Applying GIS and Geospatial Measurement Technologies in Construction Data Management in Vietnam: A Case Study of Hanoi University of Civil Engineering's Campus

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Abstract
Construction projects generally comprise three fundamental phases: design, implementation, and operation, which encompass a wide range of data types. Construction data encompasses a variety of documents, including topographic surveys, planning and design records, construction reports, and as-built documentation. In Vietnam, the development of Building Information Modeling (BIM) offers promise for managing design and construction data. However, challenges persist in effectively managing and sharing attribute data throughout a construction project's entire lifecycle. This study presents a solution that integrates Geographic Information Systems (GIS) to establish and facilitate the efficient sharing of building data information among pertinent stakeholders. The research has implemented a data system for the H3 lecture hall at Hanoi University of Civil Engineering's campus, encompassing a 3D map database of the entire area, 3D design model data, and associated attribute data. The management of building data for construction projects entails the establishment of geospatial data processing procedures, attribute data systems, and the development of 3D model solutions using the ArcGIS Pro platform. The data is presented and shared through the ArcGIS Online platform, resulting in the creation of a web map designed to enhance the effective management and sharing of construction data.

Keywords: 3D Model, Data Management, Data Sharing, Geospatial Data, UAV, TLS, Web Map

1. Introduction

Construction projects typically involve three main phases: design, implementation, and operation management, all of which require the use of various types of data. Construction data encompasses documents such as topographic surveys, planning-design, construction, and as-built records, among others. Traditional methods represent this data through 2D drawings, which often fall short in fully describing the attributes of the project's current status. Consequently, there is a lack of clear visualization of the ongoing progress, necessitating site visits by the design team to develop appropriate solutions. Historically, data management within each department (survey, design, construction) has been localized, leading to fragmentation, lack of connection, and a lack of synchronization of building data throughout the project's lifecycle.

To address the data collection needs of contemporary construction projects in Vietnam, low-altitude remote sensing methods employing Unmanned Aerial Vehicles (UAVs) and terrestrial laser scanning systems (TLSs) are commonly utilized to acquire geospatial data. Numerous studies have demonstrated that these methods enable the development of large-scale maps for construction projects. For instance, in a study conducted by the authors [1], topographic maps at scales of 1:500 and 1:1000 were successfully generated using UAVs at different flight patterns and altitudes. Similarly, the authors in another study [2] combined UAVs with CORS (Continuously Operating Reference Stations) technology to establish topographic maps at scales of 1:2000 and 1:5000. In a different research endeavor focusing on the application of UAVs in supporting topographic surveys for construction project design, the authors [3] surveyed regional and linear projects, creating topographic maps at a scale of 1:1000, which were then displayed on WebGIS. Additionally, combining point cloud data from TLSs and UAVs, the authors [4] proposed an integrated data processing procedure for surveying, designing, and inspecting construction projects.

Following a similar research direction, the authors [5] developed an algorithm to integrate point cloud data from these two technologies in construction project information collection. These studies collectively underscore the effectiveness of using UAVs and/or TLSs for collecting spatial data in construction projects.

In addition to utilizing orthoimage data, point clouds, and digital elevation models for the creation of large-scale 2D topographic maps, UAVs and TLSs offer a significant advantage by enabling the construction of 3D simulation models. One noteworthy application of TLSs is the development of 3D models for Building Information Modeling (BIM) data management. The author [6] argues that despite certain limitations in collecting and processing point cloud data, this approach holds potential as a solution for gathering asset management data in small projects. In a research area spanning 10 hectares, the authors [3] opted to employ UAVs for collecting 3D point cloud data, which they visualized on the Potree platform for design purposes. According to the authors, this method proved highly efficient in processing point clouds and sharing visual models with users. By combining UAVs and TLSs, more detailed and accurate data sources can be created. For instance, the authors [7] studied the process of generating 3D models with LoD 3 (LoD) detail level for high-rise buildings. These products effectively address the lack of survey data and support designers and managers in visually reviewing 3D simulation models of the current project status.

In the evolving landscape of the construction industry, the demand for effective management of construction information during the design and construction phases has prompted the introduction of BIM solutions in recent years [8] and [9]. In their research on the application of BIM and common data environments in construction progress management, the authors [10] identified three key factors: technology, processes, and behavior. Notably, the utilization of 3D current models enhances efficiency in field surveys, while information models improve design visualization and record updates. However, challenges remain in the information exchange process between project stakeholders. Pertaining to infrastructure and transportation projects, the research conducted by the authors [11] early on suggested that UAVs offer an effective means of providing highly visual and information-rich survey data suitable for input into BIM models. In recent years, BIM applications have gained widespread adoption and have become more specific in their implementation. For instance, the authors [12] developed an information model for a steel box girder overpass at intersection 550 in Binh Duong province, aiming to support simulation and construction information management throughout the design and construction phases. Similarly, in a study by the authors [13] focusing on applying BIM in the design stage of the Thu Thiem 2 bridge, significant benefits were identified, emphasizing the need for continuous synchronization throughout the entire life cycle of the bridge project. Particularly, the synchronization and sharing of information data between project parties were highlighted as crucial aspects to address.

Based on the aforementioned studies, there is a widespread agreement regarding the effectiveness of utilizing UAVs and TLSs to collect geospatial data in the construction field. However, there remains a gap in discussions concerning the processing of large data sets to achieve high levels of detail and unified construction data management solutions that facilitate connectivity and efficiency in sharing between different departments. Recognizing this gap, this study aims to address these challenges by leveraging the advantages of GIS. The proposed solution involves the processing of UAV and TLS data to develop a web map that enables unified management and sharing of construction databases. Specifically, this web map incorporates current situation survey data and design models (such as the H3 lecture hall) from the Hanoi University of Civil Engineering campus. By implementing this solution, the study aims to enhance the accessibility, connectivity, and efficiency of construction data management within the university's campus.

2. Method and Data

The workflow process is depicted in Figure 1, consisting of three main stages: data collection, data standardization, and web map creation. Data collection in the first step includes UAV and TLS survey data, 3D building design models, and accompanying attribute data such as information fields that describe the characteristics of the building, 2D AutoCAD drawings, and/or documents of work reports. In the second stage, the ArcGIS Pro software was employed to design geospatial and attribute database structures that adhere to technical standards. The collected input data was first normalized and then incorporated into Shapefile templates. These resulting Shapefiles would be stored in a Geo Database and managed as layers that can be flexibly used in both offline and online modes. For this study, the Geo Database was uploaded on the Esri server.

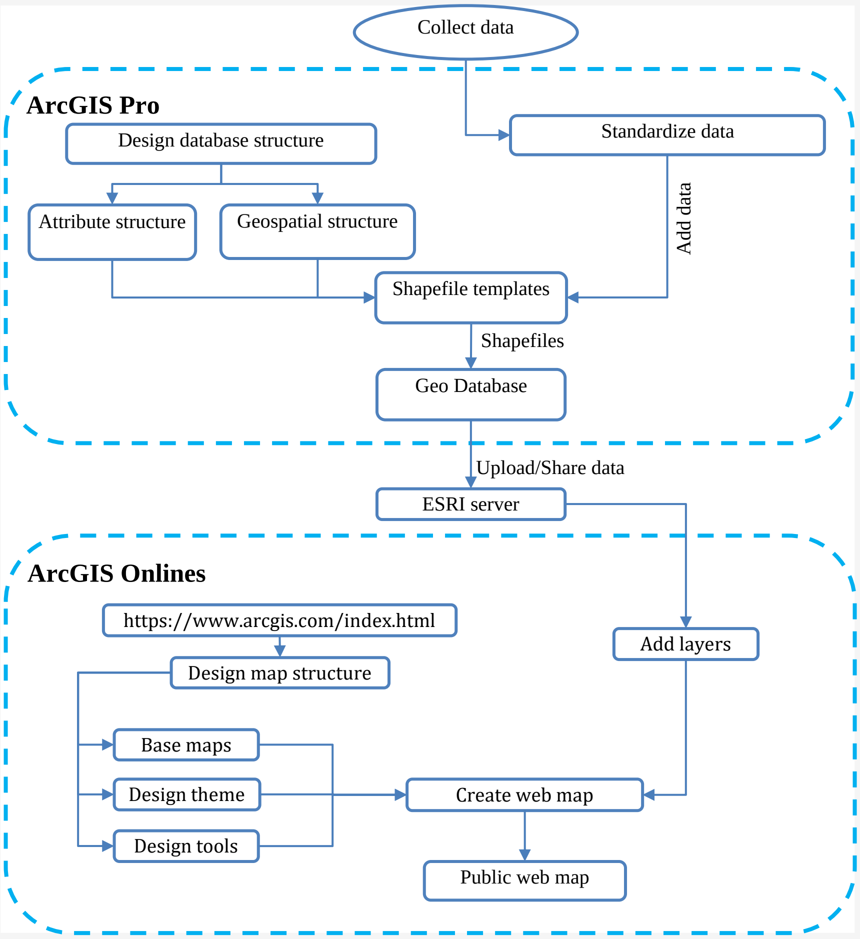


Figure 1: Study workflow

In the third stage of designing a web map, ArcGIS Online provides users with the flexibility to select a base map and customize themes as well as tools that enable the creation of a desired map structure. The following process involves integrating the data layers from the uploaded Geo Database into the map structure, resulting in a comprehensive web map that can be published for display and data sharing of the project.

2.1 Data Collection

2.1.1 Survey Data Collection

The current surveying data was gathered using TLS (Terrestrial Laser Scanning) devices, specifically the TOPCON GLS-2000, and UAVs (Unmanned Aerial Vehicles), specifically the Phantom 4 Pro V2. For the Hanoi University of Civil Engineering campus, a reference network was established in the VN-2000 coordinate system with a 3^0 projection zone at the 105^0 center meridian. This reference network was used to link the locations of stations and targets in the process of collecting data using TLS, Figure 2(a). These station positions require offering good coverage of the survey area and ensuring that relevant features and objects are captured. Therefore, the data collection involved 17 scanning stations with a scanning density of 1 cm/1 point. After collecting the data from multiple scan positions, it is necessary to register or align the individual scans using common reference points. Figure 2(b) illustrates some images of the registration process ensuring that all the data points are accurately connected and overlapped, creating a unified and comprehensive representation of the survey area. The results of the point cloud data from the experimental area are shown in Figure 3.

The collected TLS data was processed by merging stations and removing unnecessary elements using Magnet Collage software provided by TOPCON. Point cloud data processing for each device typically relies on specialized software provided by the manufacturer.

(a) (b)

Figure 2: TLS data collection process (a) TLS reference network (b) Field data collection

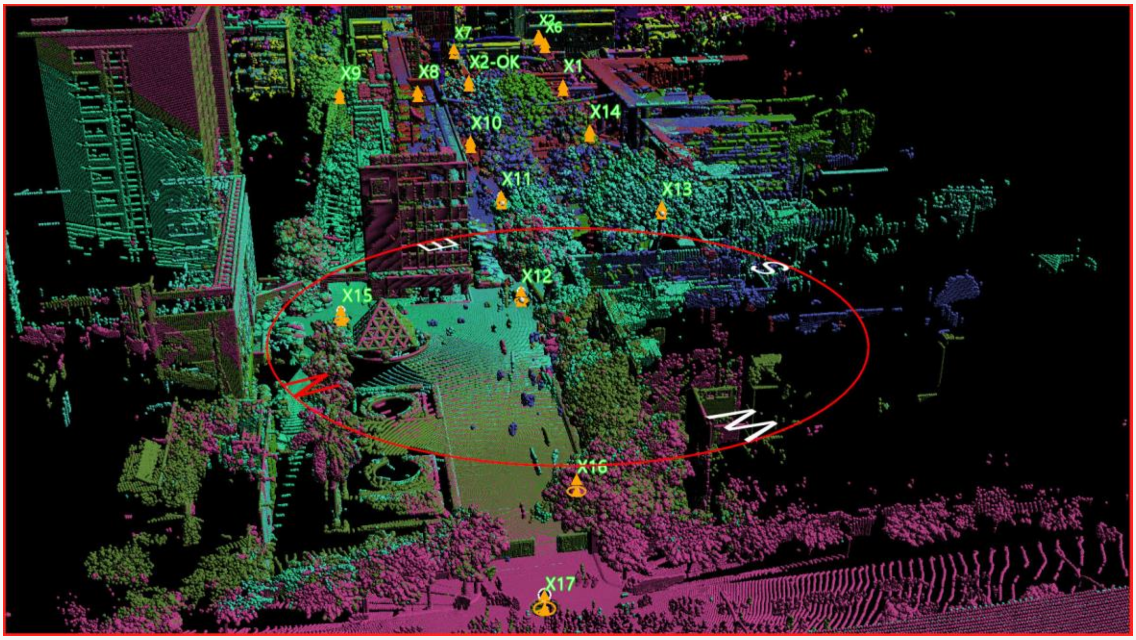


Figure 3: Points cloud data of TLS after processing

The basic data processing steps include identifying the shape of scanning elements, determining colors from captured images, creating panoramic images (stitch panoramas), and filtering and smoothing the resulting model. After completing the data processing step, the point cloud data is used to edit and create 3D current state models. The processed TLS point cloud data is depicted in Figure 3.

While TLS data provides highly detailed simulation results for various objects, it has some limitations. These include a large amount of redundant data (e.g., people, vehicles, road surfaces) that needs to be refined and removed, the inability to capture data on the roof sections of buildings, and the large size of point cloud data, which can affect processing and storage. Therefore, terrestrial laser scanning devices are best suited for collecting data for individual objects in small spaces to construct highly detailed 3D models. For data collection using UAVs, the Phantom 4 Pro V2.0 drone was employed. The drone was flown at an altitude of 80m, providing a vertical coverage of 70% and a horizontal coverage of 80%. Additionally, 12 ground control points were set up. These parameters met the technical requirements for constructing a 1:500 scale topographic map [14]. The data obtained from the UAVs consisted of 412 photos, which were processed using Agisoft MetaShape software. The processing results included point cloud data, orthoimages, and a digital elevation model (DEM), as shown in Figure 4. The orthophoto data and DEM, combined with additional ground measurements, were used to create a topographic map at a 1:500 scale. The topographic map data in AutoCAD format served as an attribute type managed in the experimental region's database.

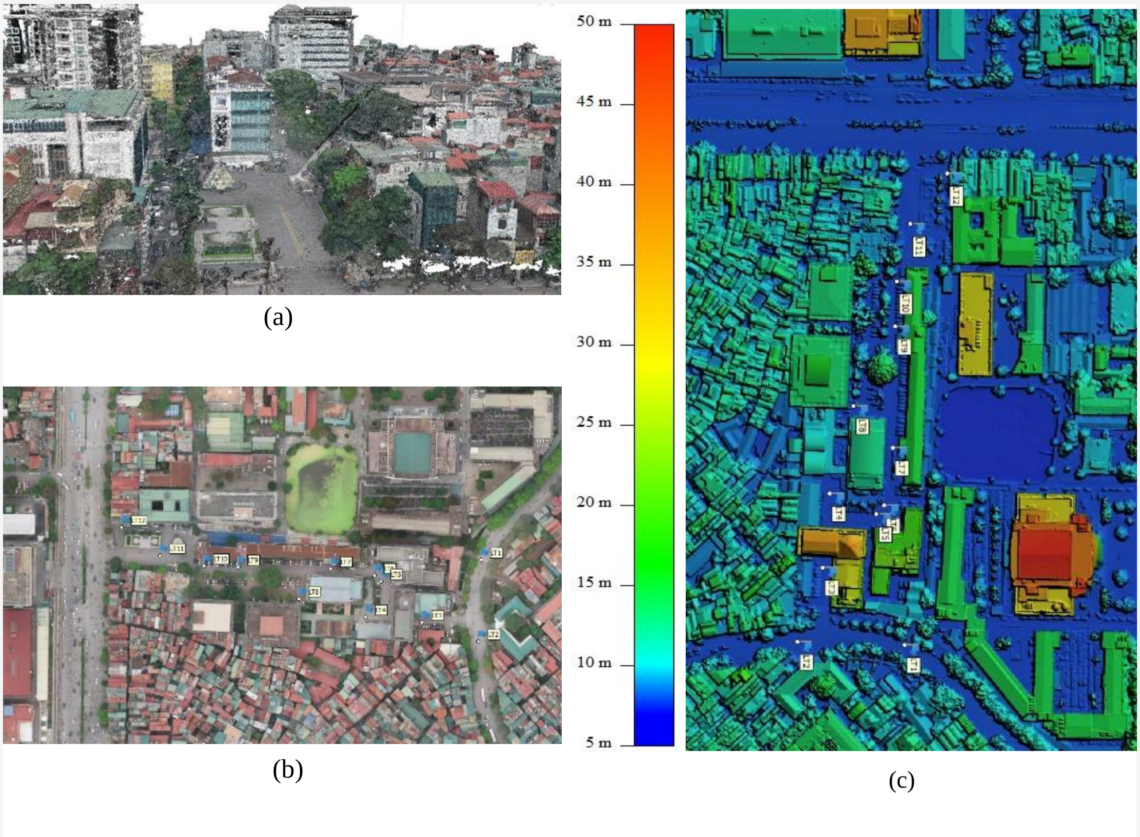


Figure 4: (a) UAV derived points cloud (b) UAV derived orthoimage and (c) UAV derived digital elevation model

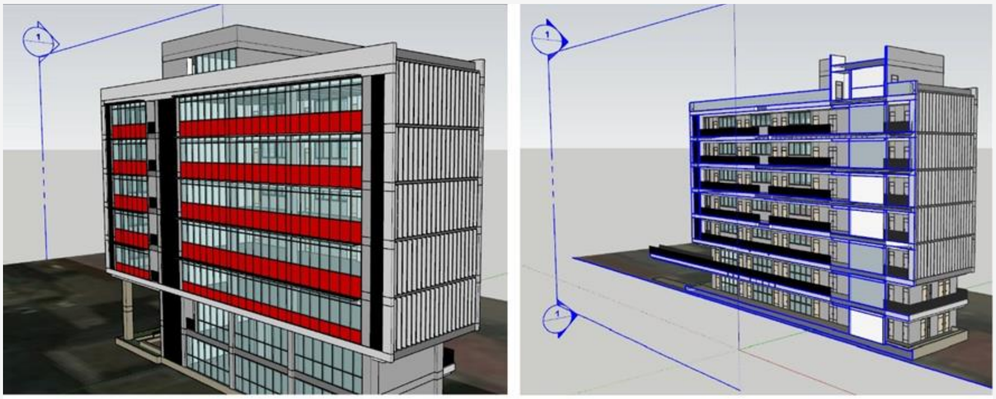
Points cloud data is one of the most crucial products obtained from TLS and UAV surveys, serving as a fundamental data source for building 3D models. While a combination of TLS and UAV point cloud data has been widely researched in Vietnam [7] and [15], processing such big data still poses challenges. Considering the data characteristics of each method, it is recommended to utilize only UAV data to create 3D models of the entire area or individual structures at a detailed level of LoD3. Terrestrial laser scanning data, on the other hand, should be used to create 3D models at the as-built stage of the project with a detailed level of LoD4, which involves capturing individual objects within the structures. In this research, only UAV point cloud data was used to construct a 3D model for the entire current experimental area.

2.1.2 Design data collection

The design data for the H3 lecture hall (shown in Figure 5(a) was obtained from the design unit in a 3D model format. The data was created using SketchUp software with a level of detail close to LoD4 [7]. It includes structural information layers until each classroom inside the building. Figure 5(b) showcases a detailed view of the interior corridors in LoD4 of the H3 building. To process the design data, it was necessary to align it with the correct spatial coordinate system used in the survey data. The Geo-location function in SketchUp was utilized to move and rotate the 3D model to the correct position, followed by exporting it to the *.kmz format for Google Earth File. After importing this design data into ArcGIS, it became a parameter of the database for management.

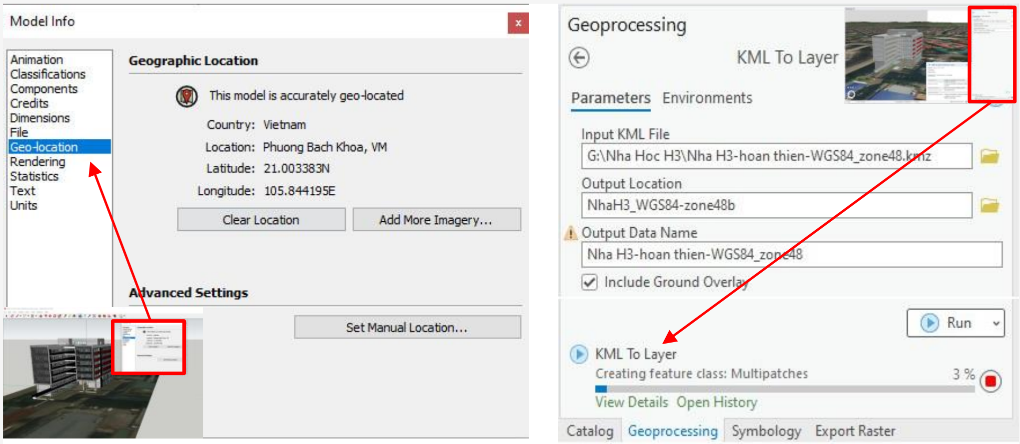
2.2 Web Manage and Share Data

Web maps are recognized as effective tools for data sharing due to their user-friendly nature and support for various data types. Building a web map involves two stages: standardizing spatial data suitable for the web environment requirements and determining how the data will be shared. The standardization of spatial data for the web environment depends on factors such as input data format, processing algorithms, and display of geospatial data.



(a) (b)

Figure 5: (a) Design data of lecture hall H3 in LoD3 and (b) The interior corridors in LoD4



(a) (b)

Figure 6: Data standardization processing of 3D design model (a) Geo-location of .SKP files and (b) Conversion of .KMZ files to Multipatches format

In this research, ArcGIS Pro was utilized for data standardization, editing, and formatting, including attributes and 2D/3D models. Data sharing can be done through a third-party service provider or by developing a private server-based system for web services and data resources. In this study, data sharing was facilitated through the ArcGIS Online platform and third-party links.

2.2.1 Data standardization

With the survey and design data processed into 2D and 3D formats, a database was created using ArcGIS Pro software. Geospatial data was standardized as shapefiles, including points, lines, polygons, and multipatches. Attribute data was edited as tables and hyperlinks in the popups. The standardized data encompassed survey maps (in 2D format), survey reports (in text format), panoramic images (in media format), and object characteristics and properties of 3D geospatial data. The 3D data layer comprises both the current state model and the design model. As the current 3D model did not separate the details into individual building objects, this geospatial data was only linked to attribute data fields such as survey reports and a topographic map in AutoCAD format. To create attribute data for each building object and transportation in the experimental area, a spatial points layer was created. An example of data standardization for a 3D design model is illustrated in Figure 6. The geolocation process using SketchUp Pro 2020 is shown in Figure 6(a), which involves converting SketchUp formart (*.SKP) to GoogleEarth format (.KMZ) and georeferencing them within a geographic coordinate system.

Subsequently, the resulting .KMZ data was transformed into Multipatches format within the ArcGIS Pro environment, as demonstrated in Figure 6(b). This standardization process is essential for preparing 3D model data layers that can be readily shared on web maps.

2.2.2 Data sharing

Data sharing and display on web maps can be achieved through either a service provider's web platform or by developing a separate hardware and software web system. In this study, after normalizing the experimental data, data sharing in the form of web maps was carried out using Esri Vietnam's server system, as shown in Figure 7.

The process of sharing web map data involves checking and correcting the structural information of the data format and the spatial coordinate system. The web map theme is designed using pre-made or custom templates provided by Esri's ArcGIS Online application. This application offers various tools for measuring, searching, analyzing, and extracting geospatial and attribute data. However, it has limitations, such as not supporting the sharing of orthoimage data in *.tiff format and not being an open-source environment for developing tools to address specific specialized problems. Moreover, sharing data on web maps through service providers like Esri is currently available only as a 21-day trial. For extended access, transitioning to the paid version is an option. To maintain access for a longer duration, one may consider switching to the paid version. Alternatively, building a server system for managing and sharing data on a web map throughout the project's lifecycle would require investment in hardware (server) and software (website). However, for construction projects with geospatial data characteristics that describe a small area (such as a high-rise building) and require a high level of detail (structures, documents, property equipment, etc., in each room), developing an in-house server system offers the advantage of synchronized management and usage. This approach aligns with the effective trend in the field of BIM during the operation of works.

3. Results and Discussion

The created web map provides users with convenient access to geospatial data anytime, anywhere. Users can utilize basic surveying functions on the web map, similar to conventional 2D maps. Figure 8(a) demonstrates the measurement tool for area and perimeter, while Figure 8(b) showcases the attribute table of the H2 lecture hall. The inclusion of a 3D model on the web map enables users to visualize simulated images of the current state of the space. Figure 9(a) illustrates a panoramic image of the current state of the Hanoi University of Civil Engineering campus, with associated attribute data such as survey reports and 2D maps linked in the popup table. This data provides designers with comprehensive topographic survey documents.

Additionally, the 3D model data assists designers in reducing the need to visit the field for design corrections or adjustments. The web map tools also aid designers in obtaining a rough understanding of the current topographic profile, as shown in Figure 9(b).

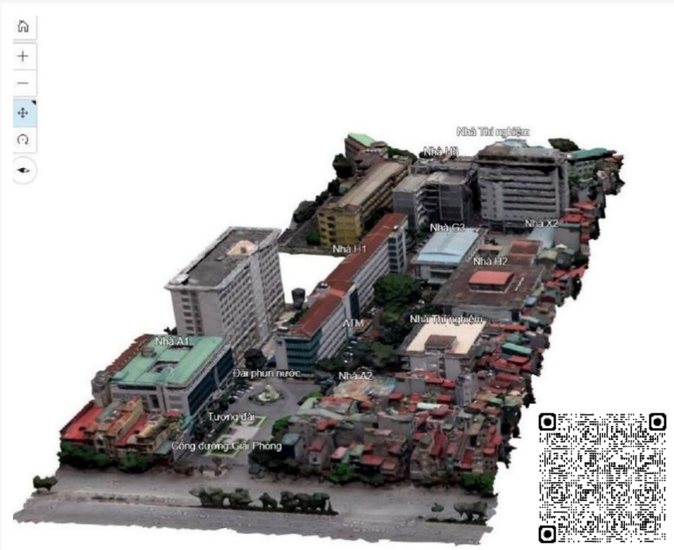


Figure 7: Web map of Hanoi University of Civil Engineering campus (access the web map by scanning the QR code or by URL link at *https://shorturl.at/zBPQX*

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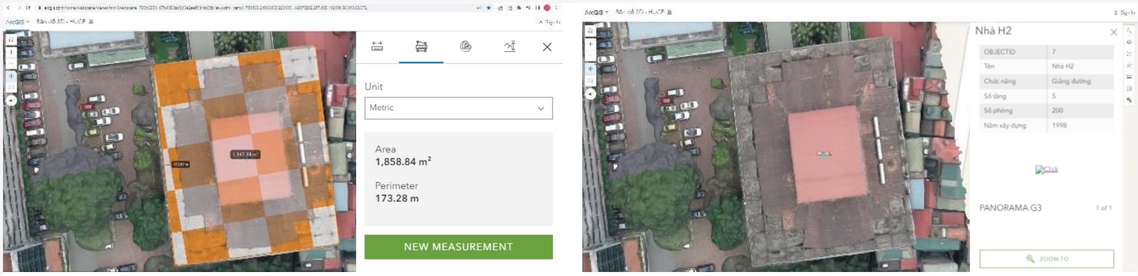
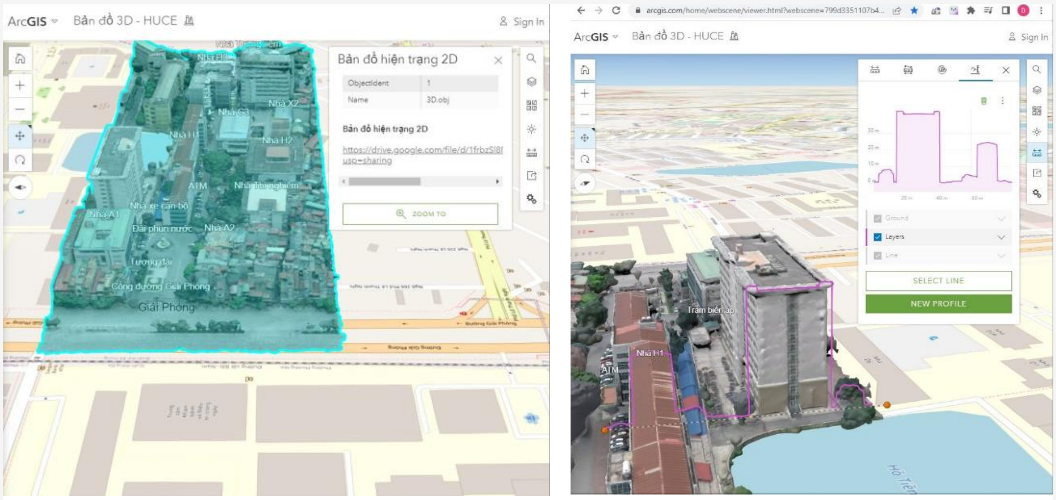


(a) (b)

Figure 8: (a) Measurement tool for area and perimeter and (b) attribute table of the H2 lecture hall



(a) (b)

Figure 9: (a) 3D current model with attribute table and (b) an example with the topographic profile described tool

These advantages highlight the superiority of web maps over traditional 2D drawings. Figure 10 is a floor map of the H3 lecture hall obtained using the "Slide Objects" tool of the web map. This map allows users to easily observe the internal details of the floor, including classrooms, corridors, elevators, and more. The information provided in this figure is beneficial for management, operation, and maintenance purposes.

At a detailed level, the design 3D model (or as-built 3D model) on the web map enables the tracking of spatial information and properties for each structural detail. Figure 11 showcases the tool for viewing and measuring the details inside the H3 lecture hall. This functionality allows for the examination of building geospatial and attribute data at LoD4 for the as-built stage, despite its large size. The as-built datasets stored in this manner can serve as a valuable database for future repair, renovation, and restoration work. This web map effectively manages and shares data of the Hanoi University of Civil Engineering campus at both the project-wide level and the detailed level of individual objects. However, there are some challenges that still need to be addressed, such as the collection and processing of geospatial data and attributes for each detailed object within the building at LoD4. Spatial coordinate discrepancies between shared data and the web basemap (e.g., Google Maps) also require attention. It is essential to resolve the relationship between VN-2000 national coordinates (used in survey, design, and construction data) and WGS 84 coordinates (used for data displayed on the web map).

Furthermore, there is a need to develop additional tools to address specific professional problems in the context of using web maps for data sharing, management, and analysis in various fields such as land, environment, and traffic.TLS, UAV, and SketchUp can be employed to create 3D models of fully constructed buildings. However, when it comes to evaluating construction progress during the construction stage, BIM emerges as the more suitable approach.

Figure 10: Interior details of the H3 lecture hal

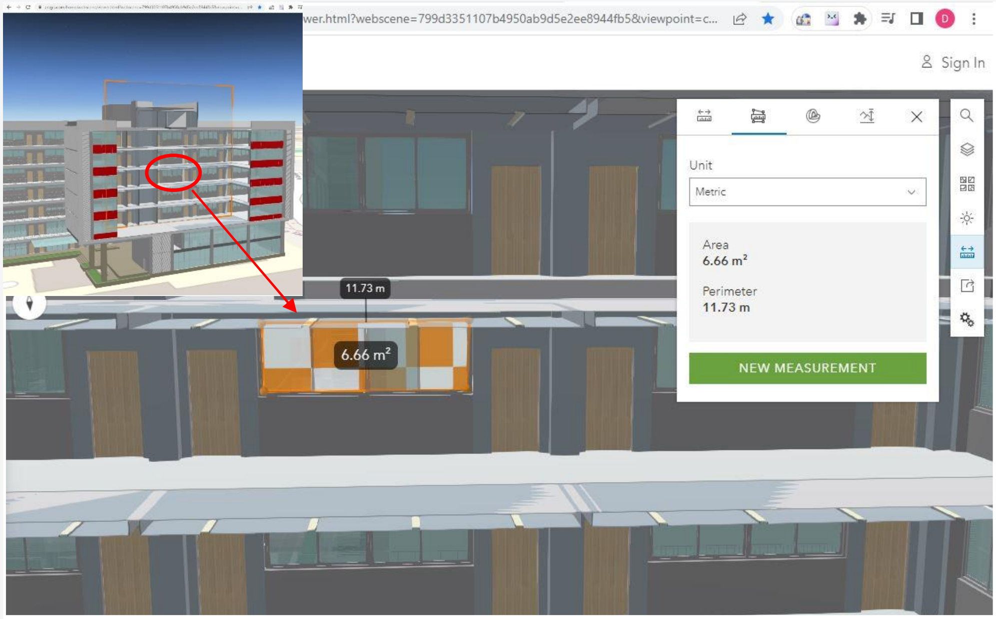


Figure 11: Tools for viewing and measuring inside detail of the H3 lecture hall

In terms of visualizing buildings in 3D, if an AutoCAD file is available, creating a 3D model in SketchUp is a cost-effective and user-friendly option compared to the other techniques. However, considering the inconsistent management or lack of data for construction projects in Vietnam, often due to contractors not storing or only sharing hard copies, the integration of TLS and UAV becomes more appropriate. This integration is suitable for construction projects that have been put into operation without AutoCAD files, which is a common occurrence in our country. The study has successfully developed a web map basing on ArcGIS platform for Hanoi University of Civil Engineering, offering user-friendly features, 3D visualization, and comprehensive data integration. It enables convenient access to geospatial data, aiding in data management and sharing. The web map enhances the visualization of the campus, reduces the need for frequent field visits, and provides valuable data for designers, management, and maintenance.

4. Conclusions

This study has demonstrated the application of GIS and geospatial measurement technologies in construction data management, with a specific focus on the case study of Hanoi University of Civil Engineering in Vietnam. For Vietnam, one of the significant advantages of employing UAVs and TLSs in construction data collection is the ability to generate detailed and accurate spatial data. Studies have shown that these technologies can produce high-resolution orthoimages, point clouds, and digital elevation models, which are essential for creating large-scale 2D topographic maps. Furthermore, they facilitate the construction of 3D simulation models, allowing for a comprehensive visualization of the project's current status. The integration of TLSs and UAVs provides even more detailed and accurate data sources, enabling the capture of individual objects within structures and supporting designers and managers in visually reviewing 3D simulation models. The application of GIS and geospatial measurement technologies brings significant advantages to the construction industry. These technologies enable the collection of large-scale, detailed, and accurate data, leading to improved project planning, design, and construction management. The integration of UAVs and TLSs enhances the country's capabilities in data acquisition and processing, supporting the development of sophisticated 2D and 3D models.

The application of GIS and geospatial measurement technologies in construction data management in Vietnam, as demonstrated through the case study of Hanoi University of Civil Engineering, offers numerous advantages. These include improved data acquisition, visualization, and sharing, enhanced project planning and design, and increased collaboration among project stakeholders. The implementation of these technologies paves the way for the transformation of Vietnam's construction industry, supporting its growth and contributing to the country's overall development goals.The study underscores the effectiveness of web maps for construction-related data management and sharing, with the potential to benefit academic and operational contexts at Hanoi University of Civil Engineering.

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