z) stored in the netCDF, it can be visualized in the GIS voxel layer, and the spatial relationships with different 3D models can be assessed.

For instance, an underground geological model visualized as a 3D GIS voxel layer can be viewed together with multiple boreholes or construction that is planned in a development area.

Fitting of BIM data with surrounding topography – it also provides practical solutions for locally adjusting/modifying the 3D mesh model and the 3D digital terrain model such as elevation layer in tile package generated by LiDAR data by using ArcGIS software.

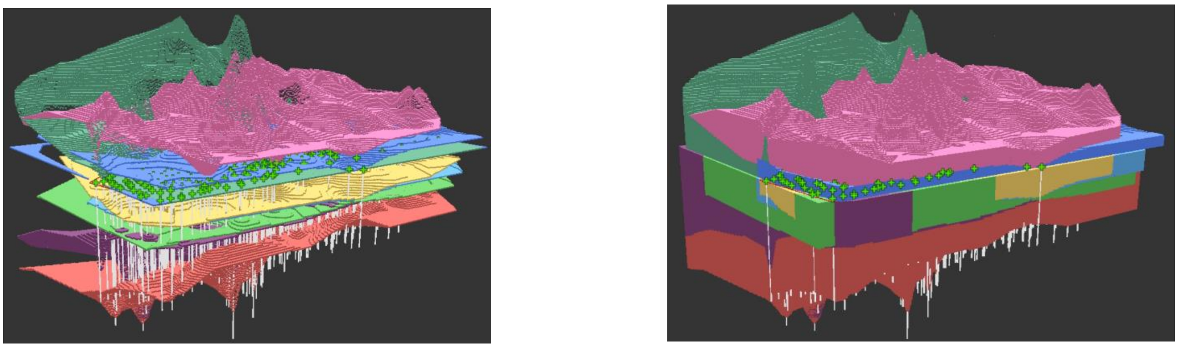

Plate 4: The GIS voxel layer showcases the surface type (left) and volume type (right) of the full model visualization of the geological conditional in the study site.

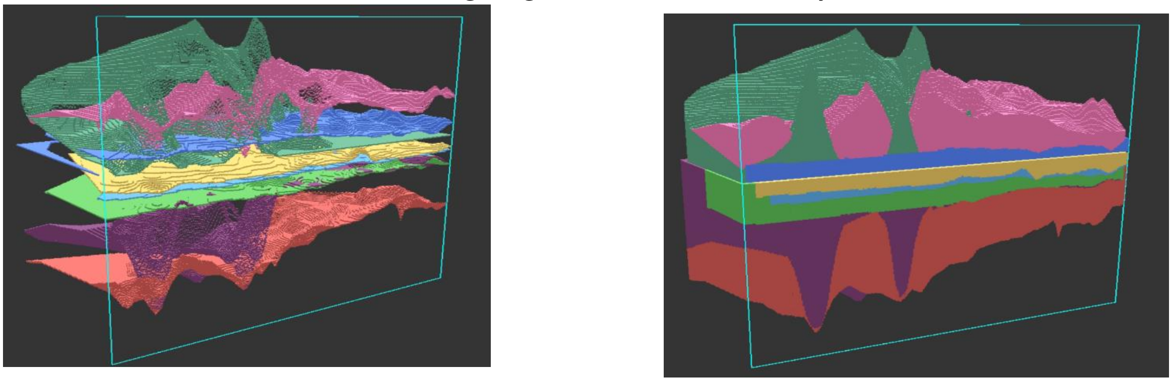

Plate 5: The slice view of the voxel layer in surface type (left) and volume type (right).

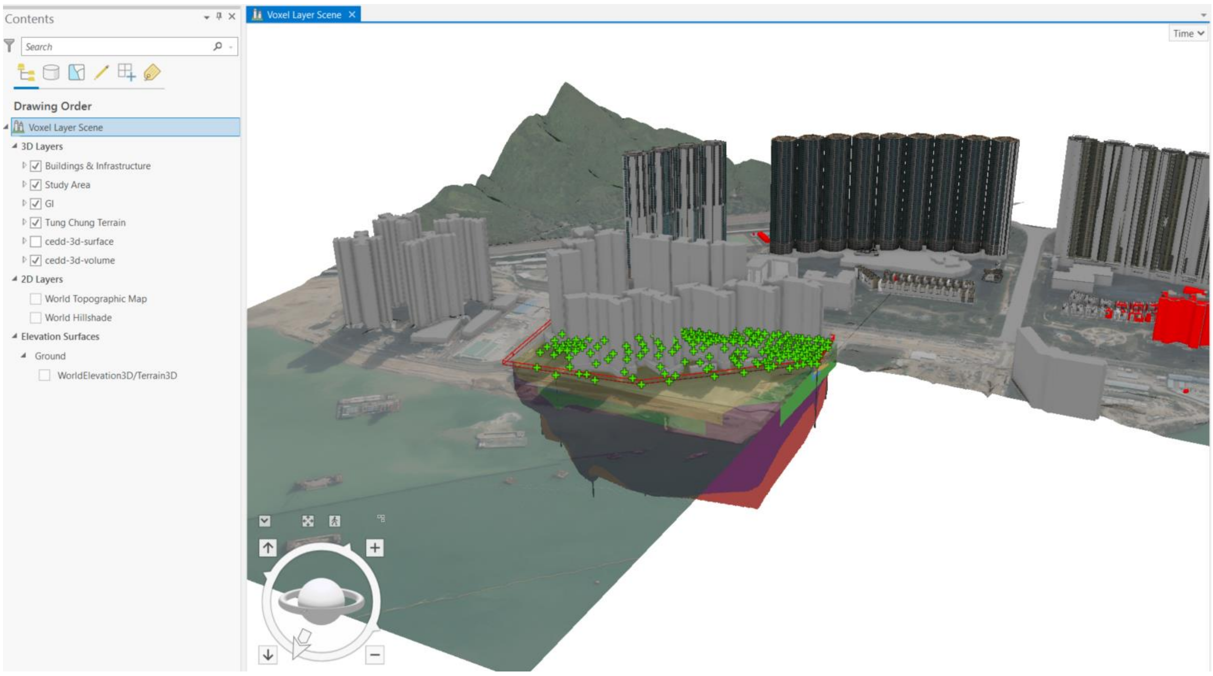

Plate 6: In the Tung Chung study site, the integration of voxel layer, boreholes, 3D digital terrain model, 3D building, and infrastructure objects were displayed in ArcGIS Pro.

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3D GIS voxel layer provides various forms of applications for construction digitalization. The Netherlands has been developing a 3D voxel model to visualize the soil types underneath her territories. According to Seler (2020), a GIS voxel layer was created to visualize different soil types in the Netherlands. Peat soil is one of the soil types found within the territories. It is a soft substance and would cause higher construction costs. By early detection of peat soil via the 3D voxel information system, AEC sectors can make a better decision before the project starts.

ArcGIS Pro and ArcGIS Enterprise have been used in the 3D GIS voxel project in Tung Chung, Hong Kong.

3.4 GIS-BIM-IoT Integration for Real-Time Slope Safety Monitoring

With the adoption of GIS-BIM integration and IoT technologies, the landslide prevention and mitigation system at Po Shan, Mid-levels was built by the GEO of CEDD. The innovative regional groundwater regulation system provides real-time groundwater monitoring and regulation to maintain slope stability, therefore, protecting lives and property.

The Po Shan Drainage Tunnels were constructed to regulate the regional groundwater level and reduce the potential landslide risk in the Po Shan area. The drainage tunnels comprise a network of 172 sub-vertical drains for controlling the groundwater level in the soil mass (Civil Engineering and Development Department, 2021a). The groundwater level is continuously monitored by the pressure gauges installed on the sub-vertical drains and the piezometers in the slope.

The monitored data are fed to a pressure relief system with automatic valves mounted at the ends of the vertical drains and they would open and close in order to keep the groundwater level within a pre-defined range. Given the slope stabilization nature of the system and availability of real-time monitoring data, a pilot digital twin for the Po Shan Drainage was prepared by GEO on GEO's 3D Mapping System. The 3D mapping System can directly incorporate the BIM model of the tunnel structures with the automated instrumentation system. The digital twin can assist the project team to monitor the groundwater level in the Po Shan area and allow them to carry out regular reviews for the performance of the drainage system.

For the development of the BIM model, the alignments of the drainage tunnels, 172 sub-vertical drains, associated water flow controlling valves, pipelines and standpipes/piezometers were generated in the 3D BIM platform based on the as-built records (Plate 7). The digital twin would send alert message to notify the project team when the readings of sub-vertical drains and piezometers exceed the pre-defined range and the respective location of the exceedance will be highlighted in the BIM model.

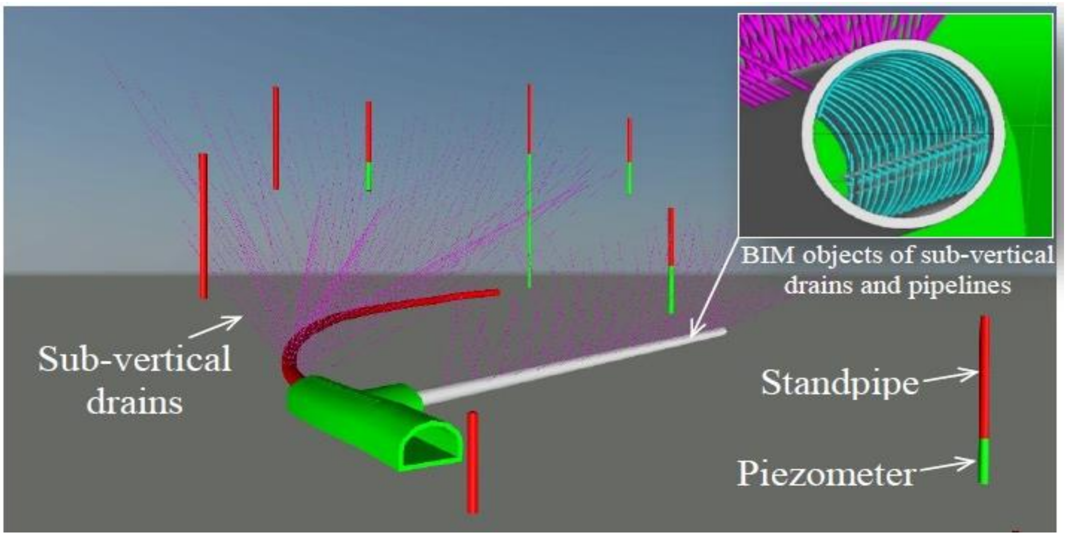

Plate 7: Po Shan Drainage Tunnels displayed on the BIM platform

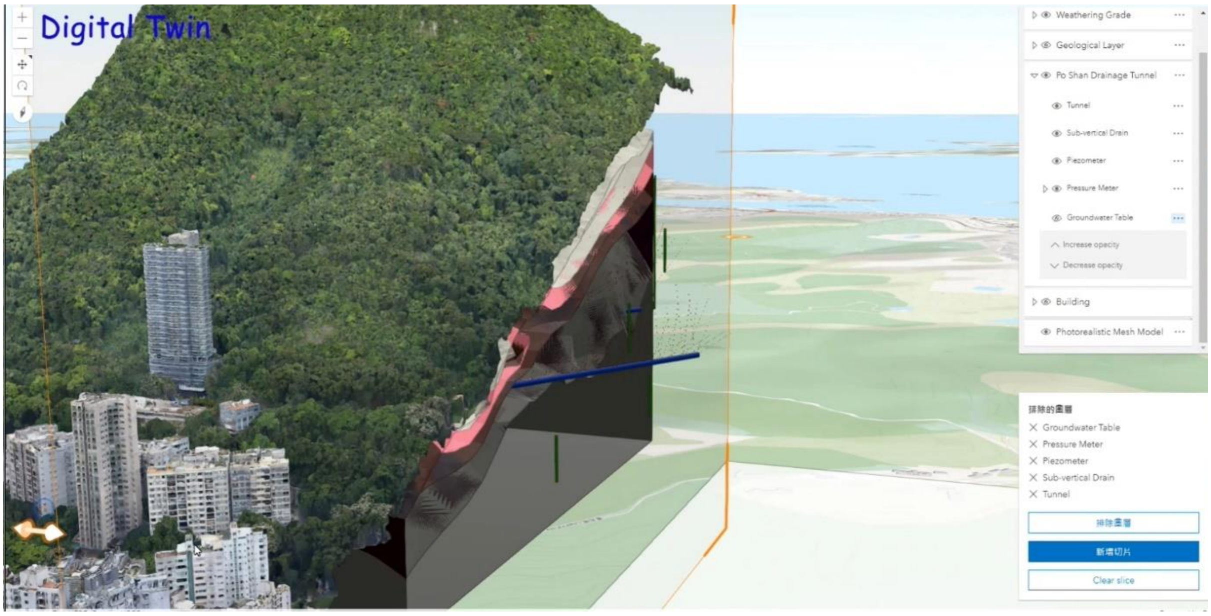

Plate 8: 3D photogrammetry and BIM model coupled with real-time monitoring sensors are integrated into a GIS system to create a digital twin for data and as-built records visualization.

The digital twin allows 3D visualization of the site environment and the underground geological profile, as well as the simulation of the temporal groundwater regime based on interpolation of site-specific piezometric readings. Users can examine the water pressure at individual sub-vertical drain and piezometer to promptly retrieve their real-time and historical data in tabular and graphical format.

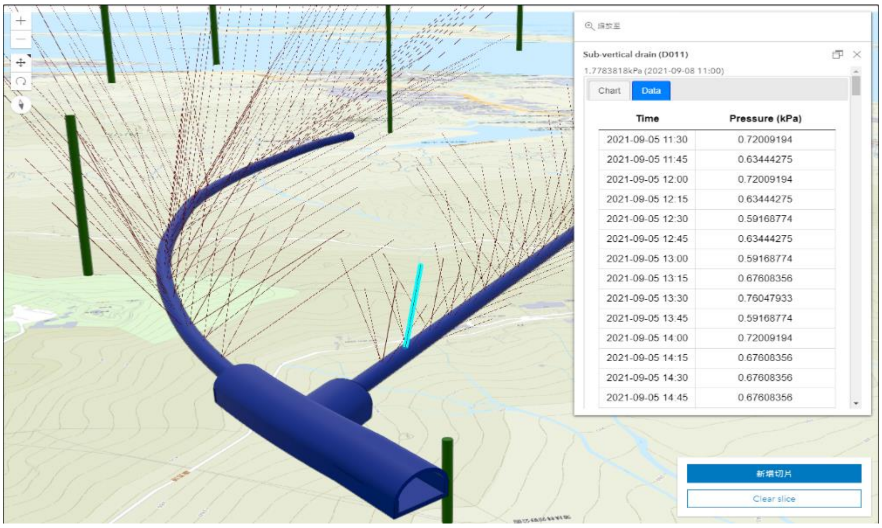

Plate 9: Equipped with real-time BIM visualization of data, the Po Shan Drainage Tunnels allow the operators to react promptly to the changing situation with a much better quality of the information available.

The benefits of adopting GIS BIM integration Web platform for Po Shan Groundwater Regulation System are numerous. The quality of the information presented to the operators is greatly improved. It allows immediate access and preliminary analysis of real-time data for both automatic groundwater monitoring devices and sub-vertical drains on computers or mobile devices with internet connection. The system is equipped with real-time BIM visualization of data, which allows the operators to react promptly to the changing situation with better quality of the information available. In addition, the key information would be acquired in real-time for preliminary analysis and decision-making.

ArcGIS Pro, ArcGIS Enterprise, and ArcGIS GeoEvent Server have been adopted in the Po Shan Drainage Tunnels use case.

3.5 Landslide Debris Simulation

Two-dimensional modeling of landslide motions has routinely been used to assess landslide mobility in natural terrain hazard studies in Hong Kong. With the advance in digital and computer technology, 3D debris mobility assessment can be carried out on a GIS platform with GEO's data. In this example, a GIS application that incorporates the Smoothed Particle Hydrodynamics (SPH) module for 3D debris mobility assessment of landslides was developed.

Smoothed Particle Hydrodynamics (SPH) is a computation modeling for simulating the flow of fluid or solid mechanics. Landslide debris is one of the applied areas. A landslide simulation system was developed in a GIS platform to interact and integrate with the SPH program provided by the GEO so that 3D debris mobility assessment of landslides can be undertaken in a GIS environment.

Identification of design flow path through batch analysis can be delivered in a GIS platform through the integration with GEO's SPH program. The flow path is determined according to the steepest path of the topography. In case of a flat path encountered, continue the path in a straight line when the flow path met the Area of Interest (user-defined boundary) in GIS. A developed application shall allow users to amend the flow path by manually editing.

For identification of the flow path with the highest runout, users can choose the source location from the source region (defined debris area), in grid form to allocate the source location within the source region (boundaries of source groups). The individual runout analysis is using the same set of input parameters and it could provide an environment to integrate with 2D debris mobility assessment analysis. The parameters shall be given in batch run for example (friction angle = 15º, 20º, and 25º), volume, and channel width.

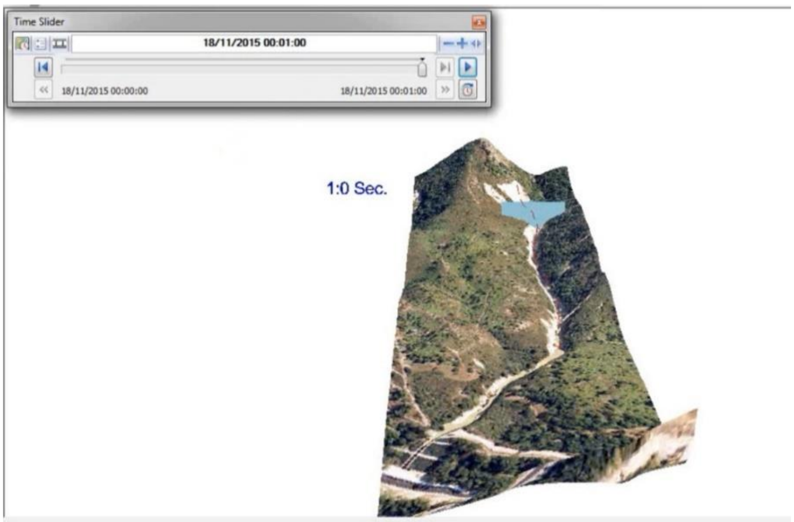

Plate 10: The simulated landslide occurred on the slope (circled). The debris flow simulation (arrowed) was computed by application of the Smoothed Particle Hydrodynamics.

The source region can be drawn by the user in a GIS system and manually amendable. The flow path with the steepest path analysis shall be automatically generated by selecting a single source location and multiple source locations. The flow path (steepest path) also can be easily amended by the user via the editing function.

ArcGIS Desktop has been implemented in the landslide debris simulation project.

3.6 Common Operational Picture for Natural Disaster-related Intelligence Sharing

Common Operational Picture is an example of a GIS-based information sharing platform for emergency response. Climate change is one of the factors to worsen extreme weather in terms of intensity, frequency, and impacts. Such adverse weather condition brings Hong Kong unforeseen work incidents and economic loss. For instance, on the North Lantau Highway (NLH) natural terrain in June 2008, some 35 landslides were initiated on a natural hillside above the NLH. As a major transportation corridor to the Hong Kong International Airport, the NLH was closed for 16 hours (Civil Engineering and Development Department, 2021b). Another extreme weather event was Super Typhoon Mangkhut battered Hong Kong in 2018. Severe weather causes interruptions in our city that required emergency responses through collaboration with different parties. Common Operational Picture (COP) was developed in 2017 and launched in 2020 for better communication, collaboration, information sharing, and enhancing situational awareness in natural disasters.

Developed by CEDD, COP is a common GIS platform for real-time incidents information sharing including landslides, flooding due to heavy rain, storm surge inundation, and major road incidents with "supporting information" such as weather and traffic condition. The Lands Department, Hong Kong Police Force, Fire Services Department, Hong Kong Observatory, Government Flying Service, Hospital Authority, Civil Aid Service, Auxiliary Medical Service contribute input to the databank of "supporting information" in the COP when natural disasters occur (Security Bureau, 2018).

The COP aims to enhance the existing communication channel among bureaus and departments to share emergency information. The COP is a Web GIS-based cloud platform to ensure its availability at anytime and anywhere with an internet connection. High-resolution territory-wide maps with accurate mapping data would be useful for field workers to collect data and update the COP in real-time under severe weather conditions for formulating contingency plans (Lam et al., 2021). When COP was launched in 2020, six government works departments including CEDD, Buildings, Highways, Housing, Drainage Services, and Lands Department collaboration on sharing emergency incidents like landslides, flooding, and major road blockages, and structural incidents (Tang 2022).

Plate 11: The Common Operational Picture (COP) is shown in the interactive map dashboard for government bureaus and departments' cross-collaboration.

The COP is expanding the data integration with more bureaus and departments. Home Affairs, Transport, Census and Statistics, Environmental Protection, Marine Department, and with Tree Management Office share "supporting information" such as temporary shelters, traffic, landfill information, tidal, past tree failure incidents respectively. Meanwhile, the Independent Checking Unit of Transport and Housing Bureau, Water Services Department, and Architectural Services Department report emergency incidents information to the COP directly.

ArcGIS Pro and ArcGIS Enterprise have been adopted in the COP use case.

4 Conclusions

The GIS-BIM integration for construction digitalization provides a geographical context for project visualization and management. By integrating with the latest technologies such as IoT sensors, advanced computer simulation, and 3D data modeling, the GIS-BIM integrated environment can be further empowered. Collaboration with stakeholders and public engagement can be achieved through web-based applications and dashboards. The examples cited in this paper also demonstrated GIS is a system of record, insights, and engagement. All in all, GIS is one of the driving forces for smart city development.

5 Declarations

5.1 Acknowledgement

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