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# AN INTEGRATED BIM–GIS METHODOLOGY FOR AS-BUILT INFRASTRUCTURE MODELING AND ANALYSIS: A CASE STUDY

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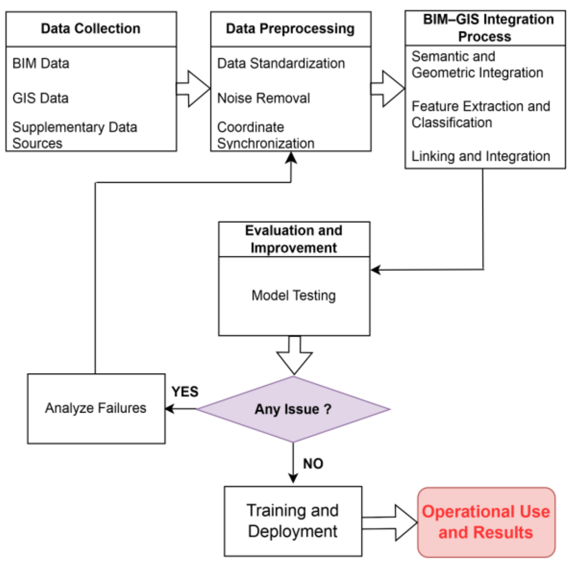
**Graphical abstract**




**Abstract**

Integrating Building Information Modeling (BIM) and Geographic Information Systems (GIS) remain challenging due to differences in data schemas, coordinate systems and semantic representation. This paper proposes and validates a VN-tailored BIM–GIS workflow for as-built infrastructure modeling that (i) standardizes data exchange using IFC and CityGML, (ii) harmonizes spatial data to the VN-2000 coordinate system, and (iii) automates semantic mapping via FME middleware. The workflow fuses multi-sensor acquisitions (UAV–LiDAR, terrestrial laser scanning — TLS, handheld SLAM, GNSS-RTK and GPR) to produce a high-fidelity digital twin of the University of Transport and Communications (UTC) campus (Hanoi). Geometric validation comprised two stages: point-cloud vs CAD (64.3% of points within ±0.10 m; 86.5% within ±0.30 m) and BIM vs point-cloud (91.4% of points within ±0.05 m), confirming centimeter-level alignment for most elements. The integrated model, deployed in ArcGIS Pro, enables asset tracking, space-use queries and risk analyses (e.g., flood susceptibility), demonstrating operational utility for facility and infrastructure management. The study contributes a practical, policy-relevant pipeline that preserves semantic and geometric fidelity for national-scale applications and outlines directions for automation, semantic interoperability and IoT-enabled digital twins.

*Keywords*: Building Information Modeling (BIM); Geographic Information System (GIS); IFC; CityGML; Infrastructure Management



## 1.0 INTRODUCTION

Building Information Modeling (BIM) and Geographic Information Systems (GIS) were originally developed to meet distinct professional needs: BIM focuses on the detailed geometric modeling of buildings, while GIS analyzes spatial contexts and relationships of existing objects [1]. Individually, both systems have demonstrated substantial capabilities for infrastructure projects: GIS excels in large-scale spatial analysis, such as land-use planning, transport network analysis [2] and flood risk assessment [3], whereas BIM enables precision design, clash detection and lifecycle management of building elements [4].

However, their separate use limits potential benefits; BIM lacks the city-scale context of GIS, and GIS cannot easily convey BIM's object-level detail. This complementarity motivates integrated BIM–GIS workflows. BIM–GIS integration is defined as the process of harmonizing object-level parametric BIM data (Industry Foundation Classes - IFC) with georeferenced multi-scale GIS models (City Geography Markup Language - CityGML), including coordinate transformation, semantic mapping, and bidirectional linkage between datasets [5].

Recent advances have improved both conceptual and operational aspects of BIM–GIS integration: semantic mapping methods, IFC→CityGML conversion tools, and multi-sensor scan-to-BIM pipelines that fuse Terrestrial Laser Scanning (TLS), Unmanned Aerial Vehicle – Light Detection and Ranging (UAV–LiDAR), and mobile/SLAM data. Table 1 summarizes representative studies, comparing objectives, data sources, semantic strategies, validation levels and limitations. While these works advance the state of the art, particularly in semantic formalisms and sensor fusion, they reveal persistent gaps: limited handling of national coordinate systems for VN-scale projects, few end-to-end pipelines that combine SLAM + TLS + UAV-LiDAR within an IFC→CityGML workflow, and scarce per-object validation tied to operational asset-management use cases (see Table 1).

The recent literature (2021–2024) demonstrates clear progress on two fronts: (1) semantic methods for IFC→CityGML translation [6-8], and (2) multi-sensor Scan-to-BIM pipelines that fuse TLS, UAV-LiDAR and mobile/SLAM data for as-built reconstruction [9-10]. However, gaps remain in operationalizing these advances for national-scale projects: few studies explicitly handle national coordinate-system harmonization (e.g., VN-2000), and there are limited works that combine SLAM + TLS + UAV-LiDAR within a validated IFC→CityGML pipeline aligned with local policy contexts. Our study addresses these gaps by (i) harmonizing multi-sensor data to VN-2000, (ii) implementing an FME-based semantic mapping pipeline tailored to Vietnamese datasets, and (iii) conducting per-object visual validation of the as-built BIM model to demonstrate practical readiness for GIS-based infrastructure management.

Interoperability challenges remain central: IFC and CityGML differ in purpose, schema and level of detail, causing semantic mismatch, geometry transfer issues and potential loss of attributes during conversion. The author adopts an operational definition of interoperability as the successful preservation of geometry and semantic attributes (e.g., material, level) through round-trip conversion and validation metrics [11]. Prior approaches, ranging from semantic-web enrichment and ontology mapping to middleware pipelines (e.g., Feature manipulation engine - FME)—address parts of the problem but often require manual intervention or lack scalability for large-scale infrastructure applications.

While numerous studies have sought to address these challenges, gaps remain in existing research. Initial efforts, such as web-based visualization platforms, primarily focused on integrating BIM and GIS for viewing and querying models without addressing deeper data-level interoperability. Attempts to resolve this include semantic web approaches, custom georeferencing algorithms, and data schema alignment frameworks [12-13]. More advanced techniques, including semantic web integration and tools like the Unified Building Model (UBM), have improved data exchange processes. However, these methods often require significant manual effort, rely on proprietary tools, or suffer from scalability issues when applied to large-scale urban or infrastructure projects [14-16].

Additionally, existing conceptual frameworks have primarily targeted specific applications, such as energy assessments or land-use planning, without exploring comprehensive solutions applicable to diverse infrastructure contexts [17-19]. The lack of standardized workflows and automation in BIM-GIS integration further limits their practical adoption, particularly in regions like Vietnam, where infrastructure development projects face unique challenges in urbanization and resource constraints, high-density environments, and data fragmentation [20].

To clarify the novelty and contributions of this research, the specific gap addressed is summarized as follows: although numerous studies have explored BIM–GIS integration, most either propose conceptual frameworks or focus on unidirectional conversions that compromise semantic integrity and geometric fidelity.

This study responds to those gaps by proposing and validating a VN-tailored, operational BIM–GIS workflow for as-built infrastructure projects. Specifically, the work makes three main contributions: (1) a bespoke semantic mapping and ontology framework adapted to Vietnam's VN-2000 geodetic context to preserve semantic and geometric fidelity during IFC↔CityGML conversion; (2) a multi-sensor automated pipeline that integrates UAV-LiDAR, SLAM (handheld), and TLS (BLK360) datasets to produce a comprehensive as-built digital twin; and (3) a per-object geometric validation approach (walls, slabs, columns, doors, windows, stairs) that demonstrates the practical readiness of the integrated model for asset tracking and management. These contributions are demonstrated through a campus-scale case study at the University of Transport and Communications (UTC) in Hanoi and benchmarked against the recent literature summarized in Table 1.

**Table 1**. Comparative review of recent BIM–GIS approaches

| No | Primary objective / contribution | Data sources / sensors | Semantic approach / tools | Validation (level) | Strengths | Limitations |
|---|---|---|---|---|---|---|
| [6] | Proposes semantic-graph approach to integrate IFC and CityGML for advanced 3D city/digital-twin visualization. | IFC models, sensor feeds, city models (CityGML) | IFC→CityGML mapping using FME; semantic graph (OWL/RDF) for enrichment. | Case study visual validation; discussion of LOD4 CityGML conversion. | Strong semantic model; focuses on digital-twin visualization and semantic enrichment. | Emphasis on conceptual semantic graph; limited per-object geometric validation. |
| [7] | Presents IFC→CityGML conversion algorithm based on geometry and semantics. | IFC models | Algorithmic conversion; attention to geometry/semantic mapping. | Prototype tests; LOD2 outputs reported. | Solid algorithmic basis for conversion; addresses geometry semantics. | Prototype stage; scalability and full semantic coverage limited. |
| [8] | Proposes CityGML extensions to preserve IFC information when converting. | IFC, CityGML | Schema extension (CityGML ADE) for carrying IFC semantics. | Prototype and examples. | Addresses loss of IFC semantics in CityGML conversion. | Requires standard adoption; implementation overhead. |
| [9] | Demonstrates multi-sensor integration (TLS, UAV-LiDAR, smartphone LiDAR) into BIM workflows and assesses outcomes. | TLS, UAV-LiDAR, Smartphone LiDAR | Point-cloud fusion → ReCap / Revit for BIM; processing with CloudCompare. | Quantitative accuracy analysis for case studies. | Empirical multi-sensor integration; provides accuracy assessment. | Case limited to buildings; semantic GIS export not primary focus. |
| [10] | Comprehensive review of scan-to-BIM methods, sensors and processing steps. | TLS, UAV LiDAR, photogrammetry, MMS | Reviews techniques (registration, segmentation, modeling) and tools. | Literature synthesis; summarizes accuracy ranges. | Useful survey of scan-to-BIM best practices and typical accuracies. | Review — no new workflow; highlights gaps in automation and semantics. |

Beyond the technical workflow, the proposed approach emphasizes operational feasibility and policy relevance: it aligns with Vietnam's national BIM roadmap and digital-transformation initiatives, ensuring the method can scale from campus to municipal applications. By bridging BIM and GIS with automated semantic mapping and rigorous validation, the study offers a replicable framework for improved planning, risk assessment and lifecycle management of infrastructure under Vietnamese conditions.

## 2.0 METHODOLOGY

This section presents the proposed BIM–GIS integration methodology. Figure 1 summarizes the overall framework.

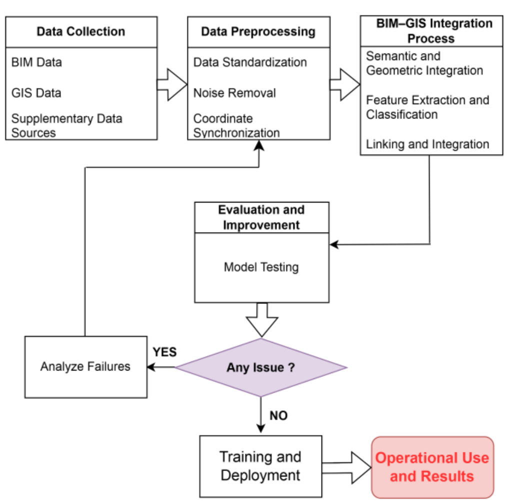



**Figure 1** The proposed BIM–GIS integration model for as-built infrastructure projects. The "Any Issue?" checkpoint denotes a validation step for detecting geometric, semantic, or coordinate inconsistencies before proceeding to integration

Figure 2 illustrates steps of BIM–GIS integration process (such as semantic and geometric integration; feature extraction and classification; linking and integration).

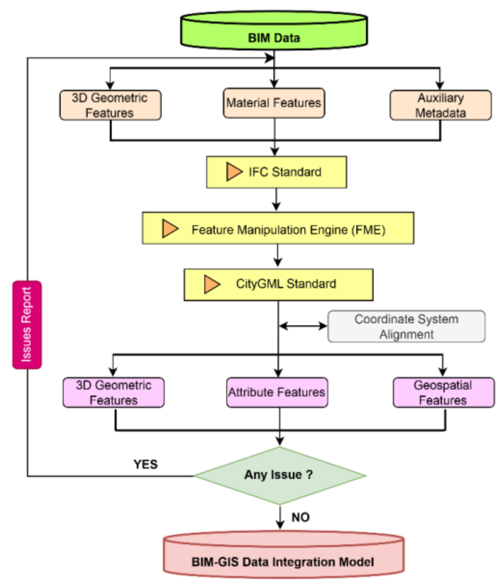



**Figure 2:** The proposed BIM-to-GIS data Integration and conversion process

## 3.0 A CASE STUDY

### 3.1 Study Area

The UTC campus, covering approximately 21.7 hectares in Dong Da District, Hanoi, was selected as the pilot site for validating the proposed workflow (Figure 3). The site comprises academic buildings (A1–A10), road networks, underground utilities, and open spaces.

The UTC campus was selected as the study area for three key reasons, including (1) the availability of extensive and high-quality datasets, including both spatial and attribute information; (2) the authorized access for UAV–LiDAR surveys, allowing for high-resolution 3D data acquisition; (3) its status as a self-contained urban microcosm, which simulates the full range of real-world infrastructure elements.

This combination of data richness, survey accessibility, and urban complexity makes UTC an ideal environment for validating the proposed BIM–GIS integration process. Moreover, conducting the case study under Vietnamese conditions is strategically significant, as Vietnam currently faces considerable barriers to BIM adoption, ranging from technical limitations to regulatory challenges [21]. As such, this study contributes not only to methodological advancement but also to practical discourse on digital transformation in infrastructure management within developing country contexts.

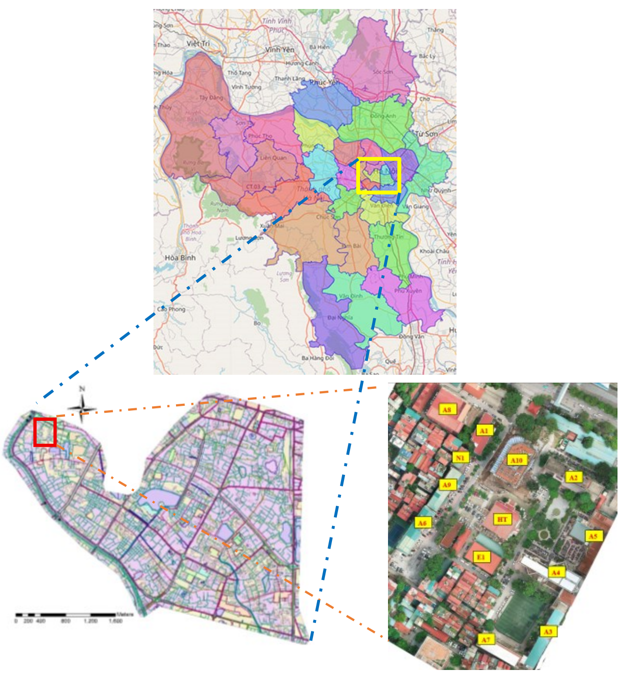


**Figure 3** The study area – main campus of the UTC, in Hanoi, Vietnam. The inset map shows the location of the UTC campus within Dong Da District in Hanoi, Vietnam

### 3.2 Data Collection

BIM data was obtained from design drawings and 3D models, including structural systems, dimensions, and materials, typically generated by authoring tools such as Revit or ArchiCAD, and containing both geometric and semantic information. GIS data comprised terrain, transport networks, land use zoning, and cadastral maps, sourced from national databases, planning agencies, and remote sensing [22]. To supplement these, high-precision field surveys using GNSS-RTK, UAV–LiDAR, terrestrial and handheld 3D scanners, and total stations provided accurate topographic and structural data, enhancing the completeness and detail of the integrated BIM–GIS model [23–24].

#### *3.2.1 Existing Data Collection*

Initial data included topographic and cadastral maps, building plans, and infrastructure system layouts (roads, cables, electricity, water, drainage). However, much of this information was outdated or incomplete, so most datasets were re-measured to ensure accuracy for subsequent modelling.

#### *3.2.2 Supplemental Data Collection*

High-resolution data were obtained using UAVs, handheld SLAM scanners, Leica BLK360, and total stations. A geodetic reference network was established at the UTC campus in the VN-2000 national coordinate system (3° projection, 105° meridian) to ensure alignment across all surveys. The BLK360 scanner captured building interiors, while the handheld SLAM device (CHC RS10) recorded exteriors and ground features. UAV-based photogrammetry and LiDAR (Matrice 350 RTK with Zenmuse L2) complemented ground data, covering rooftops and vertical structures. This multi-sensor integration provided full campus coverage at a 1:500 mapping standard. Device specifications are summarized in Table 2.

**Table 2**. Technical Specifications of Surveying Equipment Used in the Study

| Device/System | Parameter | Specification |
|---|---|---|
| Leica BLK360 | Scanning speed<br>Level of detail<br>IP protection rating<br>Operating temperature<br>Scanning range<br>3D data quality<br>Station registration<br>Processing software | 680,000 points/second<br>Medium (4 mm at 10 m)<br>IP54<br>0°C to +40°C<br>Short (up to 45 m)<br>Good<br>Automatic registration with VIS<br>Cyclone Register 360 Plus |
| CHC RS10 (SLAM Scanner) | Absolute Accuracy (Horizontal/Vertical)<br>Relative Accuracy<br>Laser Scanner Accuracy<br>Point Cloud Density<br>Scan Rate<br>GNSS RTK Accuracy (H/V)<br>GNSS Initialization Time<br>GNSS Reliability<br>Camera Resolution | < 5 cm RMS<br>< 1 cm<br>Level 1, 16 channels<br>2 cm<br>10 Hz (up to 320,000 pts/sec)<br>8 mm + 1 ppm / 15 mm + 1 ppm<br>< 10 s<br>> 99.9%<br>15 MP (5 MP × 3) |
| Matrice 350 RTK (UAV) | Flight Altitude<br>Max Horizontal Speed<br>GNSS RTK Accuracy (H/V) | 80 m<br>23 m/s<br>1 cm + 1 ppm / 1.5 cm + 1 ppm |
| Zenmuse L2 (LiDAR Sensor) | Horizontal Accuracy<br>Vertical Accuracy<br>Output Products | 5 cm at 150 m at 15 m/s<br>4 cm at 150 m at 15 m/s<br>Point clouds, orthophotos, Digital Elevation Models (DEM) |

### 3.3 Data Preprocessing

Preprocessing ensured interoperability through format standardization, noise filtering, and coordinating harmonization. BIM data were standardized in IFC, while GIS data were converted into CityGML, enabling semantic consistency across platforms [25–26]. Noise removal addressed overlapping geometries and misclassified features in BIM, as well as topological or attribute errors in GIS, using tools such as FME or ArcGIS Data Reviewer [27–29]. Finally, all datasets were transformed to Vietnam's VN-2000 national coordinate system to resolve misalignments and guarantee spatial compatibility [30].

In this study, the author used Revit software (version 2022), with its advanced features suitable for simulating buildings on the campus. The remaining infrastructure, including road systems, surface drainage, groundwater systems, green areas, and lighting systems, etc. were processed using AutoCAD Civil 3D software (version 2022).

#### *3.3.1 Data Cleaning and Quality Control*

Collected datasets were initially checked for errors, such as duplicate geometries, misaligned boundaries, missing attribute values, and noise and drift in point clouds.

Point cloud datasets from BLK360, SLAM, and UAV-LiDAR were denoised using CloudCompare software and Leica Cyclone Register 360, applying statistical outlier removal and surface smoothing. Building footprints were corrected in AutoCAD Civil 3D, and topological relationships in GIS layers were fixed in ArcGIS Pro (version 3.3) using geoprocessing tools such as Topology Checker and Repair Geometry.

The Leica Cyclone Register 360 software was used to filter noise from the indoor data collected by the BLK360 device. Figures 4 and 5 show the data before and after the filtering noise.

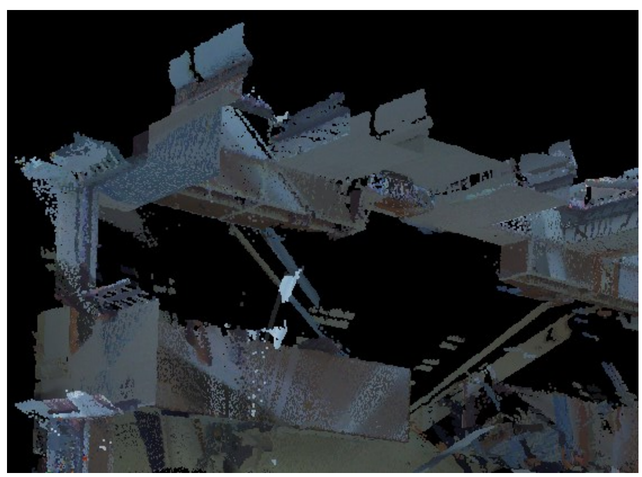


**Figure 4** Data before noise filtering

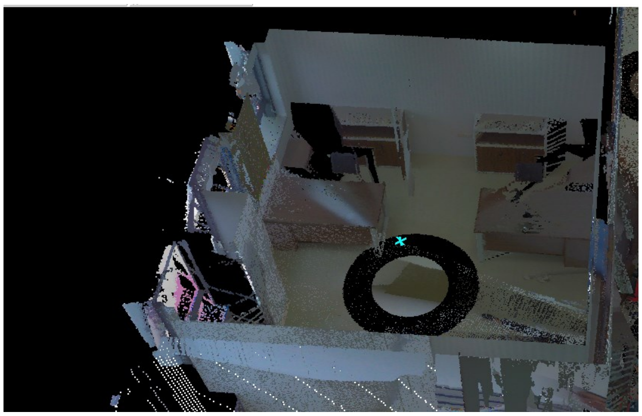


**Figure 5** Data after noise filtering

Using CloudCompare software, the CHC RS10 SLAM data was post-processed to combine the scanned data and eliminate extraneous components. Identifying the shape of scanned components, identifying colors from captured images, producing panoramic images, and smoothing the resultant data were among the fundamental data processing steps. Following the completion of this stage, 3D as-built models were refined using the point cloud data. Figure 6 displays the final processed point cloud data, which offers a thorough overview of the survey area.

**Figure 6** Slam CHC RS10 device's Points Cloud data following processing

In addition, UAV-based photogrammetry and LiDAR scanning were conducted using the Matrice 350 RTK equipped with the Zenmuse L2 sensor, offering comprehensive vertical and horizontal geospatial coverage. The Zenmuse L2 system exhibited a horizontal accuracy of 5 cm and vertical accuracy of 4 cm at a flight height of 150 meters and speed of 15 m/s.

Post-processing through DJI Terra generated a full suite of geospatial products, including:

- Georeferenced point cloud data (.las format)
- High-resolution orthophotos
- A detailed Digital Elevation Model (DEM)

These products were evaluated and validated alongside ground data, providing highly accurate baselines for topographic and structural modeling. Figure 7 presents the final UAV–LiDAR results, which contributed significantly to the completeness of the integrated dataset.

**Figure 7** UAV images processed using the Matrice 350 RTK device

### 3.3.2 Format Conversion and Standardization

To support cross-platform integration, BIM and GIS data were standardized as follows:

- BIM models were exported from Revit and AutoCAD Civil 3D in IFC 4 format.
- Point clouds were converted to .las/.e57 formats for compatibility with meshing software.
- GIS data were stored in CityGML and GeoPackage formats to support semantic 3D city modeling and efficient geospatial data handling.

This standardization ensured compatibility with FME pipelines and supported semantic mapping to the unified schema.

### 3.3.3 Coordinate Harmonization

All spatial data were transformed to the VN-2000 coordinate system, using the WGS84 ellipsoid, 3° UTM zone cantered at 105°E. Transformation parameters were applied using ArcGIS Pro to ensure precise spatial alignment of datasets originating from UAV, GNSS RTK, and legacy paper sources.

### 3.3.4 Feature Classification and Attribute Structuring

Geospatial features were categorized into:

- 3D Geometry: extracted from point clouds and converted to TIN/mesh surfaces. The point cloud was classified into the following classes: buildings, cars, ground, trees, and lighting systems.
- Attributes: including floor type, structural function, utility capacity, material strength.

-Attributes were stored in a GeoPackage file managed within ArcGIS Pro, linked via object IDs to BIM elements and geospatial features, forming the semantic core of the digital twin.

-Zoning and Utility Layers: roads, pipes, drainage, and electrical networks were vectorized and tagged with domain-specific identifiers.

## 3.4 BIM–GIS Integration Process

Following data standardization and spatial alignment, BIM and GIS are integrated to create semantically rich digital environments that combine detailed architectural information with broader spatial context, supporting planning, analysis, and lifecycle management.

### 3.4.1 Semantic and geometric integration

BIM employs object-oriented entities (e.g., walls, beams, HVAC), while GIS focuses on topological relationships (e.g., parcels, networks). Middleware platforms such as FME automate the conversion of IFC-based BIM data into GIS-compatible formats (CityGML, GML, Shapefiles) [31]. Ontologies like the UBM map BIM objects to geospatial features, ensuring bidirectional semantic consistency—for instance, converting an IFC "Slab" to a CityGML "FloorSurface" [32].

### 3.4.2 Feature extraction and classification

BIM data—including geometry, attributes, and metadata—are standardized in IFC and transformed into CityGML Levels of Detail. Features are classified into 3D geometry, attributes, and geospatial references, and aligned to the VN-2000 coordinate system for national compatibility [30,33].

### 3.4.3 Linking and validation

Converted BIM features are linked to GIS layers via IDs, extents, or topology, enabling integrated queries such as linking HVAC to zoning or overlaying structures with flood zones. A validation checkpoint ("Any Issue?") ensures data integrity and consistency before final integration. In this workflow, an *"issue"* refers to any detected inconsistency in geometry, coordinate alignment, or semantic mapping—for example, misplaced elements, missing attributes, duplicated features, or deviations exceeding tolerance thresholds. Such issues are automatically flagged during the conversion and overlay process in FME and ArcGIS Pro. When errors are identified, the affected datasets are redirected to the preprocessing stage for correction and revalidation, while validated models advance to integration. The final output is a unified digital twin combining geometry, semantics, and spatial attributes for applications such as urban simulation, infrastructure monitoring, and regulatory compliance [34].

### 3.4.4 Semantic Mapping Process and Workflow Efficiency

To achieve interoperability between BIM and GIS environments, a semantic mapping framework was established using the UBM ontology and extended IFC–CityGML schemas. The process was implemented in FME Workbench, which automated the translation of IFC-based BIM data into GIS-compatible formats such as CityGML while preserving both geometric and semantic attributes [35].

Table 3 summarizes the key object correspondences and attribute mappings used during the conversion process. This mapping ensured that architectural and infrastructure elements from the BIM model could be correctly represented within the GIS environment while maintaining consistent metadata and spatial relationships.

The conversion workflow followed three major steps:

- Schema interpretation and translation – IFC entities were parsed and mapped to corresponding CityGML classes using custom FME transformers.
- Attribute harmonization – object attributes (e.g., material, floor level, function) were standardized and embedded into GeoPackage feature tables.
- Coordinate alignment – all output datasets were georeferenced to the VN-2000 coordinate system, ensuring consistency with other spatial layers in ArcGIS Pro.

During the mapping process, several technical challenges were encountered:

- Semantic mismatch: Certain BIM elements, such as complex MEP components, lacked direct CityGML equivalents. These were generalized to broader infrastructure categories (e.g., tun:Pipe or bldg:Installation) to maintain logical consistency.
- Geometric complexity: Highly detailed or curved parametric surfaces occasionally failed during triangulation. This issue was mitigated by simplifying boundary representations (BRep) and applying tolerance-based meshing in FME.
- Vertical datum inconsistency: Minor height discrepancies (2–3 cm) were observed when integrating point clouds, BIM, and GIS data. These were corrected by applying VN-2000 height offsets and referencing ground control points.

Although the study did not include a quantitative benchmark of processing time, the adoption of an automated semantic mapping workflow substantially improved efficiency compared with traditional export–import methods. The FME-based approach minimized manual reformatting, reduced attribute loss, and ensured consistent validation across software platforms. The improved automation and semantic consistency contributed to smoother data integration and faster validation during the UTC campus case study implementation.

**Table 3** Example of Semantic Mapping between IFC and CityGML Entities

| BIM Object (IFC Class) | Description | Corresponding CityGML Feature | Key Attributes Mapped | Conversion Notes |
|---|---|---|---|---|
| IfcWallStandardCase | Vertical structural element | bldg:WallSurface | Material, height, thickness | Preserved geometry using BRep representation |
| IfcSlab | Floor or roof element | bldg:FloorSurface | Elevation, material, area | Adjusted for vertical offset in VN-2000 |
| IfcDoor | Opening component | bldg:Door | Width, height, type | Minor alignment corrections in FME |
| IfcWindow | Transparent opening | bldg:Window | Frame type, dimensions | Reflective surfaces simplified for stability |
| IfcPipeSegment | Utility infrastructure | tun:Pipe | Diameter, material, function | Linked to underground GIS layer via unique ID |
| IfcColumn | Load-bearing vertical member | bldg:Column | Material, cross-section | Simplified to centroid line for visualization |
| IfcSpace | Enclosed area or room | bldg:Room | Function, volume, occupancy | Used for spatial analysis in ArcGIS Pro |

## 3.5 Validation and Results

### *3.5.1 Geometric Accuracy Validation between Point Cloud and CAD Model*

Figure 8 presents a visual comparison used to assess geometric deviations between the as-built condition (captured using 3D laser scanning technology) and the design model (3D CAD), aiming to validate the geometric accuracy of the input data. The assessment was performed by calculating the perpendicular distance from each point in the point cloud to the corresponding surface of the 3D CAD model. The deviations are color-coded to enhance interpretability.

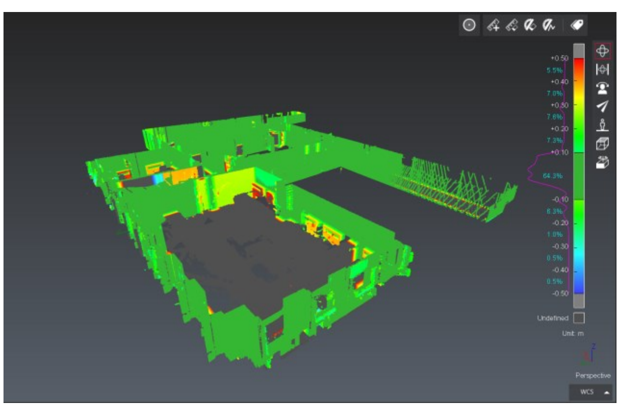


**Figure 8** Geometric Accuracy Assessment between Point Cloud and 3D CAD Model

Color Bar Explanation:

- Green: Very small deviation within the acceptable threshold (±0.1 m), indicating a high level of agreement between the point cloud and the CAD model → excellent construction accuracy.

- Yellow, Orange, Red: Positive deviations where point cloud data lies above the CAD model, implying that the constructed surface protrudes more than the design specification.

- Blue, Purple: Negative deviations where point cloud data lies below the CAD model, suggesting that the constructed elements are recessed or lower than the intended design.

- Dark Gray/Black: Undefined areas due to:

+ Missing scan data (e.g., occluded or shadowed regions).

+ Absence of corresponding CAD model surfaces.

+ Deviations exceed the visualization threshold.

Histogram on the Right:

- Displays the frequency distribution of deviation values.

- The peak centered near 0 m indicates that most points have minimal deviation, confirming strong alignment between the as-built scan and the CAD model.

- Quantitatively, 64.3% of points fall within ±0.10 m, 77.9% within ±0.20 m, and 86.5% within ±0.30 m. Only about 6.0% of points deviate beyond ±0.40 m.

- The distribution is slightly asymmetric: ~27.4% of deviations are positive (+0.1 → +0.5 m) while only ~8.3% are negative (−0.1 → −0.5 m), suggesting a small systematic offset between the datasets.

- Smaller peaks around ±0.2–0.3 m represents localized areas that may require closer inspection due to larger deviations.

Area-Based Interpretation:

- Walls and Doorways (green regions): Show excellent agreement between the point cloud and CAD model, indicating high construction precision.

- Central Floor Area (black regions): No point cloud data available — likely caused by occlusions, missed scans, or processing errors.

- Staircase Area on the Right (striped and color-shifting zones): Exhibits significant deviations — possibly due to scanning difficulties or actual construction discrepancies.

- Red-Hued Room Corner: Indicates a region of large deviation that warrants on-site verification.

The results confirm that the integrated model achieves an accuracy level sufficient for urban asset management, facility monitoring, and infrastructure planning, while also highlighting specific areas where further inspection or model adjustment is required.

This quantitative validation demonstrates the reliability of the BIM–GIS integration workflow for large-scale applications, providing engineers with a robust foundation for quality control and decision-making.

While the previous section validated the geometric consistency between the point cloud and the CAD design model, a further validation was carried out to assess the alignment accuracy between the as-built BIM model and the point-cloud data, as described below.

### 3.5.2 Validation of the As-Built BIM Model

To assess the geometric reliability of the proposed BIM–GIS integration workflow, a validation process was conducted to compare the as-built point cloud with the reconstructed BIM model of the UTC campus. The validation aims to verify the consistency between the actual survey data obtained from SLAM (RS10) and TLS (Leica BLK360) and the digital BIM representation developed in Autodesk Revit.

The validation was performed using Leica Cyclone 3DR software. The combined point-cloud dataset (merged from SLAM and TLS scans) was aligned with the BIM model exported in the VN-2000 coordinate system. A point-to-surface deviation analysis was then executed to visualize the difference between the measured surfaces and the designed BIM geometry. The tolerance threshold was set at ±1 cm, with the BIM model resolution defined at 5 cm, consistent with the scanning accuracy of the BLK360 device.

The validation focuses on the main BIM object categories visible in the survey area, including walls, columns, ceiling edges, door frames, and furniture.

The deviation results, shown in Figures 9, are expressed as a color-coded deviation map, where:

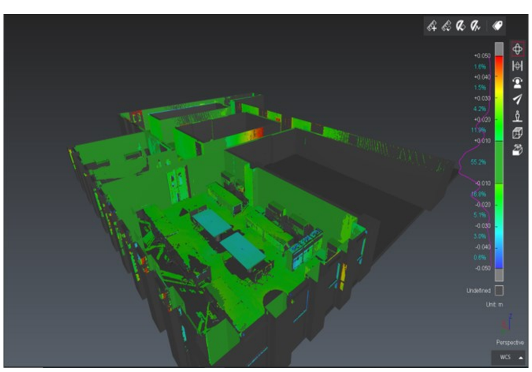


**Figure 9** Validation result between BIM model and point-cloud data in Leica Cyclone 3DR

Histogram on the Right:

- Displays the frequency distribution of elevation deviation values (in meters) between the scanned point cloud and the reference surface.
- The main peak centered near 0 m indicates that most points exhibit minimal deviation, showing strong alignment between the captured 3D data and the reference geometry.
- Quantitatively, approximately 55.2% of the points fall within the deviation range of ±0.01 m, 73.8% within ±0.03 m, and 91.4% within ±0.05 m, indicating that the majority of the scanned surfaces deviate by only a few centimeters.
- The distribution is slightly asymmetric, with a small bias toward positive deviations (red/yellow zones), suggesting a minor systematic offset—possibly due to scanner calibration or surface reflectivity effects.
- Small peaks near ±0.04–0.05 m represent local deviations that could correspond to surface irregularities or occlusion-induced errors.

Area-Based Interpretation:

- Walls and Furniture (green zones): Show very high correspondence to the reference surface, confirming accurate geometric reconstruction and consistent point density.
- Ceiling Edges and Door Frames (red/orange areas): Exhibit localized upward deviations approaching +0.05 m, likely caused by partial occlusion or multi-path laser reflections.
- Corners and Shadowed Regions (blue/cyan patches): Indicate downward deviations of up to −0.05 m, often associated with limited scan visibility or angular surfaces.
- Dark Gray Areas: Represent missing data or unscanned zones, possibly due to line-of-sight limitations during the scanning process.

The visual comparison demonstrates that the majority of BIM elements fit well with the as-built point cloud, confirming accurate registration and alignment. Slightly higher deviations are observed around doors, windows, and reflective surfaces, mainly due to temporary movement or laser reflection noise during the scanning process.

Overall, this validation confirms that the proposed BIM–GIS workflow achieves an acceptable level of geometric precision for infrastructure mapping and provides a reliable foundation for integrating as-built spatial data into GIS-based management systems.

### 3.5.3 Integrated BIM–GIS Modeling of Campus Infrastructure

The results show that Figures 10-14 illustrate the modeling and integration process of various infrastructure components at the UTC campus. Figure 10 shows the drainage system modeled using Autodesk Civil 3D, while Figure 11 illustrates the architectural and structural elements on the 11th floor of Building A10 and Figure 12 illustrates the as-built BIM model of Building A10 developed in Autodesk Revit. These individual models were combined to represent the broader infrastructure context of the UTC campus, as illustrated in Figure 13. The final integrated model was visualized and analyzed using ArcGIS Pro (Figure 14), providing a comprehensive spatial view of both above- and below-ground assets.

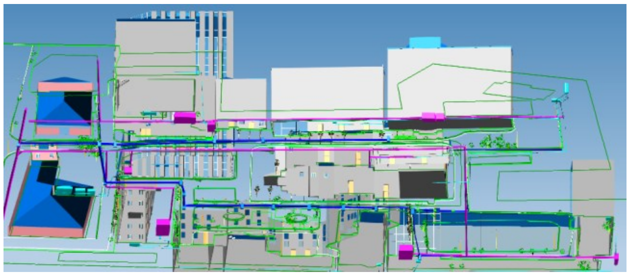


**Figure 10** The drainage system is modeled using Civil 3D software

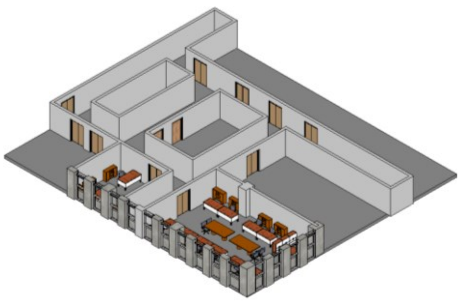


**Figure 11** The as-built BIM model on the 11th floor of Building A10

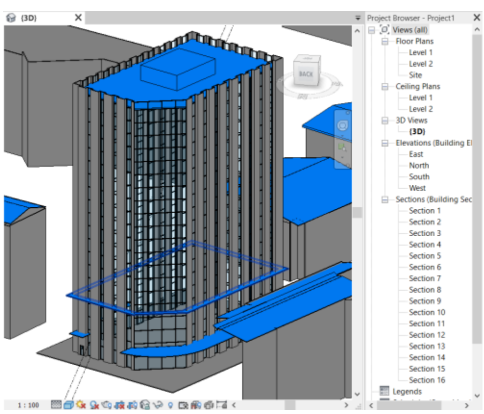



**Figure 12** The as-built BIM model of Building A10

For the UTC campus, a fully integrated GIS-based model was created to support data visualization, asset management, and decision-making. Figure 13 presents a comprehensive digital representation of the campus infrastructure, complete with detailed attribute data such as building condition, classroom functions, and facility inventories, accessible via interactive pop-up tables within ArcGIS Pro. This integration enables managers to monitor and update infrastructure conditions without frequent site visits and allows designers to synchronize modifications directly within the BIM environment, ensuring both accuracy and operational efficiency.

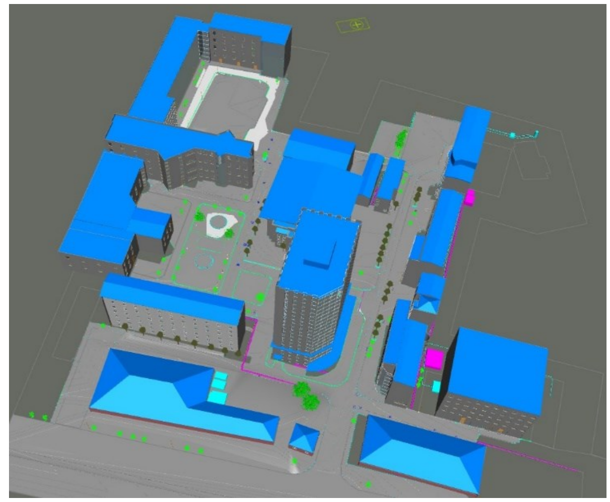


**Figure 13** The infrastructure of UTC campus after being modeled using Civil 3D and Revit software

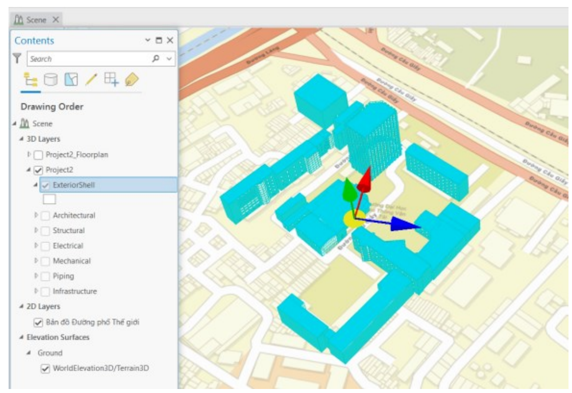



**Figure 14** The UTC campus is displayed by using ArcGIS Pro software

## 4.0 DISCUSSION AND IMPLICATIONS

The integration of BIM and GIS represents a significant advancement in infrastructure management and urban planning, particularly within developing countries such as Vietnam. BIM provides precise, object-based 3D modeling capabilities, while GIS excels in spatial analysis and data management at larger scales. Their combination creates a comprehensive framework for digital infrastructure management, supporting decision-making across design, construction, and operation stages.

However, technical and semantic interoperability challenges remain persistent. Divergent data schemas (e.g., IFC for BIM versus CityGML for GIS), differences in geometric representation (object-based vs. topological), and coordinate transformation issues can reduce data fidelity during cross-platform conversion. Prior studies such as [12] and [35] have proposed intermediary formats or ontological alignment methods, but these often require complex manual intervention or lead to partial data loss. The workflow proposed in this paper mitigates these issues through standardized IFC–

CityGML conversion, semantic mapping via FME, and harmonization using the VN-2000 coordinate system, ensuring that geometry and attributes are preserved throughout the integration pipeline.

The results also reveal small but systematic deviations during geometric validation (Sections 3.5.1–3.5.2). These deviations are primarily attributed to sensor characteristics and environmental conditions. Positive offsets around reflective or glass surfaces result from multi-path laser reflections, while negative deviations in shadowed or occluded areas occur due to partial line-of-sight obstruction. Slight vertical discrepancies between the SLAM (RS10) and TLS (BLK360) datasets can be linked to variations in device calibration and mounting height. Although these systematic errors are minor in magnitude (mostly within ±0.05 m), they underscore the importance of rigorous multi-sensor alignment and periodic calibration when merging heterogeneous spatial datasets for digital twin applications.

Beyond geometric validation, the integrated BIM–GIS model demonstrates substantial practical utility. Within ArcGIS Pro, the model allows interactive linkage between BIM object attributes (e.g., floors, drainage) and geospatial datasets, enabling various operational analyses. Facility managers can perform spatial queries to identify underused classrooms, assess maintenance priorities, or evaluate accessibility. Likewise, by integrating elevation data and rainfall inputs, the model supports flood susceptibility assessment across the campus, helping planners identify low-lying zones or critical drainage bottlenecks. These capabilities demonstrate that the proposed workflow is not only technically sound but also operationally relevant for data-driven infrastructure management and smart campus applications.

From a policy perspective, the results align closely with Vietnam's ongoing digital transformation agenda. The proposed BIM–GIS workflow supports national directives such as the Prime Minister's Decision No. 258/QĐ-TTg (2023) on BIM adoption in the construction sector [36] and the Ministry of Construction's Decision No. 554/QĐ-BXD (2025) on digital transformation [37]. Both emphasize developing national BIM and GIS platforms for smart infrastructure and open-data management. Consequently, this study not only contributes a technically validated workflow but also reinforces the policy direction toward establishing a unified digital ecosystem for infrastructure governance in Vietnam.

## 5.0 CONCLUSION AND FUTURE WORK

This study developed and validated an integrated BIM–GIS methodology for infrastructure modeling and management under Vietnamese conditions. The case study at the UTC campus demonstrated the feasibility of combining BIM and GIS to enhance visualization, spatial analysis, and lifecycle asset management. The novelty of this study lies in three main aspects:

(1) a bespoke semantic mapping and ontology framework adapted to Vietnam's VN-2000 geodetic context;

(2) a multi-sensor automated pipeline integrating UAV-LiDAR, SLAM, and BLK360 datasets for comprehensive as-built data acquisition; and

(3) a per-object geometric validation approach, rather than a global point-to-surface comparison, to ensure higher model reliability.

Two validation stages confirming strong geometric accuracy: (i) Point cloud–CAD comparison: 64.3% of points < ±0.10 m and 86.5% < ±0.30 m; (ii) BIM–point cloud validation: 91.4% of points < ±0.05 m.

The findings demonstrate that the proposed workflow is technically sound and aligns with Vietnam's digital transformation policies, particularly Decision No. 258/QĐ-TTg (2023) on BIM adoption and Decision No. 554/QĐ-BXD (2025) promoting national BIM–GIS platforms for smart infrastructure and open data management.

Future research will focus on automating BIM–GIS data synchronization, enhancing semantic interoperability, and integrating AI and IoT-based monitoring toward developing comprehensive digital twin systems for large-scale infrastructure.

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## Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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