INTEGRATING BIM INTO WEB GIS TO ENHANCE THE VISUALIZATION OF PORT INFRASTRUCTURE

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Abstract: This paper provides a detailed procedure to transform a seaport into a digital format, with the objective of creating a precise, effective BIM model of the port infrastructure. We execute on-site surveys to acquire point cloud data of the port infrastructure, encompassing a variety of data types from terrestrial to underwater regions. Additionally, we suggest a solution for data collection in inaccessible areas, by utilizing a range of equipment and combining advanced survey technologies to overcome the limitation of each separate survey type. The collected data undergoes processing to generate a comprehensive BIM model of the port, which encompasses data from the land to the underwater area. This BIM model is subsequently converted to a GIS-compatible format, and then integrated into the ArcGIS online platform. This fusion allows the merging of engineering design data with geospatial attributes into a comprehensive model. The final output, as demonstrated in a real case study of seaport in Vietnam, will be presented along with insights into optimizing data processing for integration.

Keywords: BIM, GIS, Laser scanning, USVs, UAS, Point cloud

1. INTRODUCTION

Building Information Modeling (BIM) is a digital process used in the construction and management of a virtual designed model for building or infrastructure projects. This innovative method employs various software tools to foster collaboration among diverse stakeholders such as designers, architects, engineers, and contractors, who all contribute to a singular, cohesive model of the construction project. This model contains 3D visuals along with the specifications of individual building components, including their materials, size, performance metrics, and maintenance requirements. Prior to integrating the BIM process into any building project, it's crucial to perform a 3D survey to collect essential geometric data for producing the 'as-built' model of the structure (Murphy et al., 2017), in addition to gathering other types of relevant data. This step calls for the use of cutting-edge 3D survey techniques like 3D laser scanning or photogrammetry, which generate point clouds as the foundation for the subsequent parametric modeling phase (Wang et al., 2019). There are several proven methods to transform point clouds into a BIM model, as documented in a wide array of literature (Moyano et al., 2020; Pepe & Costantino, 2020).

The use of 3D digital models and the object parameterization within the Building Information Modeling (BIM) environment allows for a comprehensive association of physical and mechanical characteristics with each structural or architectural component, along with any additional relevant information. However, most contemporary research primarily concentrates on the generation of BIM models for terrestrial structures. The question remains on how to handle data not based on land, such as underwater data, which is relatively important for projects like seaports.

Moreover, the capacity of the BIM environment to store and detail elements is somewhat restricted. This limitation can be addressed by associating semantics, images, or other forms of information with model components using a specialized field. Applications of these models can be seen in Cultural Heritage contexts (Pepe & Costantino, 2020), and in complex structures like historical bridges and cathedrals.

To counteract the constraints of BIM, initiatives are underway to connect BIM with external databases for streamlined data management. These solutions are expected to enhance flexibility in data access and administration in the future (Adami et al., 2018).

Addressing these limitations requires the identification of an efficient environment capable of managing various databases and bridging them with 3D spatial objects. In this context, a 3D Geographical Information System (GIS) environment provides the ability to establish numerous fields and link multiple databases from a variety of sources. These sources can encompass satellite images, aerial photos, terrestrial and underwater surveys, and more. The 3D GIS environment is further useful for generating maps and performing spatial data analyses. In addition, Web GIS, a variant of GIS, leverages the internet to provide access to geospatial data and analysis tools. This system allows users to retrieve GIS data and tools from any location via a web browser, thus facilitating data sharing and collaboration. Since users can access the same data from anywhere with internet connectivity, Web

GIS broadens accessibility to a more diverse range of users, including those without prior GIS expertise. (Narindri et al., 2022)

Building Information Modeling (BIM) and Geographic Information Systems (GIS) can work together to enhance building and infrastructure planning, design, and operation. However, integrating data from various survey technologies into GIS can be challenging due to disparities in data formats, resolution, accuracy, and georeferencing methods.

This paper will detail the process of high-accuracy field data collection for BIM models and integrating BIM data into web GIS. This approach has been applied to a port infrastructure project in Vietnam, where the BIM model includes data from aerial, terrestrial, and underwater sources.

2. METHODOLOGY AND PROCEDURES

2.1. Data Acquisition

Data collection for a BIM-GIS project requires details on a building or infrastructure's physical and functional attributes, along with its spatial context. This data aids in crafting a precise digital model for design, construction, and operation. Various surveying techniques are often combined to solve the problem of location challenges, especially when surveying objects such as the seaport, situated at land-sea interfaces. Terrestrial Laser Scanning (TLS) was utilized for on-land surveys, while a UAV photogrammetric survey targeted upper building parts inaccessible from the ground. Additionally, a USV multibeam sonar system collected data for the underwater and front-side port regions.

The Trimble GNSS R12i, known for its high-precision capabilities, was used during the survey to collect GPS data and create accurate control points, thereby enhancing the point cloud and grid model data's accuracy. The data's reliability was crucial for accurate analyses.

- **Terrestrial 3D laser scanning**

3D laser scanning, an advanced technique using directed laser beams, records characteristics of various objects around a structure (Guo et.al., 2020). This highly accurate process can create a detailed 3D model of the surveyed area, covering large expanses across diverse terrains without line of sight (Zhou et al., 2019).

In this study, laser scanning was employed on land to gather precise point cloud data of equipment and buildings. Preceding the scan, a traverse network was established and adjusted, with each point's coordinates and elevation measured via a Leica TS60 total station and LS10 digital level, respectively, to ensure high accuracy. Leica RTC360, P50, and Trimble SX12 scanners were then used to capture all physical features of the existing facilities. Main scanners were stationed at each traverse point, with additional scanners closer to the traverse network to record shape, size, and surface color details of existing objects. Figure 1.a displays the onsite 3D laser scanning process. The TLS collected data then was processed using professional software like Cyclone to serve as the source for BIM model creation and the base map in GIS.

- **Aerial surveying with drones**

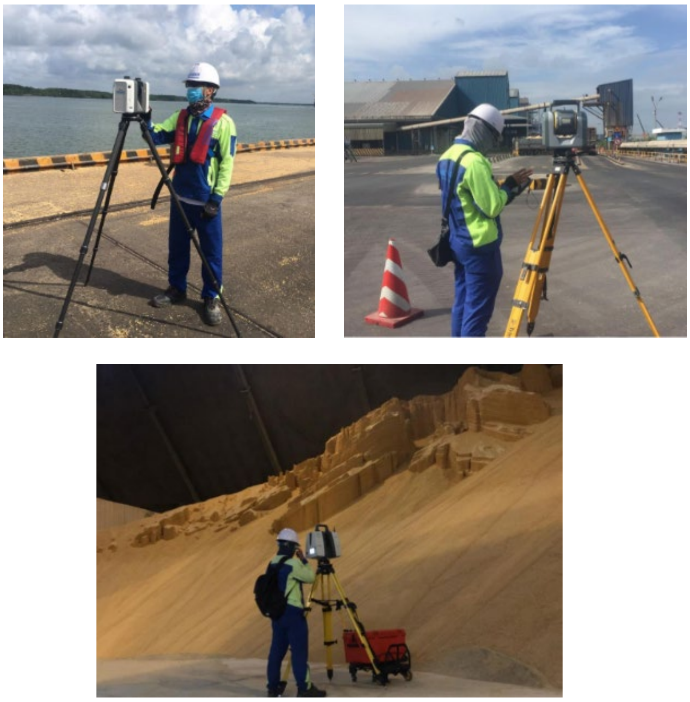
Aerial surveys are utilized to address on-land surveying limitations, particularly when terrestrial laser scanning is less effective due to large site size or inaccessible areas like high roofs. Modern unmanned aerial systems (UAS) with high-quality cameras, onboard GPS, and other sensors have streamlined aerial surveys (Abdulla Al-Kaff et al., 2018). The captured images undergo processing using photogrammetry techniques for delivering accurate and detailed 3D information from measured image correspondences at any scale.

In this project, a 3D map of the port area was field-collected using a DJI Matrice RTK300- Zenmuse P1 with a 45MP Full-frame Sensor (Figure 1.b). The drone followed designed flight paths to capture overlapping aerial photos every 0.7 seconds over the worksite (Figure 1b- right hand side). The Zenmuse P1 can capture centimeter-accurate data with real-time position and orientation compensation technology. In essence, the drone's GPS and onboard sensors embed latitude, longitude, and altitude data in the image metadata as it's captured. These images are then processed and analyzed using DJI Terra software, which employs photogrammetry techniques to generate photorealistic 3D representations of land surfaces and various objects within the port area.

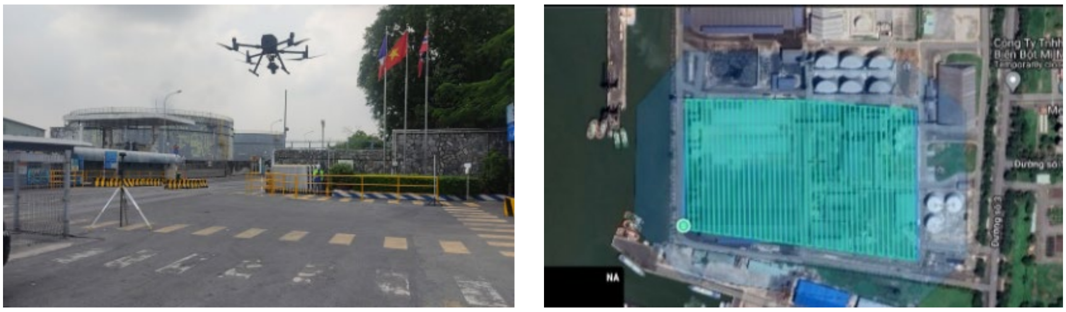
- **Underwater surveying with USVs**

Neither aerial nor terrestrial surveys can collect data from the wharf's edge to the underwater area. Thus, Unmanned Surface Vehicles (USVs) equipped with integrated iLiDAR and multibeam echo sounders are used to gather bathymetric and point cloud data of the wharf's front side. For this project, the Otter USV system, which includes two GNSS devices to receive coordinate, elevation, and orientation data, is utilized (Figure 1c).

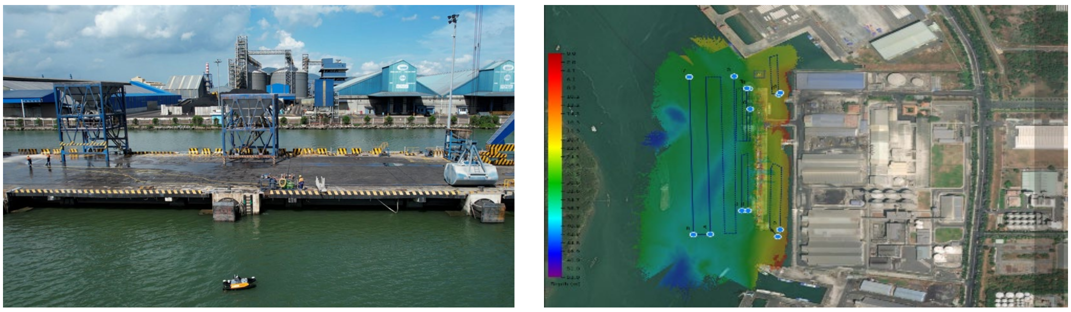
Before surveying, a high-precision control grid based on a coordinate system is established, setting the elevation for the entire project. Concurrently, an automatic water level monitoring station is set up on the shore as an RTK measurement method base station. Once the iLiDAR and Norbit iWBMS devices are attached to the Otter system, the USVs are launched to collect bathymetric data and 3D point cloud data of the wharf's front side.



a) Terrestrial 3D laser scanning



b) Aerial survey



c) Underwater survey

Figure 1. Conducting the field surveys

2.2. BIM

The process of reconstructing 3D models from profiles, as discussed by D. Costantino in 2021, can be used to construct a 3D model. This technique leverages a 3D point cloud to reconstruct the object or structure's 3D form using either a curve or a parametric surface. The collected point cloud data is then exported and imported into suitable software such as Revit, which aids in the model's creation (as shown in Figure 2). By considering the distance between the object surface's points within the point cloud and the similarity in direction of the neighboring standard faces, an engineer can create an as-built model. After this data is integrated into the software, building components are designed in the BIM model, utilizing the point cloud data and the collected images. The final stage involves correlating the BIM model's components with the point cloud to ensure each component aligns with its respective points in the point cloud.

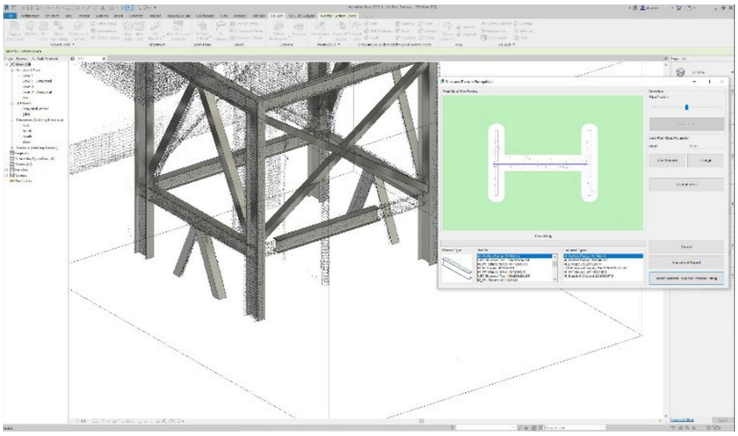


Figure 2. Building Revit model from point cloud data

2.3. Web GIS

ArcGIS Online is a cloud-based platform that integrates numerous powerful geospatial analysis tools and capabilities from Esri. Currently, this WebGIS platform is widely used for visualizing both 2D and 3D data, particularly 3D models such as building information models (BIM), 3D meshes, and 3D point clouds. Choosing a common platform like ArcGIS Online for storing and sharing data can facilitate access to and retrieval of data from any location, thus providing convenience for data management and analysis.

2.4. BIM – GIS Integration

Due to the benefits that the integration of Building Information Modeling (BIM) and Geographical Information Systems (GIS) offers, it has been the subject of extensive research and implementation across a diverse range of application field, particularly in planning and operation (Matrone et.al., 2019). The overall process of integration is illustrated in Figure 3. The accepted data format and procedure for uploading each type of data are described in the following sections.

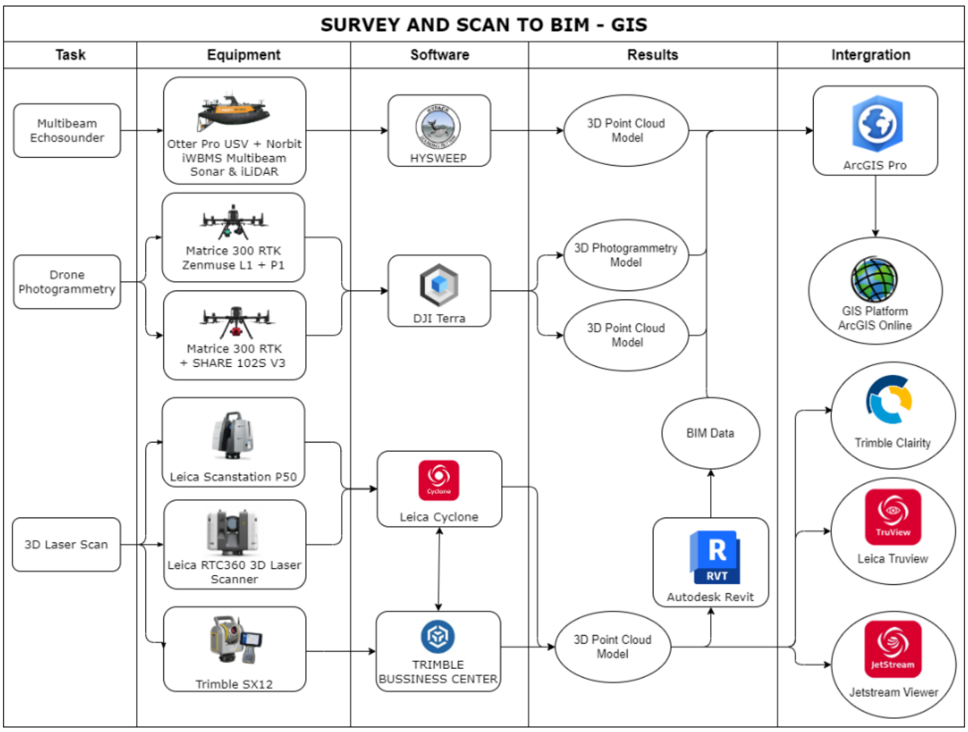


Figure 3. Workflow for collecting, processing and integrating data.

3. RESULTS

The South Vietnam port case study involved conducting several surveys to gather detailed information, which included bathymetric details, 3D laser scanning point cloud data, and aerial images. These data were merged to create a comprehensive digital model of the port. For the 3D laser scanning the cluster approach was applied to organize 3D laser scanning into logical sections. The precision achieved in internal areas was 1-3mm, and in external areas, it was 3-5mm. The survey results obtained through terrestrially conducted surveys are illustrated in Figure 4.

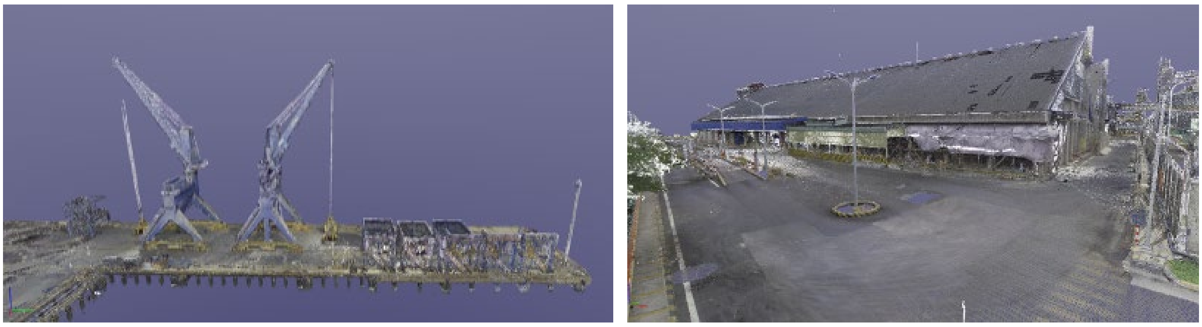


Figure 4. 3D point cloud of the wharf and the warehouse

The drone survey involves processing aerial images using DJI Terra software (Figure 5a). The images are captured with an approximate overlap of 70-80%. The initial steps involve stitching the images and generating a preliminary point cloud model. In order to adjust the images to the desired coordinate system, Ground Control Points (GCPs) are added. The deviations between the GCPs and the 3D Mesh model are shown on Table 1. Once the images are adjusted, they are exported to digital models, like 3D Mesh, which are evaluated based on mapping regulations. The 3D mesh data for the entire port area is exported in *.slpk format and uploaded onto ArcGIS Online, where it is displayed alongside other survey data which includes underwater topography and 3D laser scans.

a) b)

Figure 5. (a) 3D photogrammetry model of the port area, (b) Targets (Ground control points) layout.

Table 1. Detailed Comparison Table of Point Position Errors between GCPs and 3D Mesh model

Point ID	3D Photogrammetry model			Targets			Deviation
	x	y	z	x	y	z	
1	421038.131	1170449.281	2.774	421038.130	1170449.280	2.770	0.004
2	421167.175	1170435.472	2.724	421167.170	1170435.470	2.720	0.007
3	421325.556	1170417.005	3.144	421325.550	1170417.000	3.140	0.009
4	421110.122	1170563.385	2.653	421110.120	1170563.380	2.650	0.006
5	421097.127	1170670.862	2.944	421097.120	1170670.860	2.940	0.008
6	421085.373	1170886.116	3.215	421085.370	1170886.110	3.210	0.008
7	421101.143	1171049.992	3.092	421101.140	1171049.990	3.090	0.004
8	421141.386	1171102.745	2.704	421141.380	1171102.740	2.700	0.009

Point ID	3D Photogrammetry model			Targets			Deviation
	x	y	z	x	y	z	
9	421355.751	1171099.625	2.931	421355.750	1171099.620	2.930	0.005
10	420933.363	1171081.334	2.906	420933.360	1171081.330	2.900	0.008
11	420956.994	1170889.284	2.852	420956.990	1170889.280	2.850	0.006
12	420949.666	1170689.862	2.554	420949.660	1170689.860	2.550	0.007
13	420861.055	1171112.697	3.643	420861.050	1171112.690	3.640	0.009
14	420860.183	1170975.995	3.053	420860.180	1170975.990	3.050	0.007
15	420858.766	1170657.021	3.476	420858.760	1170657.020	3.470	0.009

(*) Note:

- Unit (m)
- Coordinates and elevations of Targets are measured using electronic total station devices.

The bathymetric and iLiDAR data from the USV survey were processed and checked for errors using Hysweep software. A raw point cloud model in *.e57 or *.las format was then generated, mapping the underwater terrain and the wharf's front side. For the accuracy checking, the comparison between the 3D Point Cloud model and Ground Control Points (Figure 6) are conducted (Table 2). This point cloud data was then imported to Autodesk Recap Pro or Leica Cyclone software for noise removal and data integration. Ultimately, the highly precise point cloud data for the area in front of the port was exported (Figure 7). To enhance storage efficiency, processing time, and rendering speed on the ArcGIS Online platform, the file formats *.las and *.e57 will be transformed into the Point Cloud Scene Layer format (*.slpk). Point cloud scene layers are capable of swiftly rendering significant amounts of symbolized and filtered point cloud data, ensuring rapid display of such datasets.

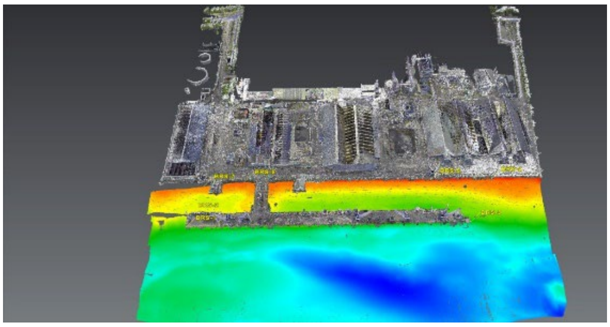


Figure 6. Targets (Ground control points) layout.

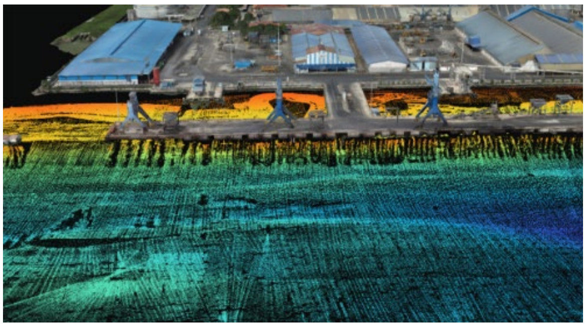


Figure 7. The point cloud model of the water area in front of the wharf and the slope of the shoreline and 3D mesh model of port.

Table 2. Detailed comparison of Point Position Errors

Point ID	Point Cloud			Targets			Deviation
	x	y	z	x	y	z	
BRS-1	420836.927	1171114.459	3.32	420836.917	1171114.459	3.315	0.011
BRS-2	420861.34	1171114.479	3.277	420861.34	1171114.478	3.279	0.002
BRS-3	420833.758	1170611.984	3.304	420833.757	1170611.985	3.303	0.001
BRS-4	420921.616	1170553.975	1.771	420921.617	1170553.976	1.773	0.002
BRS-5	420921.833	1170669.987	0.423	420921.832	1170669.988	0.423	0.001
BRS-6	420928.025	1171019.57	1.28	420928.026	1171019.576	1.289	0.010
BRS-7	420921.174	1171094.753	0.099	420921.173	1171094.752	0.097	0.002

(*) Note:
- Unit (m)
- Coordinates and elevations of Targets are measured using electronic total station devices.

Formula for evaluating Point Position Error:

$$\text{Deviation} = \sqrt{(X2 - X1)^2 + (Y2 - Y1)^2 + (Z2 - Z1)^2} \quad (1)$$

The final product from the BIM-GIS integration can be observed in Figure 8. With this WebGIS based model, the data can be shared, together with the huge amount of data to other stakeholders. Noted that the integrated model provides all information of all types of available measurable data related to the port. Furthermore, the 3D visualization makes the representation of the port more intuitive.

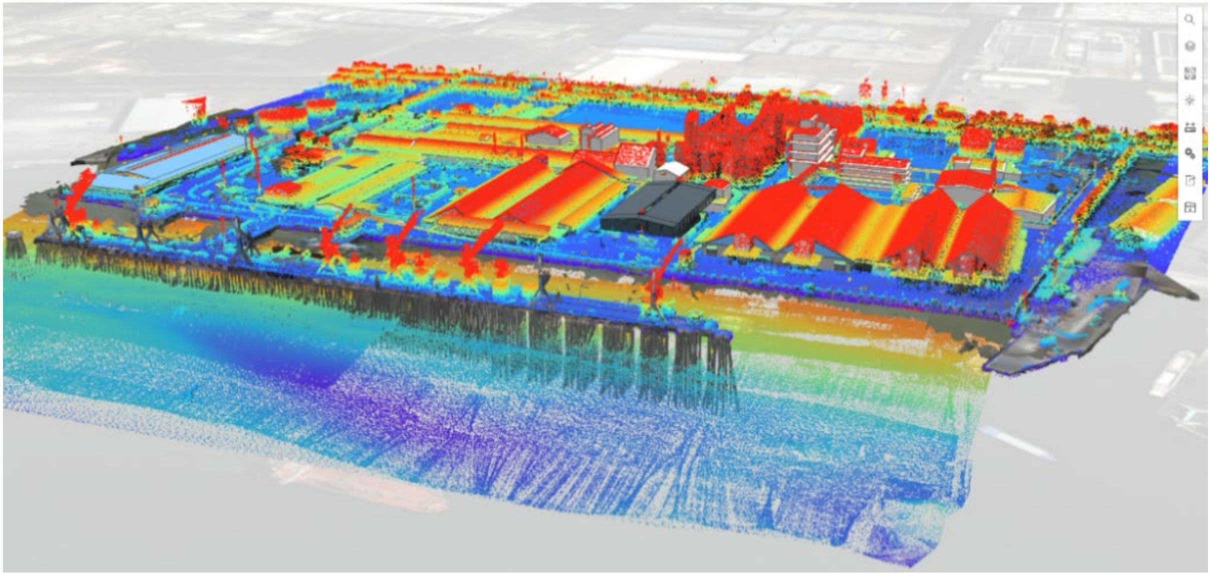


Figure 8. Integrated model visualization on ArcGIS online

4. CONCLUSIONS

This research provides a valuable case study for the application of innovative technology in infrastructure management. Through the integration of Building Information Modeling (BIM) with a WebGIS platform, we have constructed a comprehensive 3D representation of a port infrastructure system. This integration not only enriches the visual understanding of the data but also improves its practical applicability for engineering design and geographical information. The fusion of BIM and WebGIS technologies demonstrates the potency of combined systems in streamlining complex procedures and enhancing the user experience. This combination serves as a significant step in the digital transformation era, highlighting the progressiveness of innovation. As the result of data integrating, the format of output data as *. slpk is recommended to enhance the process speed in WebGIS environment. Future research should focus on improving the user interface, including additional data types, assessing performance, and addressing potential security and privacy concerns.

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