An Integration Framework of InfraHBIM-HGIS for Reconstructing Infrastructure Heritage Evolution: The Taipingling Corridor Along the Chinese Eastern Railway

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Abstract. Infrastructure heritage corridors are characterized by large spatial extents, dispersed asset distribution, complex historical transformations, and heterogeneous data sources, which make their documentation and reconstruction particularly challenged. To address these barriers, this study proposes a corridor-oriented InfraHBIM–HGIS framework for the reconstruction and documentation of infrastructure heritage, using the Taipingling Corridor of the Chinese Eastern Railway (CER) as a case study. The framework integrates an archival database, a geospatial database, InfraHBIM-based modelling, and HGIS within a unified workflow. Multi-source datasets, including georeferenced historical maps, raster and vector geospatial data, and point clouds generated through drone-based photogrammetry, are systematically organized and linked through a previously developed 12-digit identification system. A condition-based modelling strategy is adopted to combine forward modelling from archival records with reverse modelling from point-cloud data, enabling the reconstruction of extant, vanished, and transformed heritage assets across multiple historical stages. The integrated results are consolidated in a GIS-centered environment to support cross-scale visualization, semantic linkage, and spatial analysis, and are further disseminated through a WebGIS platform for remote access and interactive exploration. The study demonstrates that the proposed framework provides an operational approach for the multi-scale and multi-temporal integration of documentary, spatial, and model-based information in corridor-scale infrastructure heritage.

Keywords: Infrastructure Heritage Building Information Modelling (InfraHBIM) · Historical Geographic Information System (HGIS) · InfraHBIM-HGIS integration · Corridor heritage · Chinese Eastern Railway (CER)

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1 Introduction

Building Information Modeling (BIM) was originally developed for newly constructed buildings to manage digital assets throughout their lifecycle [27, 47]. With its rapid advancement in the Architecture, Engineering, Construction, and Operations (AECO) sector, BIM has expanded beyond design and construction into broader domains [24]. Its extension to cultural heritage led to the development of Heritage BIM (HBIM), introduced from the concept of Historic BIM [38], as a methodology for documenting, analyzing, preserving, and managing historical assets through semantically enriched 3D models [4, 34]. In parallel, BIM has also been applied to infrastructure domains, giving rise to Infrastructure BIM (InfraBIM), while Infrastructure HBIM (InfraHBIM) has emerged as a promising methodology for large-scale and linearly distributed heritage systems such as railways, canals, and defensive networks [52]. Compared with conventional HBIM applications focused on individual monuments, InfraHBIM better supports the integration of geometric and non-geometric information and the representation of historical evolution across spatially distributed assets [32, 44], and can also be applied to risk assessment, structural analysis, retrofitting, and rehabilitation [48].

Nevertheless, the effectiveness of InfraHBIM in digital representation, data integration, and cross-disciplinary collaboration remains constrained when infrastructure heritage is characterized by large spatial extents, fragmented distributions, complex historical transformations, and substantial data volumes, since object-level modelling alone is less effective in handling multi-scale spatial contexts and temporal dynamics across extensive territories. Geographic Information System (GIS) offers powerful tools for handling large-scale geospatial data, enabling spatial analysis, data integration, and visualization, while Historical GIS (HGIS) provides a suitable framework for organizing and analysing multi-source and multi-temporal historical information, including historical maps, satellite imagery, vector-based asset data, and reality-capture outputs [31, 46].

Accordingly, BIM–GIS integration has been widely applied in the management and monitoring of modern infrastructure systems [23, 37, 42] and has evolved from data-conversion experiments into a broader field supporting infrastructure planning, monitoring, asset management, and digital twin applications [24]. Most studies focus on BIM-to-GIS workflows, particularly the transformation of Industry Foundation Classes (IFC)-based models [12] into GIS environments, but major challenges remain in semantic mapping, geometry transformation, geo-referencing, conversion efficiency, and bidirectional interoperability [2, 57]. In heritage contexts, integration has progressively moved beyond technical model conversion. Earlier studies had already recognized that Historic BIM–GIS integration should support not only model management, but also maintenance, knowledge dissemination, and interactive digital representation [19]. More recent studies have expanded its scope from individual historic buildings to settlements, archaeological sites, cultural landscapes, urban districts, and infrastructure heritage [10, 18, 35, 36]. Methodologically, HBIM–GIS/HGIS integration increasingly combines historical maps, images, descriptive metadata, and multi-temporal information, while database construction, multi-phase reconstruction, and the joint use of forward modelling (FM) [11] and reverse modelling (RM) [41] have become central components of recent infrastructure heritage workflows [16, 18, 56].

Despite these advances, several limitations remain. Interoperability between HBIM and GIS/HGIS is still unstable, as model transfer often depends on intermediate formats, dedicated scripts, or platform-specific workflows [10, 16, 17, 57]. Many workflows also rely heavily on commercial software ecosystems, while open, low-cost, and long-term maintainable alternatives remain insufficiently developed [16, 36]. In addition, condition-adaptive frameworks for heritage with uneven archival documentation, physical loss, or complex intervention histories are still limited, and quantitative comparisons of alternative integration platforms remain relatively scarce [24, 25, 56]. These issues become particularly critical for corridor-scale infrastructure heritage, where dispersed assets, complex historical transformations, large territorial contexts, and heterogeneous documentary evidence must be addressed within a unified framework.

Infrastructure heritage and its associated landscape are recognized as a significant category within international heritage frameworks [51]. Accurate digital documentation of heritage structures, sites, areas, and landscapes is fundamental to conservation and to their presentation and interpretation [28]. However, such heritage is often underrepresented in conservation practice because of its large spatial extent, complex system characteristics, and continued exposure to natural and human-induced threats, which contribute to the gradual loss or transformation of original structures and spatial relationships.

To address these methodological and conservation challenges, this study proposes a corridor-oriented InfraHBIM–HGIS framework for the reconstruction and documentation of infrastructure heritage, using the Taipingling (TPL) Corridor of the Chinese Eastern Railway (CER) as a case study. The framework integrates an archival database (ADB), a geospatial database (GeoDB), InfraHBIM-based modelling, and HGIS within a unified workflow. It combines FM based on historical records with RM using point clouds derived from Structure-from-Motion (SfM) drone photogrammetry and publishes the integrated results through a WebGIS platform [53] for remote access and interactive visualization. The main contributions of this study are fourfold: (1) a corridor-oriented InfraHBIM–HGIS integration framework for infrastructure heritage characterized by large spatial extents, fragmented asset distribution, and multi-temporal evolution; (2) an operational data-linking workflow integrating ADB, GeoDB, and a previously developed 12-digit identification system to associate archival records, spatial data, and model components across multiple scales and historical stages [55]; (3) a condition-based modelling strategy that combines FM from archival sources with RM from photogrammetric point clouds to reconstruct vanished, extant, and transformed heritage assets under different data conditions; and (4) a cross-scale workflow connecting corridor-level railway alignment reconstruction, asset-level InfraHBIM development, and WebGIS-based dissemination within a single framework.

2 The Taipingling Corridor and Its Infrastructure Heritage Assets

In mountainous areas along the CER, Russian engineers developed five spiral-line systems to overcome steep topographic conditions [14] (see Fig. 1). During the construction period, temporary lines were built within these systems to transport workers and materials, and many of these routes were configured as Z-shaped switchback lines [13]. The TPL Corridor is located along the eastern section of the CER main line, a major historical railway system originally constructed between 1897 and 1903. The original historic

configuration of the corridor consists of an ascending line (AL) and a descending line (DL), located on the western and eastern slopes of TPL, the highest peak along the eastern section of the main line. Within the Qinggouzi–TPL section, the AL extends a straight-line distance of 9 km to a route length of 17 km, achieving an elevation gain of +199.36 m. In contrast, within the Zhashu–TPL section, the DL extends a straight-line distance of 6.78 km to a route length of 12.8 km, descending from 555.31 m a.s.l. at TPL Station to 406.38 m a.s.l., as shown in Fig. 2.

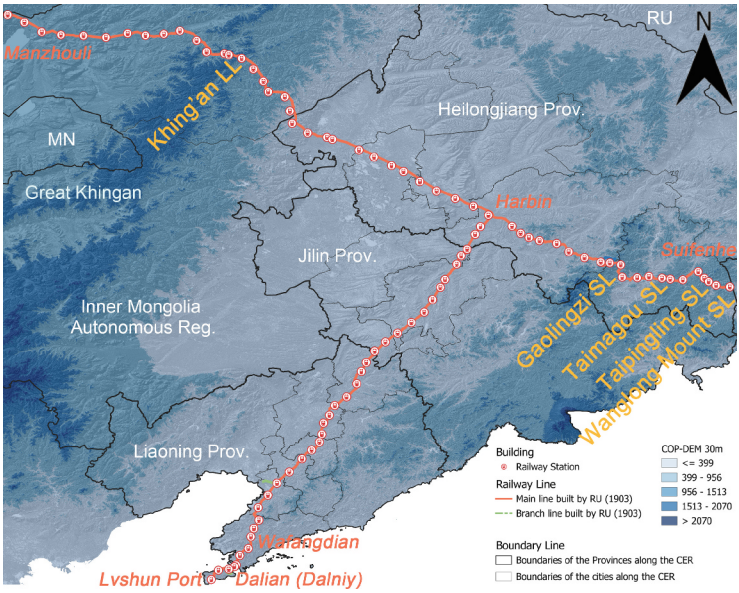


Fig. 1. Distribution of the five large-scale spiral lines along the main line of the Chinese Eastern Railway (CER) (SL = spiral line; LL = loop line).

The railway has a track gauge of 1,524 mm, a minimum curve radius of 320 m, and maximum longitudinal gradients of 15 m/km in mountainous sections and 8 m/km in flatter terrain. The Russian-built infrastructure heritage along the corridor includes four main categories with different structural scales: 15 steel plate girder bridges, 6 stone arch bridges, 14 concrete arch culverts, and 21 steel pipe culverts [14]. During the 1930s, under the administration of the South Manchuria Railway, Japanese engineers upgraded the spiral-line system to a double-track configuration and added a series of new infrastructure assets [49].

However, detailed archival records of these later interventions remain scarce. Field investigations conducted in 2021 and 2024 identified several remaining assets within the corridor. These include two stations, four bridges, and one culvert recorded in the Russian archives, as well as three Japanese concrete bridges. As an important component of the cultural heritage along the CER, this section has been exposed to continuous threats since its closure in December 2015, including climate-related factors and human interventions. Particularly significant is the recent loss of the Huli River Bridge I, which

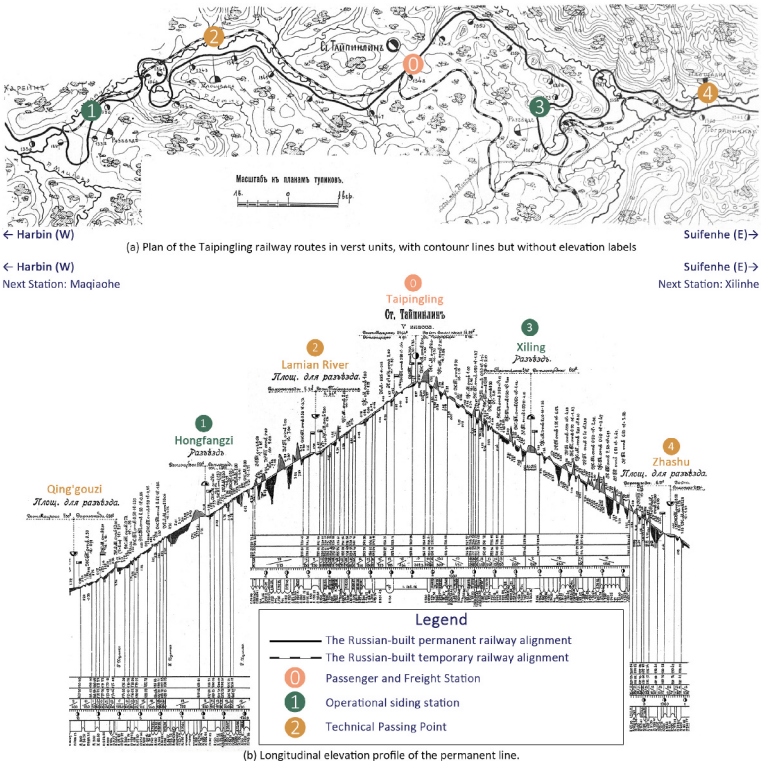


Fig. 2. Railway design drawings of the Taipingling mountainous section of the CER: (a) Plan of Taipingling railway routes in verst units, with contour lines without elevation labels; (b) Longitudinal elevation profile of the permanent line [14].



Fig. 3. Changes in the Russian-built Huli River Bridge I: (a) upstream elevation documented during the first field survey in 2021, (b) upstream elevation captured by drone in 2024, and (c) the bridge site after demolition caused by road construction in 2025.

had the longest single span along the entire line and was demolished in 2025 as part of a road renovation project (see Fig. 3). These conditions make the TPL Corridor a complex corridor-scale infrastructure heritage system characterized by dispersed assets, uneven conservation states, continued landscape transformation, and heterogeneous archival availability. These characteristics provide the basis for the multi-level reconstruction and documentation methodology presented in the following section.

3 Methodology and Workflow

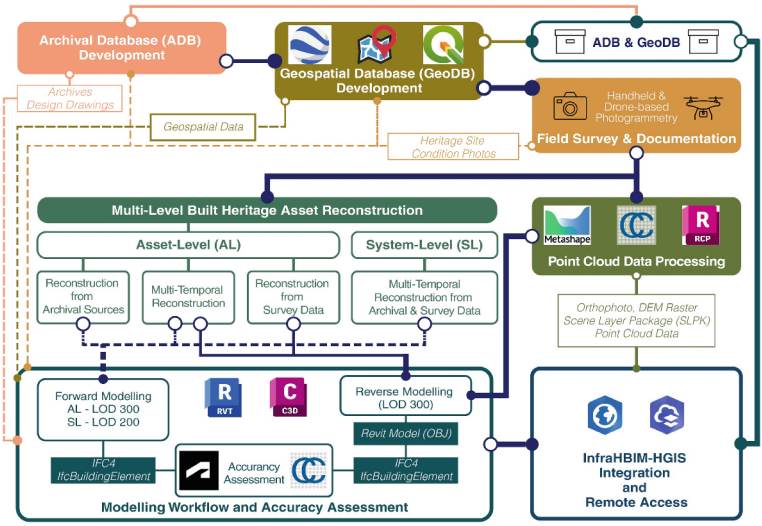


Fig. 4. The proposed workflow for integrating InfraHBIM-HGIS in this study.

This study proposes a corridor-oriented InfraHBIM–HGIS framework designed to address two interrelated problems in infrastructure heritage documentation: the reconstruction of individual assets under uneven documentary conditions and the reconstruction of railway routes and alignments at the system level. To address these challenges, the workflow integrates two complementary databases, namely ADB and GeoDB, together with two condition-based modelling strategies, FM and RM. Within this framework, HGIS serves as the common environment for linking documentary, spatial, and model-based information across temporal and spatial scales.

The workflow is organized at two complementary levels: the asset level, which focuses on the reconstruction and documentation of individual heritage assets such as bridges and culverts, and the system level, which addresses railway routes and alignments [13] in relation to the broader territorial and topographic context. Huli River Bridges II, IV, and V are used to illustrate RM-based modelling, whereas Huli River Bridge I serves as a representative FM case; railway alignment reconstruction is carried out at the system level to demonstrate corridor-scale modelling and spatial integration.

As illustrated in Fig. 4, the workflow consists of six main steps: (1) ADB development; (2) GeoDB development; (3) field survey and documentation; (4) point-cloud data processing; (5) multi-level reconstruction of built heritage assets at the asset and system levels, together with modelling workflow and accuracy assessment; and (6) InfraHBIM–HGIS integration and remote access. The following subsections describe these steps in detail.

3.1 Database Development

The development of ADB and GeoDB forms the operational data backbone of the proposed InfraHBIM–HGIS framework. ADB organizes historical and documentary evidence, including maps, engineering drawings, photographs, and descriptive records, while GeoDB provides the georeferenced spatial structure required for corridor-scale analysis, terrain interpretation, railway alignment reconstruction, and the integration of raster-, vector-, and model-based datasets. Their linkage establishes a unified and traceable data structure through which archival records, geospatial information, and InfraHBIM models can be consistently associated across multiple scales and historical stages, while field survey results contribute to the refinement and validation of both databases.

Archival Database Development
ADB was developed to systematically organize historical information related to infrastructure heritage along the corridor. It integrates multi-source archival materials, including historical maps, design drawings, engineering records, and photographic documentation collected from Russian and subsequent historical periods [3, 13, 29, 33, 40, 43, 49, 50]. Each asset was assigned a previously developed 12-digit identifier proposed by Xu et al. [55] to ensure consistent referencing and linkage across archival, geospatial, and modelling datasets (see Fig. 6). The database records both geometric-related information, such as location references and structural dimensions, and non-geometric attributes, including construction period, infrastructure type, material characteristics, and historical descriptions, thereby providing a documentary basis for GeoDB development, FM, and multi-temporal interpretation.

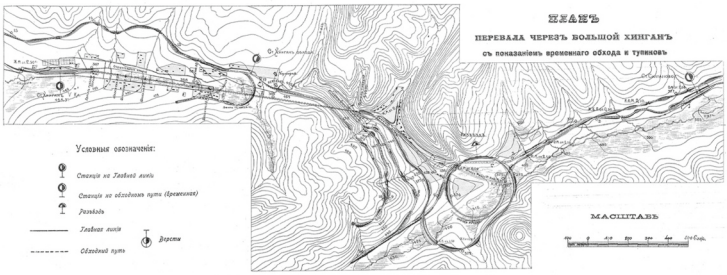
Geospatial Database Development
GeoDB was developed to organize, process, and integrate multi-source spatial data in support of analysis and reconstruction at both the asset and corridor scales. The input datasets include raster data such as satellite imagery and DEMs, vector data representing heritage asset locations, and historical spatial data extracted from georeferenced historical maps stored in the ADB. To ensure spatial consistency, all datasets were initially assigned WGS 1984 (EPSG:4326) in QGIS [45] and subsequently transformed into WGS Mercator (EPSG:3857) for visualization and data sharing in ArcGIS® Pro [21] and Online [20].

Multi-temporal satellite imagery obtained from Google Earth [25], together with field survey photographs, was used to analyze historical changes in the corridor landscape. Historical maps were georeferenced using control points derived mainly from infrastructure nodes, river confluences, and intersections between rivers and contour lines. Based on the Copernicus Global Digital Elevation Model (COP-30) [22], terrain analysis was conducted to generate contour lines at an interval of 10.67 m, consistent with historical design drawings, and to extract river networks and their spatial distribution.

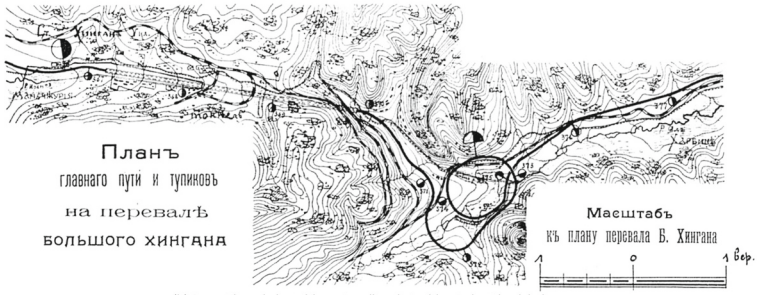
Method for Inferring Contour Intervals from Multi-Scale Historical Maps

A key challenge in this study is determining the contour interval of historical maps when elevation values are not explicitly annotated. This issue is particularly critical for the Taipingling plan (Fig. 2(a)), because terrain reconstruction and railway alignment

modelling depend on it. The inferred value of 10.67 m (5 sazhen[1]) represents a non-standard interval in modern metric systems, making direct assumption unreliable.



(a) A sazhen-based plan with contour elevation values.



(b) A verst-based plan with contour lines but without elevation labels.

Fig. 5. Plans of the Greater Khingan Range railway routes in two measurement systems, used for contour-interval inference: (a) a sazhen-based plan with contour elevation values; and (b) a verst-based plan with contour lines but without elevation labels.

To address this problem, a comparative cartographic analysis was conducted using maps from the same album. Figure 5(a) presents the 'Plan of the main railway line and switchback tracks at the Greater Khingan Range', in which the contour interval is explicitly indicated as 5 sazhen (approximately 10.67 m) [3]. Figure 5(b), depicting the same area at the same scale, does not include elevation labels; however, its contour geometry and density are consistent with those in Fig. 5(a), indicating that it was likely derived from the same interval.

Since Fig. 2(a) belongs to the same section of the album and follows the same cartographic conventions, it is reasonable to infer that the same contour interval was applied. Accordingly, the contour interval of the TPL plan is estimated to be approximately 10.67 m. Although inferred rather than directly surveyed, this value provides a historically grounded basis for terrain reconstruction under archival constraints.

These processes supported terrain interpretation, historical map georeferencing (see Fig. 6), and the reconstruction of historical railway routes. Built heritage elements, including stations, infrastructure assets, and railway alignments, were further vectorized as shapefiles and integrated into GeoDB, thereby establishing the georeferenced spatial

[1] Traditional Russian units of distance include 'verst' and 'sazhen'. One verst corresponds to 500 sazhen (≈ 1.067 km), while one sazhen is approximately 2.134 m.

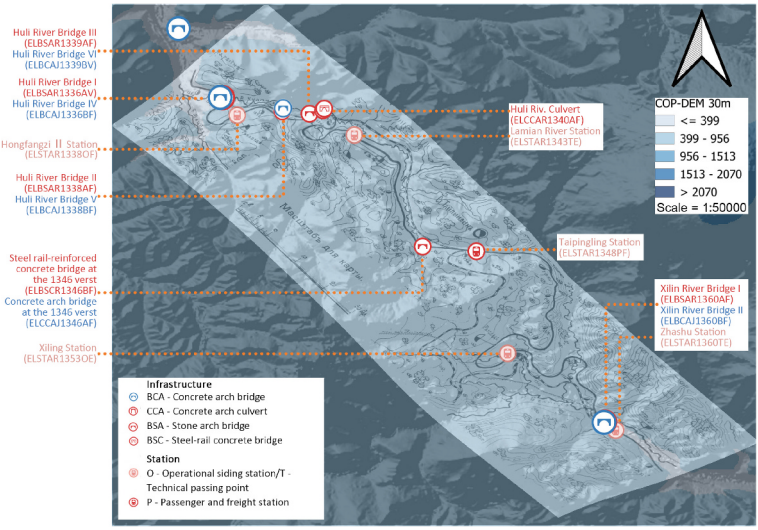


Fig. 6. Georeferenced historical map of the corridor showing the spatial distribution and identification codes of heritage assets and stations (scale 1:50,000).

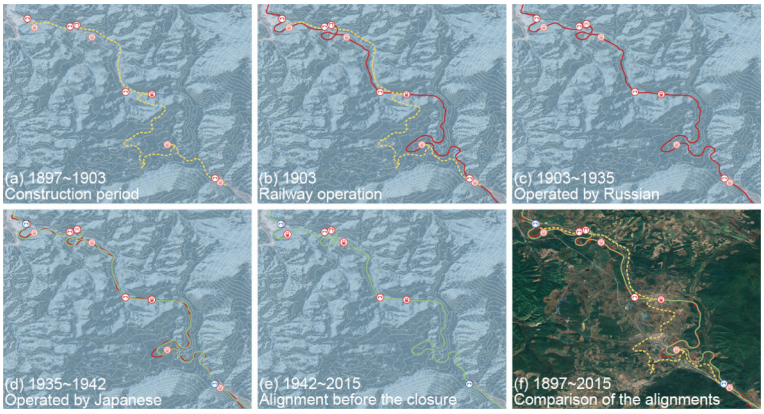


Fig. 7. Vectorized built heritage assets and railway routes within the corridor from 1897 to 2024 (a)-(e) and their comparison (f) (scale: 1:50,000).

framework required for multi-scale and multi-temporal analysis and for linking geospatial data with archival information from ADB and InfraHBIM models within the HGIS environment (see Fig. 7).

3.2 Documentation and Point Cloud Processing

Field survey and documentation were carried out based on the preliminary outputs of ADB and GeoDB, and the results further enriched and validated both databases. An initial field investigation conducted in 2021 established a preliminary record of the

existing heritage assets within the corridor. During the 2024 survey campaign, image data were collected using drone-based photogrammetry with a DJI Air 2S equipped with an FC3411 camera (8.38 mm focal length). The images were captured at a resolution of 5472 × 3078 pixels, resulting in an average ground sampling distance (GSD) ranging approximately from 0.67 to 0.94 cm/pixel, depending on flight altitude and asset extent.

Field photographs were also recorded using a handheld camera to document the current condition of the heritage assets. Due to ongoing road construction projects, certain locations were inaccessible during the survey. Consequently, several heritage assets shown in Fig. 6—including the stations, as well as ELCCAR1340AF, ELBSCR1346BF, and ELCCAJ1346AF—could not be documented. The collected image data nevertheless provided the basis for subsequent point-cloud generation and 3D modelling of the heritage assets (Fig. 8).



Fig. 8. Infrastructure heritage within the TPL Corridor documented during field investigations in 2021 and 2024.

Considering the complex topographic conditions, dispersed asset distribution, vegetation coverage, and accessibility constraints within the corridor, image acquisition was conducted using circular flight paths at appropriate altitudes to ensure sufficient coverage and overlap for 3D reconstruction (see Fig. 9). The number of images was adjusted according to the spatial extent and condition of the individual heritage assets. All datasets were referenced to WGS 84 / UTM zone 52N (EPSG:32652). Owing to the absence of ground control points (GCPs), absolute georeferencing relied on navigation-grade Global Navigation Satellite System (GNSS) data recorded onboard the drone. For this reason, the reliability of RM-based models was assessed primarily through internal photogrammetric indicators and subsequent geometric consistency evaluation rather than through external control-point-based validation.

Dense point clouds were generated using an SfM-Multi-View Stereo (MVS) workflow [26] implemented in Agisoft Metashape (version 2.2.0) [1], providing the primary geometric basis for RM-based InfraHBIM development. For the assets used in RM, ground resolution ranged from 0.67 to 0.94 cm/pix, reprojection error from 0.82 to 0.93 pix, dense point-cloud size from 3.40 to 6.41 million points, and DEM resolution from 1.34 to 1.88 cm/pix. These indicators suggest that the datasets are sufficiently dense and

internally consistent for asset-level RM, although absolute geolocation accuracy remains constrained by GNSS-only referencing.

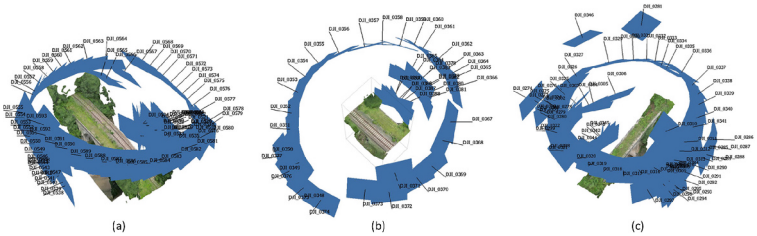


Fig. 9. Circular drone flight paths for image acquisition: (a) ELBCAJ1336BF, (b) ELBSAR1338AF and ELBCAJ1338BF, and (c) ELBSAR1339AF.

To improve usability in the HBIM environment, the initial point clouds were exported in.las format and processed in CloudCompare (version 2.11.1) [15] for slicing, denoising, filtering, and elevation-based recolouring, before conversion using Autodesk® Recap Pro® (version 2025) [6] (see Fig. 10). Asset-scale DEMs and tiled models were then generated in Scene Layer Package (SLPK) format for GIS integration and visualization. These operations improved the readability and interoperability of the point-cloud datasets without altering their underlying photogrammetric accuracy.

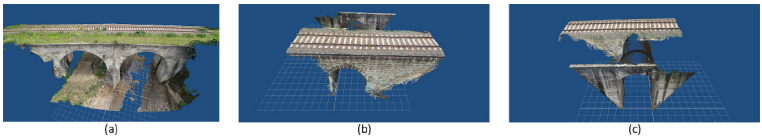


Fig. 10. Drone-based photogrammetric point clouds of (a) ELBSAR1338AF, (b) ELBCAJ1336BF, and (c) ELBCAJ1338BF.

3.3 InfraHBIM Development at the Asset-Level and System-Level

InfraHBIM Modelling Strategy for Multi-Source Data Integration and Railway Reconstruction

In this study, InfraHBIM development is structured around two complementary tasks: asset-level reconstruction of individual heritage assets and system-level reconstruction of railway routes and alignments. This structure supports both detailed object modelling and large-scale infrastructure representation, while the modelling strategy is selected according to the availability, quality, and type of evidence rather than object category alone, thereby accommodating extant, vanished, and transformed assets within the same corridor-scale heritage system.

At the asset level, modelling strategies are selected according to data conditions. FM is applied where reliable archival documentation is available but physical remains are absent or incomplete, enabling the reconstruction of lost structures from historical records. RM is adopted for well-preserved assets with sufficient point-cloud data,

enabling geometry to be reconstructed directly from survey-based evidence. In cases where assets have undergone structural transformations over time, FM and RM are combined to support multi-temporal reconstruction and maintain consistency between historical states and current conditions.

All asset models are developed in Autodesk® Revit® [7] at Level of Development (LOD) 300 [9]. Semantic information derived from ADB and GeoDB is embedded into the model components and subsequently mapped to IFC4 [12] to support interoperability between InfraHBIM and HGIS platforms (see Fig. 11(a)–(d)). In this way, the asset-level models serve not only as geometric reconstructions, but also as semantically structured information carriers linked to archival and geospatial data.

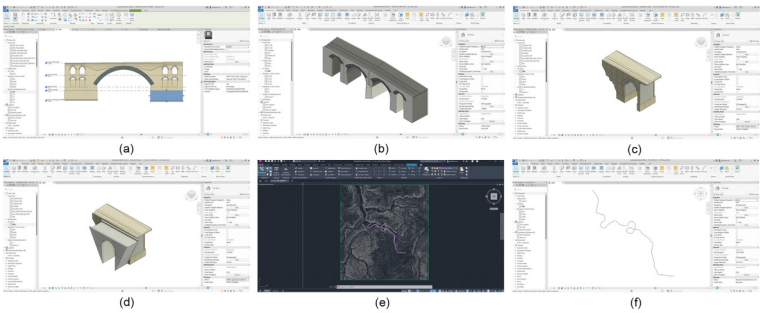


Fig. 11. InfraHBIM models of heritage assets within the TPL Corridor: (a) forward modelling of ELBSAR1336AV; (b) reverse modelling of ELBCAJ1336BF for a single historical stage; (c, d) multi-temporal modelling of ELBSAR1338AF and ELBCAJ1338BF (1897 ~ 1930s and 1930s ~ 2024); (e, f) railway alignment modelling based on the initial route extracted from georeferenced historical maps using C3D and Revit.

At the system level, railway alignment reconstruction is carried out through the combined use of Autodesk® Civil 3D® (C3D) [5] and Revit. Georeferenced railway routes, represented as shapefiles with elevation values derived from the Forest And Buildings removed Copernicus DEM (FABDEM) V1–2 [39], are imported into C3D. Using *corridor* modelling functions, railway models are generated with standardized track gauge and cross-sections at LOD 200. These models are then exported in.*dwg* format and transferred to Revit, where semantic attributes are assigned and integrated into the overall InfraHBIM environment (see Fig. 11(e) and (f)). This system-level reconstruction is not intended solely to visualize railway geometry, but to relate distributed heritage assets to their broader operational and territorial context, thereby linking corridor-scale evolution with asset-level documentation.

To ensure data integrity and modelling reliability, all IFC4 models are checked using Autodesk® Viewer® [8], while RM-based assets are further evaluated through geometric consistency assessment against the corresponding point-cloud data.

Geometric Consistency Assessment of Reverse-Modeled InfraHBIM
To evaluate the geometric consistency of reverse-modelled InfraHBIM assets, a multi-stage assessment framework was established by comparing the models with photogrammetric point clouds derived from drone-based reconstruction. Owing to the absence of ground control points and direct field measurements, the assessment relied on model-to-point-cloud comparison rather than external control-based validation.

Because photogrammetric point clouds are inherently incomplete and spatially variable, especially in occluded or poorly reconstructed areas, a two-stage filtering strategy was adopted to distinguish missing-data effects from actual geometric deviations. First, bidirectional *Cloud-to-Cloud (C2C)* distance analysis was used to identify unreliable regions and define a valid comparison domain. Then, overlap-based *Iterative Closest Point (ICP)* registration was applied within this domain to refine alignment and isolate the effective comparison area. More details are reported in Xu et al. [56].

Finally, the Multiscale Model-to-Model Cloud Comparison (M3C2) algorithm [30, 54] was used to quantify geometric discrepancies between the InfraHBIM models and the reference point clouds. By computing distances along local surface normals, this method enables robust consistency assessment under heterogeneous data conditions. The results indicate that the RM-based InfraHBIM models achieve an acceptable level of consistency within the validated comparison regions, with most deviations concentrated in localized areas affected by data incompleteness, occlusions, or modelling complexity. Overall, these results support the suitability of RM for asset-level documentation under the survey conditions of the present study.

This strategy enables flexible and condition-based modelling of infrastructure heritage, while ensuring both geometric reliability and semantic interoperability across multiple platforms and scales.

3.4 Integration of InfraHBIM and HGIS

Due to the heterogeneity of infrastructure heritage data, including documentary materials, spatial datasets, and three-dimensional models generated in different software environments, achieving unified integration and consistent representation within a single platform remains challenging. In particular, the integration of ADB, GeoDB, and InfraHBIM models requires interoperability while preserving both geometric reliability and semantic information. To address this, the study adopts a GIS-oriented platform as the central environment for organizing, integrating, and visualizing documentary, spatial, and model-based datasets within a unified HGIS framework.

The integration workflow operates through two complementary mechanisms. The first is the use of a common 12-digit identifier, which ensures consistent association between archival records, geospatial datasets, and InfraHBIM components. The second is the transfer of IFC-based semantic information into GIS attribute tables, enabling documentary, spatial, and model-based information to be queried and visualized within a single environment. Through these mechanisms, the framework supports multi-scale representation and data linkage across multiple historical stages. Rather than a simple one-way BIM-to-GIS transfer, it is conceived as a GIS-centered but cross-scale

integration framework in which InfraHBIM provides asset-level geometric and semantic reconstruction, while HGIS supports corridor-scale spatial organization, temporal interpretation, and unified access to multi-source information.

The integrated database derived from ADB and GeoDB was first imported into the HGIS environment. These datasets include: (1) raster data, such as corridor-scale DEM and DTM, asset-scale orthophotos and DEMs, and multi-temporal satellite imagery; (2) vector data, including railway alignments represented as line features and heritage assets represented as point features; and (3) archival images and documentary records linked through the common identifier. Together, they establish the geospatial and documentary basis for subsequent integration.

For the integration of built heritage models, bridge InfraHBIM models are developed in Revit with embedded geographic coordinates, while railway alignment models are reconstructed through the combined use of Civil 3D and Revit. Both types of models are exported in IFC4 format, preserving component-level geometry and semantic attributes. In parallel, point-cloud data acquired through field documentation are exported from CloudCompare in georeferenced.las format, and SLPK models generated from the processed point clouds are used to support efficient 3D visualization within the GIS environment.

All datasets are subsequently imported into ArcGIS Pro for unified organization and management. IFC files are parsed as 3D feature layers, and their component-level geometry and semantic attributes are mapped from IFC Property Sets to GIS attribute tables. This semantic transfer enables the inheritance of InfraHBIM information within the HGIS environment and supports both corridor-scale spatial analysis and asset-level information retrieval. The integrated models are represented at GIS Level of Detail (LoD) 3, which balances asset-level geometric interpretability with corridor-scale manageability.

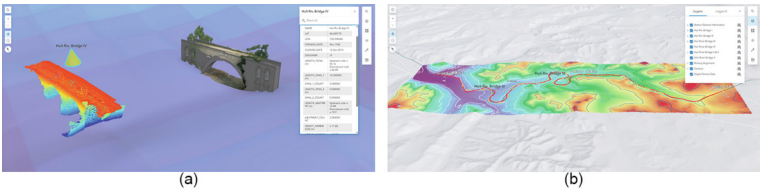


Fig. 12. Integrated results of the InfraHBIM–HGIS framework: (a) Integrated multi-source data of individual assets (ELBSAR1336AV and ELBCAJ1336BF); (b) Corridor-scale integration of built heritage assets within the Taipingling corridor (ascending line section).

Finally, the integrated results are published as Web Scenes via ArcGIS Pro and deployed on ArcGIS Online, enabling remote access, interactive visualization, and data sharing. Beyond online visualization, the WebGIS deployment allows users to navigate between corridor- and asset-level representations, retrieve associated archival materials, and access linked semantic information for individual heritage elements. In this way, the workflow establishes a unified framework for multi-scale representation, information query, and remote accessibility of infrastructure heritage (see Fig. 12).

4 Conclusion and Future Work

This study proposed a corridor-oriented InfraHBIM–HGIS framework for documenting and reconstructing infrastructure heritage characterized by large spatial extents, fragmented asset distribution, complex historical transformations, and heterogeneous data sources. Using the Taipingling Corridor of the Chinese Eastern Railway as a case study, it demonstrated the integration of archival records, geospatial datasets, InfraHBIM models, and HGIS within a unified workflow for multi-scale and multi-temporal heritage representation.

The results show that the framework supports coordinated reconstruction at both corridor and asset levels. By combining an archival database, a geospatial database, condition-based modelling strategies, and a GIS-centered integration environment, it enables the linkage of documentary, spatial, and model-based information across multiple historical stages. The combined use of forward and reverse modelling supports the reconstruction of extant, vanished, and transformed assets under different evidence conditions, while WebGIS-based deployment improves remote access, visualization, and information sharing.

Several limitations remain, including uneven archival documentation across historical phases, limited absolute georeferencing accuracy due to the absence of ground control points, incomplete field documentation caused by accessibility constraints, continued reliance on commercial software ecosystems, and validation restricted to selected assets within a single railway corridor.

Future work will extend the framework to additional corridor sections and more diverse infrastructure heritage assets, while improving reconstruction accuracy through stronger survey control where feasible. The integration of extended reality technologies will also be explored to support immersive visualization, interactive interpretation, and public dissemination of infrastructure heritage.

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References

1. Agisoft LLC: Agisoft Metashape Professional, version 2.2.0 (2024). https://www.agisoft.com/
2. Aly El Mekawy, M.S., Asif, M.U., Khan, Z.A.: BIM-GIS integration is closer than ever: a unified road model for IFC and CityGML interoperability. Int. J. E-Plan. Res. **14**(1), 1–27 (2025). https://doi.org/10.4018/IJEPR.394240
3. Anon: Album of Structures of the Chinese Eastern Railway (1897–1903). Fisher, Moscow (1904). http://elib.shpl.ru/ru/nodes/100508-albom-sooruzheniya-kitayskoy-vostochnoy-zheleznoy-dorogi-1897-1903-locale-nil-m-fisher-1904. (in Russian)

4. Antonopoulou, S., Bryan, P.: BIM for Heritage: Developing a Historic Building Information Model. Historic England, London (2017)
5. Autodesk, Inc.: Autodesk Civil 3D, version 2025 (2025). https://www.autodesk.com/products/civil-3d/overview
6. Autodesk, Inc.: Autodesk ReCap Pro, version 2025 (2025). https://www.autodesk.com/products/recap/overview
7. Autodesk, Inc.: Autodesk Revit, version 2025 (2025). https://www.autodesk.com/products/revit/overview
8. Autodesk, Inc.: Autodesk Viewer (2025). https://www.autodesk.com/viewers
9. Autodesk, Inc.: Levels of Development in BIM (2025). https://www.autodesk.com/solutions/bim-levels-of-development
10. Barrile, V., Genovese, E.: GIS-like environments and HBIM integration for ancient villages management and dissemination. Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci. **XLVIII-2/W4-2024**, 41–47 (2024). https://doi.org/10.5194/isprs-archives-XLVIII-2-W4-2024-41-2024
11. Brumana, R., Della Torre, S., Previtali, M., et al.: Generative HBIM modelling to embody complexity (LOD, LOG, LOA, LOI): surveying, preservation, site intervention—the Basilica di Collemaggio (L'Aquila). Appl. Geomat. **10**, 545–567 (2018). https://doi.org/10.1007/s12518-018-0233-3
12. buildingSMART International: Industry Foundation Classes (IFC). buildingSMART International (2019)
13. Chandra, S., Agarwal, M.M.: Railway Engineering, 2nd edn. Oxford University Press India, New Delhi (2013)
14. Chinese Eastern Railway: Album of Structures and Standard Drawings of the Chinese Eastern Railway, 1897–1903. Moscow. https://rusneb.ru/catalog/000200_000018_v19_rc_1315864/. (in Russian)
15. CloudCompare Project: CloudCompare, version 2.11.1 (2020). https://www.cloudcompare.org/
16. Dionizio, R.F., Dezen-Kempter, E.: HBIM-HGIS for a multi-level knowledge-based approach. Digit. Appl. Archaeol. Cult. Herit. **39**, e00461 (2025). https://doi.org/10.1016/j.daach.2025.e00461
17. Dionizio, R.F., López-Chao, V.: Integrating HBIM and WebGIS for the documentation, visualization and management of modern architectural heritage sites. Int. J. Archit. Herit. 1–20 (2025). https://doi.org/10.1080/15583058.2025.2502528
18. Dionizio, R.F., Marques, C.K.B., Dezen-Kempter, E.: BIM-GIS application for documenting and promoting archaeological heritage. Appl. Geomat. **17**, 693–710 (2025). https://doi.org/10.1007/s12518-025-00644-4
19. Dore, C., Murphy, M.: Integration of historic building information modeling (HBIM) and 3D GIS for recording and managing cultural heritage sites. In: 2012 18th International Conference on Virtual Systems and Multimedia, Milan, Italy, pp. 369–376 (2012). https://doi.org/10.1109/VSMM.2012.6365947
20. Esri: ArcGIS Online (2024). https://www.arcgis.com/
21. Esri: ArcGIS Pro, version 3.3 (2024). https://pro.arcgis.com/en/pro-app/latest/get-started/download-arcgis-pro.htm
22. European Space Agency: Copernicus Digital Elevation Model (GLO-30) (2024). https://dataspace.copernicus.eu/explore-data/data-collections/copernicus-contributing-missions/collections-description/COP-DEM
23. Floros, G.S., Ruff, P., Ellul, C.: Impact of information management during design and construction on downstream BIM-GIS interoperability for rail infrastructure. ISPRS Ann. Photogramm. Remote Sens. Spatial Inf. Sci. **VI-4/W1-2020**, 61–68 (2020). https://doi.org/10.5194/isprs-annals-VI-4-W1-2020-61-2020

24. Garramone, M., Moretti, N., Scaioni, M., Ellul, C., Re Cecconi, F., Dejaco, M.C.: BIM and GIS integration for infrastructure asset management: a bibliometric analysis. ISPRS Ann. Photogramm. Remote Sens. Spatial Inf. Sci. **VI-4/W1-2020**, 77–84 (2020). https://doi.org/10.5194/isprs-annals-VI-4-W1-2020-77-2020
25. Google: Google Earth Pro, version 7.3.6.10201 (2024). https://www.google.com/earth/about/versions/
26. Granshaw, S.I.: Structure from motion: origins and originality. Photogramm. Rec. **33**, 6–10 (2018). https://doi.org/10.1111/phor.12237
27. Hardin, B., McCool, D.: BIM and Construction Management: Proven Tools, Methods, and Workflows. Wiley, Hoboken (2015)
28. ICOMOS, TICCIH: Dublin Principles. Dublin (2011)
29. DeGolyer Library, Southern Methodist University: Album of Views of the Chinese Eastern Railway (1901). https://digitalcollections.smu.edu/digital/collection/eaa/id/1513. (in Russian)
30. Lague, D., Brodu, N., Leroux, J.: Accurate 3D comparison of complex topography with terrestrial laser scanner: application to the Rangitikei canyon (N-Z). ISPRS J. Photogramm. Remote Sens. **82**, 10–26 (2013). https://doi.org/10.1016/j.isprsjprs.2013.04.009
31. Lelo, K.: The HGIS of the urban cadaster of Rome (the Pio-Gregoriano Cadaster, 1819–1824). Estud. Geogr. **84**(295), e150 (2023). https://doi.org/10.3989/estgeogr.2023155.155
32. León-Robles, C.A., Reinoso-Gordo, J.F., González-Quiñones, J.J.: Heritage building information modeling (H-BIM) applied to a stone bridge. ISPRS Int. J. Geo-Inf. **8**(3), 121 (2019). https://doi.org/10.3390/ijgi8030121
33. Liu, D., Bian, B., Li, Q.: Architectural Cultural Heritage of Chinese Eastern Railway. Harbin Institute of Technology Press, Harbin (2020). (in Chinese)
34. López, F.J., Lerones, P.M., Llamas, J., Gómez-García-Bermejo, J., Zalama, E.: A review of Heritage Building Information Modeling (H-BIM). Multimodal Technol. Interact. **2**, 21 (2018). https://doi.org/10.3390/mti2020021
35. López-Ortiz, E., García-Jiménez, I., Dong, J., Pineda, P.: A multi-scale stratigraphic-HBIM-GIS method for the characterization of structures in heritage sites. J. Cult. Herit. **76**, 357–372 (2025). https://doi.org/10.1016/j.culher.2025.10.015
36. Matrone, F., Colucci, E., Iacono, E., Ventura, G.M.: The HBIM-GIS Main10ance platform to enhance the maintenance and conservation of historical built heritage. Sensors **23**(19), 8112 (2023). https://doi.org/10.3390/s23198112
37. Mohammed, B.Y., Khalifa, N.A., Hakim, S.J.S., Shahidan, S.B., Ali, S.: Bibliometric analysis of GIS studies for bridge management: trends, challenges, and future directions. Appl. Geomat. **18**, 35 (2025). https://doi.org/10.1007/s12518-025-00683-x
38. Murphy, M., McGovern, E., Pavia, S.: Historic building information modelling (HBIM). Struct. Surv. **27**, 311–327 (2009). https://doi.org/10.1108/02630800910985108
39. Neal, J., Hawker, L., Uhe, P., Paulo, L., Sosa, J., Savage, J., Sampson, C.: FABDEM V1-2. University of Bristol (2023). https://doi.org/10.5523/bris.s5hqmjcdj8yo2ibzi9b4ew3sn
40. Nilus, E.Kh.: Historical overview of China Eastern Railway (1896–1923). Tipografii Kit. Vost. zhel. dor. i T-va "Ozo", Harbin (1923). https://www.prlib.ru/en/node/335029. (in Russian)
41. Parente, M., Bruno, N., Ottoni, F.: HBIM and information management for knowledge and conservation of architectural heritage: a review. Heritage **8** (2025). https://doi.org/10.3390/heritage8080306
42. Pelden, S., Banihashemi, S., Mohandes, S.R., Arashpour, M., Kalantari, M.: Enhancing infrastructure planning and design through BIM-GIS integration. Struct. Infrastruct. Eng. 1–20 (2025). https://doi.org/10.1080/15732479.2025.2461629
43. Podolsky, B.M.: Photo album of the Chinese eastern railway. Harbin (1910). https://rusneb.ru/catalog/000199_000009_009396421/. (in Russian)

44. Previtali, M., Barazzetti, L., Banfi, F., Roncoroni, F.: Informative content models for infrastructure load testing management: the Azzone Visconti Bridge in Lecco. Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci. **XLII-2/W11-2019**, 995–1001 (2019). https://doi.org/10.5194/isprs-archives-XLII-2-W11-995-2019
45. QGIS Development Team: QGIS Geographic Information System, version 3.34 (2023). https://qgis.org/
46. Radunzel, J., Hutchinson, J.M.S.: Cartographic data and the great war: an HGIS for tactical cartography. Int. J. Cartogr. (2025). https://doi.org/10.1080/23729333.2024.2443991
47. Sacks, R., Eastman, C., Lee, G., Teicholz, P.: BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers and Contractors, 4th edn. Wiley, Hoboken (2025)
48. Salah, R., Szép, J., Ajtayné Károlyfi, K., Géczy, N.: An investigation of historic transportation infrastructure preservation and improvement through Historic Building Information Modeling. Infrastructures **9**, 114 (2024). https://doi.org/10.3390/infrastructures9070114
49. The Compilation Committee of the Harbin Railway Admission: Historical Records of the Harbin Railway Admission (1896–1995). China Railway Publishing House, Beijing (1999). (in Chinese)
50. The Compilation Committee of the Mudanjiang Railway Admission: Historical Records of the Mudanjiang Railway Admission (1896–1993). China Railway Publishing House, Beijing (1999). (in Chinese)
51. TICCIH: The Nizhny Tagil Charter for the Industrial Heritage. TICCIH, Moscow (2003)
52. Vilutienė, T., Šarkienė, E., Šarka, V., Kiaulakis, A.: BIM application in infrastructure projects. Balt. J. Road Bridge Eng. **15**(3), 74–92 (2020). https://doi.org/10.7250/bjrbe.2020-15.485
53. Vinueza-Martinez, J., Correa-Peralta, M., Ramirez-Anormaliza, R., Franco Arias, O., Vera Paredes, D.: Geographic information systems (GISs) based on WebGIS architecture: bibliometric analysis of the current status and research trends. Sustainability **16**, 6439 (2024). https://doi.org/10.3390/su16156439
54. Winiwarter, L., Anders, K., Höfle, B.: M3C2-EP: pushing the limits of 3D topographic point cloud change detection by error propagation. ISPRS J. Photogramm. Remote Sens. **178**, 240–258 (2021). https://doi.org/10.1016/j.isprsjprs.2021.06.011
55. Xu, J., Garramone, M., Scaioni, M.: Integration of HGIS/HBIM to reveal and reconstruct the vanished metal bridge heritage of the Chinese Eastern Railway main line. Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci. **XLVIII-4/W11-2024**, 161–166 (2024). https://doi.org/10.5194/isprs-archives-XLVIII-4-W11-2024-161-2024
56. Xu, J., Garramone, M., Li, F., et al.: InfraHBIM/HBIM–GIS integration for the reconstruction and remote access of the First Songhua River Bridge heritage complex along the Chinese Eastern Railway (1901–1961). Appl. Geomat. **18**, 72 (2026). https://doi.org/10.1007/s12518-026-00727-w
57. Zhu, J., Wu, P.: BIM/GIS data integration from the perspective of information flow. Autom. Constr. **136**, 104166 (2022). https://doi.org/10.1016/j.autcon.2022.104166