3D Web Map Approach using BIM-GIS Integration for Construction Supervision

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ABSTRACT: The concept of smart cities has brought significant attention to the construction and management of modern urban areas. Integration of Building Information Modeling (BIM) and Geographic Information System (GIS) has emerged as a powerful trend in the construction industry, providing comprehensive data for efficient construction management. This paper presents a study that focuses on the development of a BIM-3D GIS web-map platform for construction supervision, enabling progress monitoring and better decision-making. The study is limited to a case study of the De Zalmhaven building complex in Rotterdam, Netherlands, utilizing publicly available BIM data. The significance of the study lies in addressing the challenges posed by traditional scheduling and progress reporting methods in the construction industry. The integration of BIM and 3D GIS enables accurate visualization of building progress and facilitates collaboration among stakeholders with different expertise. Additionally, the web map provides a platform for sharing and analyzing data, allowing timely detection of potential delays and corrective actions. The developed BIM-GIS web-map platform offers a practical and efficient solution for visualizing construction progress. It empowers project managers, engineers, and clients to track activities, manage costs, and identify potential challenges. The platform's web-based accessibility enhances communication and decision-making processes among stakeholders. However, the study acknowledges limitations, such as focusing on structural and architectural BIM data and using only one case study building. Future research could explore the integration of cadastral information, enrichment with other BIM data, and algorithm development for automated processes. Overall, the BIM-GIS integration approach presented in this study offers promising potential for improved construction management and progress monitoring in the era of smart cities.

1. INTRODUCTION

Construction management of a building usually takes into account a variety of factors, which needs to be analyzed and visualized from both macro and micro perspectives. Therefore, several research studies have investigated ways to overcome these challenges, especially in the AECO/FM sector (architecture, engineering, construction, operation, and facility management), by means of exploring new methodologies and technologies. One of these developments is the integration of building information modeling (BIM) and GIS (geographic information systems). The integration of Building Information Modelling (BIM) and Geographic Information System (GIS) technology within construction management has emerged as a burgeoning and rapidly evolving trend in recent years, spanning from research endeavours to industrial application.

BIM is becoming a widely adopted method that allows the AECO/FM sector to enhance its management of information and interoperability (Sacks et al., 2018). BIM is used to visualize the real information of a building by using a digital 3D model based on relevant information data of a building project (Yin & Qian, 2013). Currently, the application of BIM technology in the management of construction projects has become a very important value and is an inevitable trend in the development of the construction industry (Zhou, 2018). On one hand, GIS technology is an advanced mapping technology commonly used in the construction industry at present. With the support of computer software and hardware systems, this technology has completed the management of all environmental information with spatial attributes in construction projects (Chen, 2019). Through GIS, complex spatial analysis and 3D spatial query can be carried out allowing to introduce new and innovative modeling and visualization methods. As a decision support system, GIS can also help users to explain and solve practical problems in various fields. GIS systems can be also integrated with the database operations and statistical analysis of other different systems for visual display in maps (Zhong et al., 2020).

The advancements in 3D Geographic Information Systems (GIS) and Building Information Models (BIM) offer innovative approaches to 3D geometric and semantic modeling of urban spaces. Both systems provide effective methods for representing the geometry and semantics of 3D objects. BIM has advantages in capturing rich geometric and semantic data throughout a building's lifecycle (Volk et al., 2014), whereas GIS encompasses a broad field involving geovisualization-based decision-making and geospatial modeling (Bery, 1999). Through this integration of GIS and BIM, a more detailed and comprehensive data information can be provided, which is well-suited to the complexities of construction management. With their respective advantages, the integration of BIM and GIS can provide complementary information and become a powerful tool, providing convenient and effective solutions for engineering practice and construction management (Ma & Zen, 2017; Liu et al., 2017; Pauwels et al., 2017). Moreover, this integration also carries broader implications, offering substantial support for the development of smart and sustainable cities through its capabilities in data integration, quantitative analysis, technological applications, and urban governance (Ma & Ren, 2017; Fosu et al., 2015; Yamamura et al., 2016).

In this study, a BIM-3D GIS web-map for construction supervision will be developed by visualizing the BIM data into the GIS platform through ArcGIS Pro and creating a web map to support construction supervision. With the integration of the 3D BIM models in a Web GIS platform for construction supervision, this will improve the procedure in monitoring the progress of a construction project. Further, this study will also explore and solve the challenges related to the processing and visualization of 3D BIM models in a GIS platform.

2. REVIEW OF LITERATURE

2.1 *BIM-GIS Integration Method and Platform*

As information technology platforms such as BIM and GIS exhibit both differences and similarities, Ma and Ren et al., (2022) have classified the platforms for BIM and GIS integration into three distinct patterns: (1) extracting data from BIM systems into GIS; (2) extracting data from GIS into BIM systems; and (3) extracting data from BIM and GIS systems to other systems. However, the methods for integrating BIM and GIS can be also categorized into three patterns based on which one leads and supports (Wang et al., 2019). Shown in Table 1 is the summary of the recommended platform for each integration method excerpted from Narindri et al., (2022).

Table 1. List of supportive platforms for integration (excerpt from Narindri et al., 2022)

Integration Method	BIM to GIS	GIS to BIM	BIM and GIS to other systems
Integration Platform	Autodesk Revit Autodesk Navisworks AutoCAD Autodesk Infraworks ArcGIS QGIS OpenSteetMap Google Earth PostGIS Vworld Desktop Matlab VBA MySQL Cesium Open CASCADE Synchro Oracle Primavera MS Project MS Access	Autodesk Revit Autocad Autodesk Civil 3D ArcGIS	Autodesk Revit AutoCAD Autodesk Civil 3D Autodesk Naviswork Autodesk Infraworks Google Earth CityEngine ArcGIS MySQL Self-Developed system

Traditionally, in the civil and construction industry, the first pattern is usually adopted. In this scenario, BIM takes the lead while GIS offers support in the design until the operational phase since BIM provides more detailed data. This pattern is particularly effective in expressing intricate internal building information since it can monitor the BIM geometry objects at the elementary level, while the GIS data strengthens the geometry data to provide spatial information easily. Through this integration, it could improve communication with stakeholders, provide geospatial analysis capability, and facilitate understanding of the impacts of a building on its surroundings (Bansal, 2021).

The second pattern, in which GIS takes the lead, and BIM provides support, is typically associated with the dominance of the GIS model. This approach is often used for city planning or other feasibility studies because of its excellent spatial data processing capabilities. However, this pattern lacks detailed attribute information for building entities while the BIM model is used only to provide data support.

Lastly, the third pattern involves equal participation from both BIM and GIS, emphasizing interoperability between the two models. This approach represents a potential future direction for these technologies and provides a remarkable fusion of capabilities within the building and its surrounding environment. However, it is essential to note that this approach demands handling substantial volumes of data, which can increase computational workload. This particular pattern is anticipated to unify realms of BIM and GIS technologies and the need for visualization within modern web browsers without requiring plugins (Wang et al., 2019).

Given the limitations of the other two patterns, the first pattern appears to be the most promising for initial integration steps within the construction industry, particularly during the building's construction and operational phase (Narindri et al., 2022).

2.2 *Implementation Challenge of BIM-GIS Integration*

Each integration method and platform's strengths and weaknesses become crucial issues for proposing a better framework. Previous studies found that many challenges during integration must be noticed and prevented to make a seamless integration (Table 2).

Table 2. Highlighted challenge of BIM-GIS integration (excerpt from Narindri et al., 2022)

Challenges	Solution
System • The system is not compatible with each other. • BIM standard is IFC while GIS standard is shapefile or CityGML	• Do the performance test on the operating system • The system needs an extra data transformation step
Data • Data formats not compatible with each other • Georeferencing • Database	• Using plugin or middleware to transform the data format • Export the BIM model directly to ArcGIS • Georeference the geometric model to match the location • Using ArcGIS to make geodatabase
Collaboration • Not all users understand the system • Data sharing	• Using WebGIS for collaboration and data sharing • ArcGIS has a supportive web application

Based on the reviewed literature, the data transformation has been the most critical challenge since some information can be lost during the integration process (Zhao et al. 2019; Matrone et al., 2019). One of the foremost apparent irregularities between those software and systems is georeferencing. It is a common long-run practice in GIS and 3D city models, but it may be new in BIM (Noardo et al., 202). Further, some software packages and systems are sometimes incompatible and require extra data transformation steps (Boanca, 2014). These problems are due to a lack of interoperability between different platforms.

It was also noted that mismatched information shows the difference in a standard format, different users, different application focuses, development stages, spatial scales, coordinate systems, geometric representations, storage, and access to various information (Liu et al., 201). With this, more research into data transformation provides a large potential for future integration.

To achieve high interoperability, a high level of detail, and to avoid data loss, the 3D model data in RVT (.rvt) or IFC (.ifc) must need to go through several more data transformation processes using Feature Manipulation Engine (FME) or other converting software. Thus, relying on several commercial software will still be the main requirement for an effective BIM-GIS integration solution. Currently, Revit was the most common BIM platform, while ArcGIS was decisively the most common GIS platform. Both are commercial software. The IFC BIM file using Autodesk Revit software is a compatible data format commonly used with the GIS environment, while shapefile (.shp) using ArcGIS Software is

commonly used as the GIS sharing format. From other BIM platforms, Revit has its advantages since RVT format could be directly exported to ArcGIS Pro without a complex transformation step beforehand. Since ArcGIS Pro can read RVT and IFC format, the BIM file could be integrated to the GIS platform easily. Data in ArcGIS Pro can also be organized in geodatabases as a system of record for geospatial information. Building information modeling (BIM) content can be converted to a geodatabase, allowing you to use ArcGIS Pro to edit and maintain building information originating from BIM design files.

With this, the study will use ArcGIS Pro since it has high interoperability and the latest technology for data sharing and collaboration which makes it more feasible framework in the building management web-based platform. The study will also demonstrate and provide a general method on how to integrate the BIM model into the GIS environment through ArcGIS Pro.

3. METHODOLOGY

3.1 Data and Software Used

In order to develop a BIM-3D GIS web map platform and demonstrate the visualization of building construction progress, we will utilize an open-source BIM data and the ArcGIS Pro application software. For this purpose, we have chosen the BIM model of the De Zalmhaven building complex in Rotterdam, Netherlands which can be downloaded from the "Learn ArcGIS" website (https://learn.arcgis.com/), an ESRI-managed hub of tutorials and exercises for learning GIS. This building complex contains two building datasets both in IFC format – high-rise and mid-rise. However, for this case, we acquired only the publicly available BIM file and specifically utilized the as-planned information of the mid-rise building to visualize the scenario of construction progress. Since ArcGIS Pro supports various BIM design files, such as IFC and Autodesk Revit, we will leverage its capabilities to visualize BIM building data within a 3D GIS platform.

For the development of 3D web map for construction supervision, we used the ArcGIS Maps SDK (software development kit) for JavaScript since it can offer customization options and 3D mapping tools that can run directly in the browser. This SDK also provides greater flexibility for handling BIM data in a 3D context and has the capability to develop 3D applications that run directly in the browser without the need for a plugin.

3.2 Development of BIM-3D GIS Web Map

3.2.1 Workflow

The development of BIM-3D GIS Web Map for construction supervision will be divided into two phases: (1) *handling of BIM Data in ArcGIS Pro*; and (2) *creating a web map using ArcGIS Maps SDK for JavaScript.* Figure 3 shown the general workflow in creating BIM-3D GIS web map.
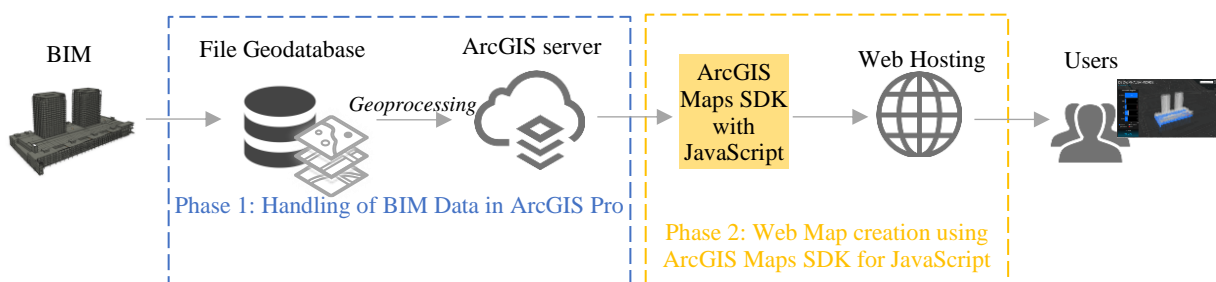

Figure 3. General workflow in creating BIM-GIS 3D web map

3.2.2 Visualize BIM Data in ArcGIS Pro

Building Information Modelling (BIM) involves creating and managing 3D information for construction projects across various disciplines. Using ArcGIS Pro, the Building Information Modeling (BIM) files can be read as an ArcGIS workspace of feature classes called a BIM file workspace. Shown in Figure 1 is the workflow that we implemented to visualize BIM data in ArcGIS Pro.
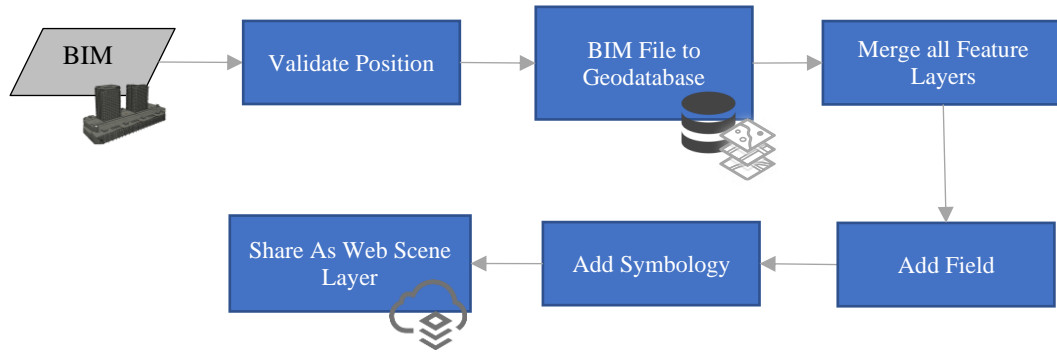
Figure 1. Workflow to visualize BIM data in 3D Web GIS

ArcGIS Pro can support both IFC and RVT files as ArcGIS BIM file workspaces. For the IFC file, the resulting feature classes included in the BIM file workspace are the IFC categories relating to building structures. The IFC categories also conform to the same categories and construction disciplines as the Revit-based BIM file workspace data. In some cases, a general IFC category can be divided into multiple BIM file workspace feature classes based on their different functions. Consequently, these feature classes within the BIM file workspace are standard and read-only feature classes. They are also valid inputs for ArcGIS Pro tools as layers, as well as geoprocessing models, geoprocessing tools, and scripts.

However, before these files can be used in ArcGIS Pro it should have an assigned coordinate system. BIM files are required to have a valid ESRI coordinate system (PRJ file) and may require an optional coordinate transformation information (WLD) file to identify how the coordinates in the BIM data should be positioned on the earth's surface. In our case, the De Zalmhaven digital models already have these additional files upon download. As the BIM design files can be read directly as native ArcGIS feature data in ArcGIS Pro, this will be interpreted by ArcGIS Pro as a single ArcGIS workspace containing multiple datasets. To convert this into an editable layer and not just a read-only file, we used the "BIM File to Geodatabase" conversion tool. This tool imports the contents of BIM file workspace into a single geodatabase feature dataset.

Once the BIM file converted, the output dataset will provide you all building feature class information. In the case of the De Zalmhaven building, only the Beams and Structural Foundation (structural) and Columns, Slabs, and Walls (architectural) layers were used since other feature layers are empty. These feature layers were merged into one feature layer using the "Merge" geoprocessing tool.

After merging the feature layer, we then add the "Status" and "SubType" field to the merged feature layer. The "Status" corresponds to the stage of construction while "SubType" corresponds to the type of building component. These information from these two fields will be used to create the progress chart in the web map. Both fields have a coded domain as summarized in Table 3. We used coded domain for easy script writing in the web map creation.

Table 3. Added fields for construction monitoring

Field Name	Data Type	Description	Domain
Status	Short	Status of construction	1 = To be Constructed 2 = Under Construction 3 = Delayed 4 = Completed
Sub Type	Short	Sub-type for De Zalmhaven Midrise	1 = Column 2 = Slab 3 = Wall 4 = Beam 5 = Structural Foundation

To simulate the construction activities of the building, a random status was applied to the features. Consequently, the symbology was applied to the layers based on the "Status" field. The layer was then published online through the ArcGIS Online (AGOL) as a web scene layer. Web scene layers are cached web layers that are optimized for displaying many features in 3D. There are several types of scene layers that can be published in AGOL. However, for this project the type of scene layer used is 3D Object. When sharing a scene layer in the web, an associated feature layer that is used to generate the cache is also shared.

3.2.3 Web Map Creation through ArcGIS API for Javascript

The ArcGIS SDK for JavaScript is a lightweight way to embed maps in web applications. It can be used to build an application that displays on a web map. For our purpose, we used this to create a BIM-GIS 3D web map (Figure 2).

Figure 2. Configuring of ArcGIS API for JavaScript to build BIM-GIS 3D Web Map

To develop the web application for construction monitoring, we used three main programming languages: HTML, JavaScript and CSS. HTML provides the basic structure of the web application, CSS is used to control presentation, formatting, and layout, while JavaScript is used to control the behavior of different elements. To bring the ArcGIS Map SDK for JavaScript into our application, we used the most common approach of accessing the API which is to use the hosted version. In this case, the API and CSS were referenced from the ArcGIS Content Delivery Network (CDN).

After referencing the API, we incorporated the specific modules needed for our web application. In ArcGIS Maps SDK for JavaScript, there are two (2) module formats available: Asynchronous Module Definition (AMD) modules and ES modules. In this case, we opted the AMD format. The AMD "require" function relies on references to determine which modules will be loaded and subsequently passes them as parameters to the callback "function" where they can be used in the application. Figure 3 displays the modules utilized in this application.

Figure 3. Loading AMD modules

In addition to visualizing the building model, charts were also added to show the progress of the construction. For this purpose, we used the *amCharts 4* JavaScript library as its charting engine. An XY Chart series was used to display the progress percentage for each layer and for each status. In *amCharts* version 4, two modules are required, the "core" (main module) and the "charts" module. These modules were loaded using the "script" version.

4. RESULTS AND DISCUSSION

Construction projects are usually known by their complexity, lengthy timelines, and diverse stakeholder collaboration (Lee and Peña-Mora, 2006; Poku and Arditi, 2006; Korde et al., 2005; Song et al., 2005; Kamat and Martinez, 2002; Koo and Fischer, 2000), and often needs decisions regarding corrections and schedule adjustments. However, these decisions are typically made during coordination meetings attended by a varied group of individuals, including project owners and subcontractors, each with unique expertise and interests. During these in-person discussions, it is crucial to convey progress information quickly and easily among participants. However, current reporting formats, such as textual reports, progress curves, and photographs, may fall short in effectively and swiftly communicating project progress. Existing monitoring methods entail manual data collection and extensive data extraction from diverse construction documents, diverting project managers from decision-making tasks. Furthermore, these methods often struggle to comprehensively present and visualize multifaceted information encompassing schedule, cost, and performance. They also lack intuitive representation of planned and actual spatial and visual aspects of construction and their associated complexities (Lee and

Peña-Mora, 2006; Poku and Arditi, 2006; Korde et al., 2005; Song et al., 2005; Kamat and Martinez, 2002; Koo and Fischer, 2000).

As the demand for comprehensive monitoring techniques continues to rise, especially on large construction sites where manual monitoring becomes impractical, the integration of Building Information Modeling (BIM) and Geographic Information Systems (GIS) technology emerges as a highly suitable solution (Han et al., 2020). This integration addresses the requirements of various phases in the building life cycle and enhances information exchange among stakeholders and processes. To improve progress monitoring and effective project management, the development of a systematic approach and visualization tools that project managers can use to track ongoing construction site work is imperative. The visualization of progress through BIM and 3D GIS has garnered recognition as an effective means of communicating progress monitoring metrics (Lee and Peña-Mora, 2006; Poku and Arditi, 2006; Kerzner, 2005; Song et al., 2005; Abeid et al., 2003).

In this case, the process of the development of a 3D browser-based mapping application will be demonstrated as a feasible solution for integrating BIM models in an existing GIS application. Figure 4 shows the web map interface, which consists of three main parts: (1) Chart Panel; (2) Map View; and (3) Filters and Widgets. Each of these features and functions is discussed in Table 4.

Table 4. Main parts and features of the 3D web map application for construction supervision

Features	Description
A. Chart Panel	The chart panel displays the construction progress of the building in percentage. It comprises an XY chart series for each sub-type and bullet points for each status level. The total percentage for all the completed features, regardless of the sub-type is also shown below the chart panel. The created chart has also been made interactive, in a way that when you click the percentage for the subtype it automatically filters the features in the map view.
B. Map View	The map view is where the 3D model of the building is being shown. Operations such as zooming in and out and panning using the mouse is applicable in map view. When a feature is selected, a pop-up appears in which shows the attributes of the selected feature.

C. Filters and Widgets	In the web map, several widgets and filters are incorporated to allow the users to easily explore and realistically visualize the building complex:
	
	• **Basemap Toggle** – allows the user to change the basemap from "Dark Gray Canvas" (default) to "Imagery".
	• **Layer List** – provides a list of operational layers, and it allows the user to turn individual layers on and off. For our purposes, two additional layers were added in the web map:
	   1) *OpenStreenMap 3D Buildings* – a 3D scene layer which presents OpenStreetMap (OSM) buildings data and is hosted by ESRI,
	   2) *Textured Buildings of Rotterdam in 3D* – this layer contains the buildings with roof shape and textures of Rotterdam City courtesy of the Municipality and is now being maintained and shared by ESRI Netherlands.
	• **Daylight Mode** – allows the user to change how sunlight and shadows affect the scene during different hours and months. This can also provide a general idea on the distribution of daylight captured by the building by simulating every pattern of daylight throughout the building structure.
	• **Compass** – reorients the scene to north.
	• **Full Screen widget** – allows to view the scene in full-screen mode.
	• **360-degree camera rotation button** – automatically rotates the scene around the 3D map.
	• **No ground** – a button to view the ground from below. This button adjusts the opacity of the basemap to easily visualize the feature below the ground.
	• **Filter by Floor** – allows the user to easily filter the map by floor level through its dropdown list. Once a floor level is selected the map and the chart automatically updates as well. This adds more options to look at the construction progress not just by sub-type but also by floor level.

The created web map was stored in Github, an internet hosting service and it can be accessed through this link: https://sarramaravilla.github.io/DeZalmhaven_Midrise/index.html.
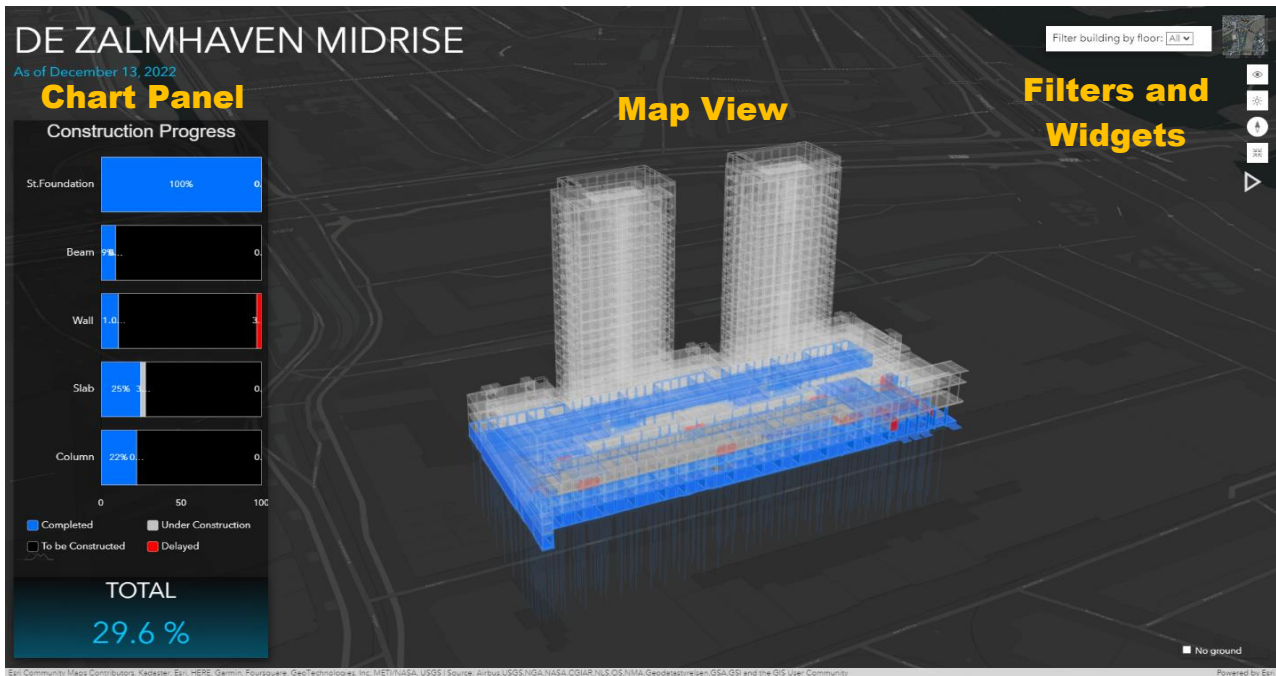
Figure 4. De Zalmhaven Construction Monitoring web map

In the developed BIM-GIS integration platform, the built environment is represented in a 3D GIS model that contains information at a high level of detail from BIM. Through this integration, the 3D GIS model of the construction building complex was visualized with intricate detail, making it easy to view and monitor the building structure for construction purposes. However, there are limitations on the model and platform, as follows:

1. Only the structural and architectural BIM data was used initially in the model.
2. Data quality was not a primary concern. The primary focus of the methods presented was on practical aspects of collecting, transforming, and sharing BIM data within the GIS environment.
3. The model currently lacks capabilities for in-depth data analysis such as determining of building condition index. It was primarily served as a visualization tool.
4. On-the-fly editing of the progress status of building structure is not currently included in the webmap.
5. Users should be aware that ArcGIS Pro is a commercial product that may require a valid license for full access and functionality.

Despite the limitations, this web-based platform can be easily configured based on the chart panel, filters and widgets that were included in order to explore and visualize realistically the building structure and to support construction supervision. For instance, the developed platform gives helpful basic functions to display the building structure including each floor of the building based on the progress of the construction of the building. The user can filter which building data (i.e., structural and architectural) should be shown or hidden, visualize in the progress bar chart. Users can also select a suitable basemap and navigate through the block scene from different viewing directions, imagining the actual representation of the city where the building is situated. Furthermore, the platform also transformed the 3D model of the building into an important geometry data to be used for building management.

5. CONCLUSIONS

3D Web GIS is a powerful tool to show complex spatial information in an intuitive and engaging manner. Through a 3D web scene representing the city with its buildings, streets, vegetation, and other urban objects can help the community at large experience the planned project the way they would in the real world. Instead of having to read through complex technical construction plans, they can navigate the scene intuitively in their web browser. Construction companies can also provide such 3D scenes to architects, engineers and even investors and city governments to plan their projects in context early on. This is also allowing the stakeholders to assess the project design and its impact on the surrounding urban environment. Thus, they can make faster and smarter decisions during the planning and design phases of the project.

In this study, we attempted to integrate and visualize BIM data into the GIS platform through ArcGIS Pro and create a web map to support construction monitoring. Through the BIM-3D GIS web-map we developed, this can provide a better way of monitoring and to support construction supervision. In this 3D web map, we provided the minimum requirements

to provide information and visualize the status of the progress of a construction project. Further, with the organized graphical form together with a 3D web map that presents the progress of a construction project, it provides the visualization of the scheduling and progress reporting to be easily viewed and provides a clearer picture of the progress of a construction project which failed to do by the traditional scheduling and monitoring methods. Clear communication and transparent project management between contractors, engineers and construction managers for a smooth workflow and better bottom lines for all involved is also being promoted in this web map application. Through the web map, the information can be also shared with other stakeholders and can provide quick reporting on a regular basis.

On the other hand, this application also highlights limitations that need to be further researched which was enumerated above. To overcome the barriers and challenges, collaboration and openness are the keys to BIM and GIS integration (Liu et al., 2017). While the semantic web technologies and service-based give high effectiveness and extensible effort. Emerging technologies such as cloud computing, semantic web techno-logy, web-based communication, and mobile BIM-GIS technologies can extend the framework implementation (Bansal, 2021).

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