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BIM-GIS INTEGRATION FOR PORT PLANNING: CASE STUDY OF HAI PHONG PORT CLUSTER IN VIETNAM

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Abstract: Vietnam has launched its first national sector planning for 2021-2030, targeting goals up to 2050, a significant move towards comprehensive transportation strategies, particularly in port planning and design. This initiative emphasizes the integration of BIM-GIS technology, an emerging trend in infrastructure development. The paper focuses on applying BIM-GIS in port planning, specifically for the Hai Phong port cluster in Northern Vietnam. Projections indicate a potential doubling of cargo throughput and a 150% increase in vessel traffic by 2030 at Hai Phong port. This growth necessitates phased expansions of the channel and infrastructure, highlighting the need for a dynamic, integrated planning model. The BIM-GIS system in this context captures diverse data over time, including bathymetric, hydrological, and navigational information. The model serves as a crucial tool for decision-making, effective management, and future development of the port, demonstrating Vietnam's commitment to advancing its transportation sector.

Keywords: Port planning, BIM-GIS, field survey, point cloud, photogrammetry

Introduction

Building Information Modeling (BIM) is a comprehensive modeling approach for the construction industry that includes the geometries of buildings, as well as their spatial and extensive data about their physical infrastructure. BIM encompasses a substantial volume of data that integrates physical and functional characteristics of buildings, necessitating advanced technical solutions for data storage and maintenance [1]. BIM's capabilities extend beyond three-dimensional modeling, providing significant advantages for civil engineers and architects [2].

Although BIM is commonly used for modeling individual buildings and analyzing their performance, its potential for application in large-scale projects, such as port systems, that include multiple types of buildings and components, has not been fully realized. Nevertheless, BIM holds the promise of serving as the physical and spatial foundation for extensive projects, for instance, within the smart city concept, by combining it with various other forms of data. This integration could revolutionize how large-scale projects are planned, executed, and managed [3].

Geographic Information Systems (GIS) are designed to capture, analyze, and present geographical data linked to specific objects. The advent of 3D GIS technology has pushed the boundaries further, enabling the creation of three-dimensional visual representations that can be managed, analyzed, and utilized to support decision-making processes. Despite the usefulness of these 3D visualizations across various domains, the single GIS has typically fallen short in offering users the ability to explore the details of the model directly, resulting in a less immersive interactive experience.

To bridge this gap, the integration of Building Information Modeling (BIM) with GIS has been proposed. This fusion brings together the strengths of both systems, significantly enhancing the visualization and interactive potential, enabling users to access and interact with the complex details of a model without interruption, thereby creating a more seamless and enriched user experience [4].

In such integrated applications of BIM-GIS model, BIM supplies comprehensive data specific to individual buildings, while GIS offers environmental level data, effectively overcoming the limitations of BIM in terms of horizontal expansion [5]. While GIS offers significant advantages in large-scale geographic representation and analysis, the complete capabilities of integrating it with BIM for infrastructure and urban planning applications have yet to be fully explored. The use of a BIM-GIS model at an urban scale could profoundly benefit planners and decision-makers by enhancing their understanding of different alternatives and their impacts [6]. Furthermore, large-scale development planning necessitates the collaboration of diverse stakeholders, which plays to BIM's strengths. Therefore, an integrated BIM-GIS model that visualizes and evaluates various metrics can deepen stakeholders' comprehension of intricate information [7].

This study presents the use of a BIM-GIS system in port planning, focusing on the Hai Phong port cluster in Northern Vietnam (Figure 1). Projected data suggests that by 2030, the cargo handling capacity at Hai Phong port could double under the most favorable conditions. Additionally, the traffic of ships entering and exiting the port is expected to increase by 50% by 2030. Considering these projections, a significant increase in cargo volume and ship traffic indicates the necessity for gradual expansion of both the navigational channels and the port infrastructure. The paper outlines a process for creating an integrated BIM-GIS model, which is designed to improve the management of the port's utility infrastructure. This digital model encompasses various types of data such as underwater, structural, land use, hydrodynamic, and geological information related to the project, thereby providing planners with a detailed and comprehensive view of the port's development needs.

Figure 1 Hai Phong port cluster location

Methodology

The suggested BIM-GIS model is designed to support port system development and to include the natural environmental patterns related to hydrodynamics, geology, land use, and other information. All essential data required for the BIM model's creation are gathered via field surveys and subsequently processed using specialized software. Regarding the platform for the integrated application of BIM and GIS, ArcGIS Online, Esri's web-based mapping software, has been selected.

Field survey

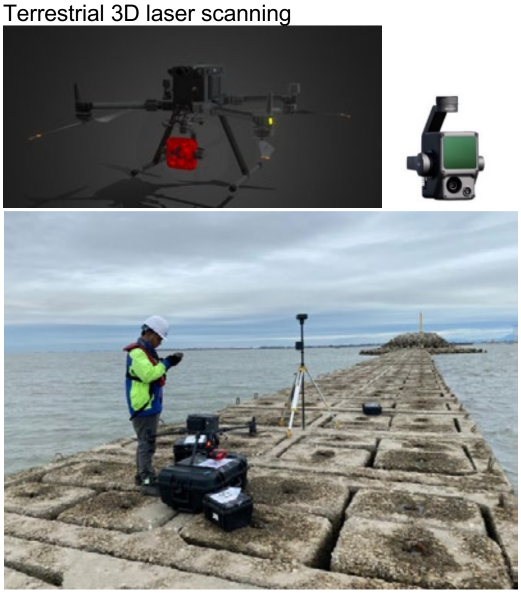
This part outlines a process for collecting data to create 3D digital models or BIM (Building Information Modeling) for large-scale infrastructure, such as ports. This involves a method known as Scan/Survey to BIM. Traditional survey methods are time-consuming and resource-intensive [8]. However, adopting modern techniques that support or substitute the old ones can lead to significant savings in time and labor costs. The deployment of modern sensor systems (equipment) offers various ways to acquire data on the state of physical assets including LiDAR (Light Detection and Ranging), Terrestrial Laser Scanners, advanced geophysical imaging techniques, and the integration of Unmanned Surface Vehicles (USV) with multibeam sonar systems for more detailed and efficient bathymetric surveys.

Sensor systems, encompassing airborne, terrestrial, and aquatic types, are utilized to acquire geo-referenced information from both underwater and on-land environments. For on-land data capture, Terrestrial Laser Scanning (TLS) is employed, specifically within port areas, to gather highly accurate point cloud data of equipment and structures. In this specific project, the Leica Scanstation P50 is utilized. This device is strategically placed at predetermined sites that have known coordinates and elevations, determined using the Leica TS60 electronic total station. Similarly, the Leica RTC360 device is also used, where targets with predefined coordinates and elevations are necessary to precisely align and calibrate the device's positional data.

Unmanned Aerial Vehicles (UAVs), as detailed by Nex et al. in 2022 [9], are equipped with Lidar and imaging systems that produce point clouds, orthophotos, and oblique imagery. Lidars have been acknowledged for their effectiveness in Building Information Modeling (BIM), offering geometrically precise measurements as noted by Liu et al. in 2021 [10]. Aerial surveys are conducted to address the limitations of terrestrial surveying, especially in scenarios where Terrestrial Laser Scanning is less efficient, such as covering extensive areas like the entire port or accessing challenging locations like high rooftops. In UAV-based surveys, the DJI Matrice 350 is employed. It is fitted with the Zenmuse L1 LiDAR device, can penetrate vegetation to gather ground data. The L1 can conduct triple-return scans, greatly enhancing data quality in vegetated regions. It achieves a scanning rate of 240,000 points per second, which doubles to 480,000 points per second during triple-return scans. Additionally, the Matrice 350 RTK integrated with the SHARE 203S Pro oblique camera system, featuring five lenses and a 225 MP image sensor, can provide high-resolution images from five distinct perspectives.

Neither aerial nor terrestrial surveys are capable of gathering data from the wharf's edge extending into underwater regions. To address this, Unmanned Surface Vehicles (USVs) equipped with integrated iLiDAR and multibeam echo sounders are deployed to simultaneously acquire bathymetric and point cloud data of the wharf's front side. For this project, the Otter unmanned surface vehicle (USV) system is employed, featuring two GNSS devices that provide data on coordinates, elevation, and orientation.

a) Terrestrial 3D laser scanning



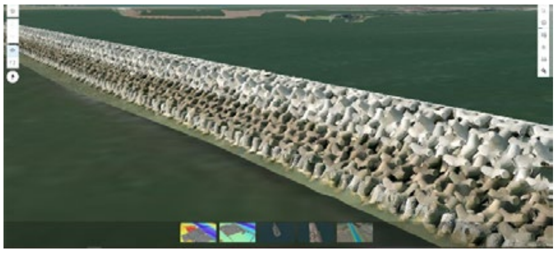
b) Aerial survey (top-left: Matrice 350P RTK + SHARE 203 Pro; top-right: Zenmuse L1; bottom: conducting survey at the the breakwater)

c) Underwater survey using USV Otter

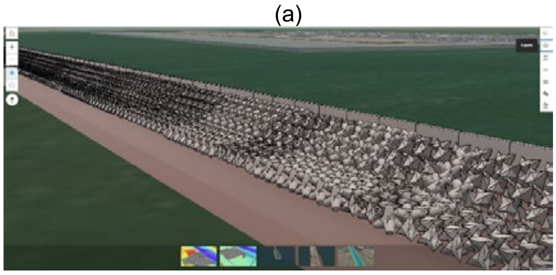
Figure 2 Conducting the field surveys

BIM model

From the obtained point cloud, a model is created by exporting data and importing point cloud data into relevant software such as Revit (Figure 3). The engineer creates an as-built model based on the orthogonal distance of points on the object surface of the point cloud and the similarity in the direction of the local standard faces around the point cloud. After importing data into the software, building objects on the BIM model are set up following the project's components based on point cloud data and the images obtained. The last part of this step is to align the objects of the BIM model with the point cloud, so each object of the BIM model is matched with the points of the point cloud.



(a)



(b)

Figure 3 Point cloud model (a) and Revit model (b) of the breakwater

BIM-GIS integration

The overall process of integration is illustrated in Figure 4. After processing, the point cloud model data from USVs survey is transferred to ArcGIS Pro software to combine with other data, such as 3D photogrammetric model from UAVs, 3D meshes, 3D point clouds from laser scanning, and BIM models from Revit to create a "full model" which contain all the available information related to the natural conditions and all facilities of the port. Then, the data is uploaded and stored on the ArcGIS Online platform for stakeholders to access, visualize and share the survey data.

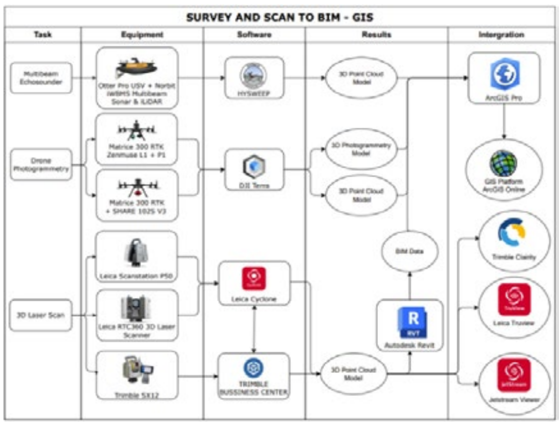


Figure 4 Procedure for creating a BIM-GIS Model of Hai Phong port system

Results

With complex topographical conditions and wide range of works (port, channel, breakwater) as well as equipment, the Hai Phong port system projects have their own characteristics. Various problems are encountered, such as complicated layouts of engineering database and different information sources. The comprehensive BIM-GIS model encompasses multiple layers of data, ranging from underwater, underground, and on-land element. This includes a 3D digital model of the port infrastructure derived from point cloud data and photogrammetry, a 3D Revit model, along with bathymetric, geological, and hydrological data, and other types of data.

Figure 5 Three-dimension pointcloud model of the port infrastructure

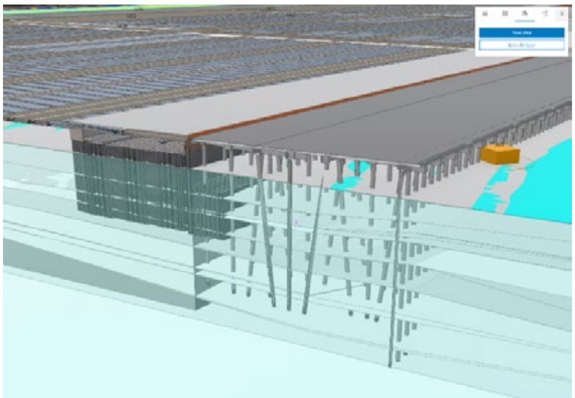


Figure 6 Three-dimension Revit model of the berth structure

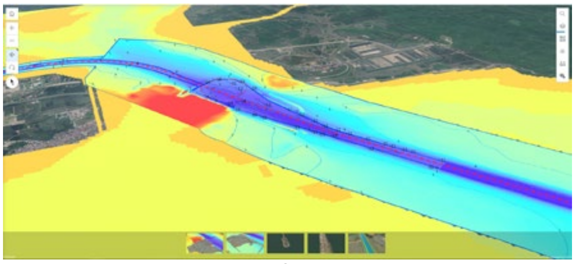


Figure 7 Bathymetric data of the navigational channel

Figure 8 Bored holes location and geological data of the construction field

A substantial amount of historical hydrological data (wave parameters, water level, current field) is accumulated and stored at the exact locations where it was collected. Thanks to the latest features from Esri, paper documents like hydrological reports can now be embedded. This enhancement brings convenience and offers a quick, comprehensive overview for planners.

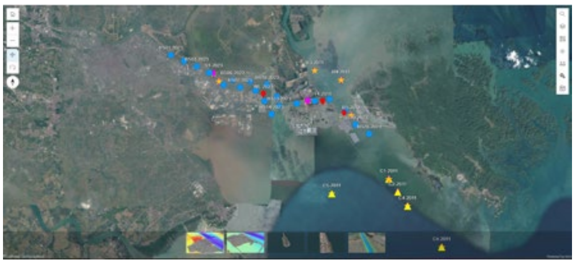


Figure 9 Layer of hydrological survey data

The model also includes information about the navigational aid system, and the condition of each navigational buoy can be retrieved from it.

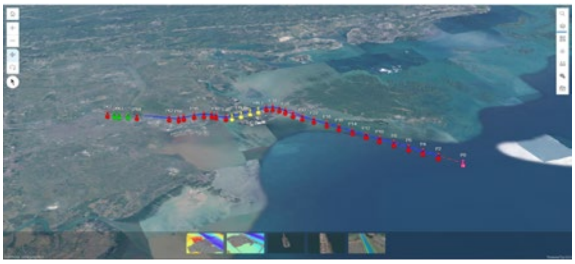


Figure 10 Information about the navigational buoy system in the integrated model

Discussion

The integration of Building Information Modeling (BIM) and Geographic Information Systems (GIS) provides substantial benefits for users, particularly planners. This integration creates a dynamic and visual interactive platform that is invaluable for planning, designing, and verifying construction processes. The advantages are manifold:

Enhanced Visualization: Users can view detailed graphical representations of 3D building models with the very high resolution in a cohesive environment. This is exemplified by the ability to observe a highly detailed three-dimensional model of a container yard based on collected point cloud data (Figure 11).

Application in Extended Reality (XR): The 3D models derived from this integration can be utilized with XR technologies to significantly improve both the quality of visualization and the user experience, thereby offering a more immersive and interactive planning tool.

The integrated model not only simplifies the process of design and planning but also enriches the way we interact with and understand spatial data.

Figure 11. Three-dimensional visualization interface of the port

The inclusion of multi-layer data management is a key benefit of Building Information Modeling (BIM), offering a clear representation of diverse information sources. Each data type is stored in a distinct layer, which can be individually visualized or concealed as needed. This multi-layer approach facilitates a collaborative environment where users with varying expertise can share, analyze, and manage disparate data seamlessly.

For planners, the ability to handle 3D object information within the BIM and GIS interface is particularly advantageous. It allows not only for an immediate and clear visualization of the study area but also for access to extensive details about the port, such as berth length, available equipment, current speeds near berths, and water depth. Meanwhile, design engineers can access and analyze structural data, including the parametric details of design piles, their locations, and geological conditions. This multi-disciplinary integration ensures a comprehensive and detailed view of projects, enhancing both the efficiency and depth of planning and design processes.

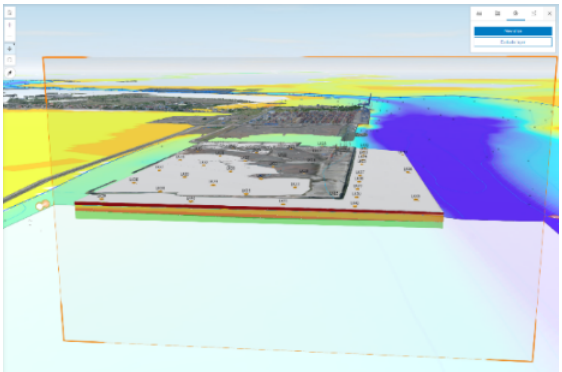


Figure 12 Making cross-section of geological model in BIM-GIS integrated model

Leveraging this model, planners can effortlessly position a 3D model of a prospective project into its intended location, enabling them to assess its visual integration and impact on the surrounding landscape. This capability simplifies the evaluation of future developments in context, ensuring that they complement their environments effectively.

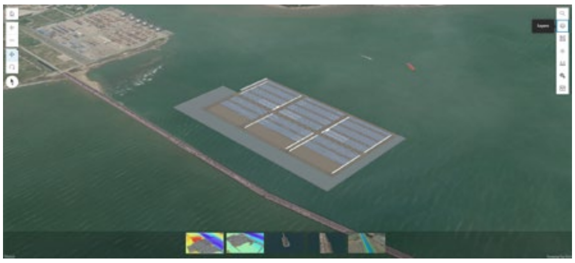


Figure 13 The project design model at its planned location

Overlaying the captured 3D model with the design BIM model enables engineers to conduct detailed analyses for construction verification. For instance, as illustrated in Figure 14 with the sand protection breakwater, engineers can identify and evaluate any damages that may have resulted from an incident. This method allows for accurate evaluations of structural integrity and supports effective remediation planning.

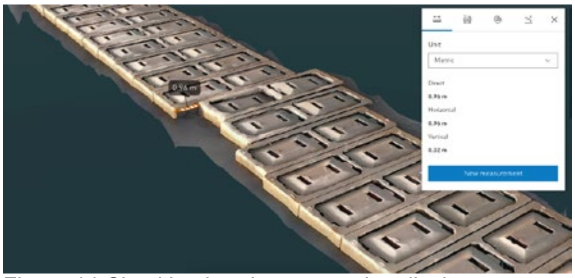
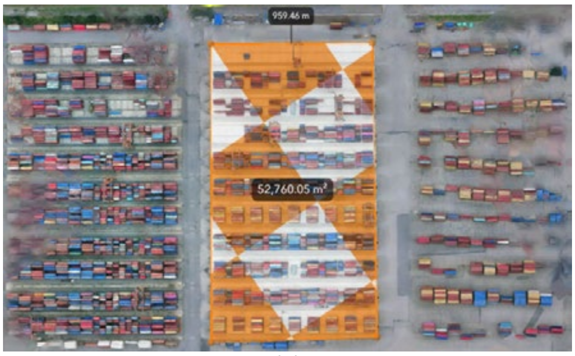
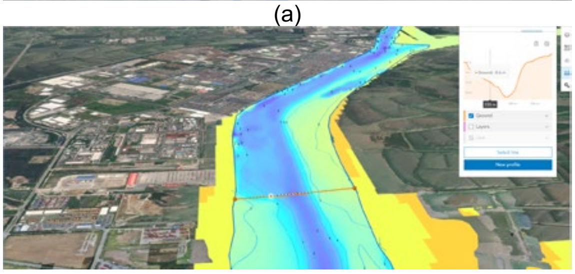


Figure 14 Checking breakwater section displacement

The models within the system are designed to be quantifiable, enabling users to conveniently define dimensions, such as the area of a container yard, or to effortlessly export cross-sections of any part of a channel. Additionally, the GIS system's capability to automatically generate contours is a valuable tool, providing planners with a comprehensive view of the bathymetry within their area of interest. These features enhance the practicality and precision of spatial analysis in planning.



(a)



(b)

Figure 15 Measurement tool (a) and cross-section creating tools (b) in Web-GIS platform

Finally, for assessing the risks posed by typhoons, BIM design models can be combined with typhoon data—including track, central pressure, maximum wind speed, and other relevant information—within a GIS environment. This integration allows for a thorough vulnerability analysis of the project area under extreme weather conditions, enabling designers to modify designs to mitigate potential typhoon-related damages.

Figure 16 Typhoon data integrated in GIS environment

Conclusions

The BIM-GIS integrated model offers a cutting-edge framework for port system planning. The GIS environment offers planners an overall view of projects, whereas the BIM model provides crucial engineering details for each element. This hybrid model facilitates the storage and integration of vast data sets from multiple disciplines within a web-based platform, promoting efficient collaboration among stakeholders from various professional backgrounds. This paper outlines the primary uses of the BIM-GIS model in the context of port planning. However, as technology rapidly advances, the capabilities and applications of this integrated model should be further investigated.

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