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Application and Comparison of Different HBIM/GIS Integration Methods in Railway Infrastructure Heritage: A Case Study of the Muling River Bridge along the Chinese Eastern Railway Main Line

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Abstract:

The infrastructure heritage built between 1897 and 1903 constitutes an important part of the Cultural Heriatge of the Chinese Eastern Railway (CER), a designated National Key Cultural Relics Protection Unit in China. However, most of these heritage assets remain unlisted, unprotected, and undocumented, and are increasingly at risk from natural degradation and human activities. The Muling River Bridge, China's first stone railway arch bridge located on the eastern section of the CER main line, is facing such challenges. While HBIM/GIS integration has become a widely used method in architectural heritage conservation, its application in infrastructure heritage remains limited. This study applies the HBIM/GIS integration approach to the Muling River Bridge by establishing a unified historical archive database, a geographic information database, and an HBIM model composed of both forward modelling (based on historical drawings) and reverse modelling (based on current point cloud data). The source-consistent dataset was integrated using three platforms: a commercial GIS solution (ArcGIS®-based), an open-access GIS solution (QGIS-based), and an BIM/GIS integration platform (Autodesk® InfraWorks®). The platforms were evaluated and compared in terms of four aspects: (1) integration complexity, (2) supported data types, (3) 3D visualization quality, and (4) ease of remote public access. The findings contribute to improved strategies for the digital management and protection of linear infrastructure heritage, offering guidance on selecting appropriate platforms for public engagement with digital conservation results.

1. Introduction

With the advancement of surveying and mapping technologies such as photogrammetry and laser scanning, Heritage/Historic Building Information Modelling (HBIM) has become increasingly prominent in the field of cultural heritage (CH) conservation. Its advantages include time efficiency, reduced labour requirements, high accuracy, and strong effectiveness, which make it a powerful tool for documenting and managing historical structures. (Murphy et al., 2009). In parallel, the integration of HBIM with Geographic Information Systems (GIS) has gained significant attention in recent years, driven by the growing needs for heritage management, monitoring, remote accessibility, and tourism development (Garramone et al., 2020). Despite these advances, integration efforts remain constrained by challenges such as inconsistent system standards and limited software interoperability.

Currently, three primary approaches to HBIM–GIS integration exist, distinguished mainly by their choice of integration platform: the open-source QGIS, the commercial ArcGIS® Pro, and Autodesk® InfraWorks®. At the HBIM stage, most workflows involve the creation of 3D models in Autodesk® Revit® and the use of Industry Foundation Classes (IFC) standards to structure the data. However, the integration process diverges significantly thereafter. For instance, ArcGIS® Pro has recently added native support for Revit® models, simplifying the integration process (Colucci et al., 2020).

Nonetheless, in cases involving custom Revit® families, interoperability issues may necessitate the use of IFC as an intermediary format. In contrast, open-source platforms such as QGIS still require third-party tools or conversion platforms to make IFC data accessible. This can be achieved either by transforming the data into readable formats (Xu et al., 2024) or by attaching them as linked documents (Garramone and Scaioni, 2023).

InfraWorks® is widely regarded as an effective platform for integrating BIM and GIS. platform. It supports not only the creation, modification, and management of BIM content within a geospatial context, but also the integration of a wide range of data types, including Revit® models, ESRI Shapefiles, point clouds, Digital Elevation Models (DEMs), and raster imagery (Pozzoni et al., 2024).

As a case study, this research focuses on the Muling River Bridge, part of the Chinese Eastern Railway (CER) main line. This historic railway was designed by Russian engineers to connect Manzhouli in the west to Suifenhe in the east via Harbin. As an extension of the Trans-Siberian Railway into Chinese territory, the CER served as a vital transportation corridor linking mainland Russia with the Russian Far East (Китайско-Восточная ж. д, 190AD). Today, both the railway and its associated infrastructure are recognized as important examples of linear, industrial, and cross-cultural heritage in China (National Cultural Heriatge Administration, 2020).

Located in Muling Town, Heilongjiang Province, the Muling River Bridge is the longest stone arch bridge along the CER, featuring ten arches each spanning 12.80 meters (Fig. 1). Completed in 1901, it was the first stone railway arch bridge constructed in China (The Compilation Committee of the Historical Records of Chinese Railway Bridges, 1987). Since then, it has undergone two major episodes of damage and repair (Fig. 2), resulting in a complex structural composition.

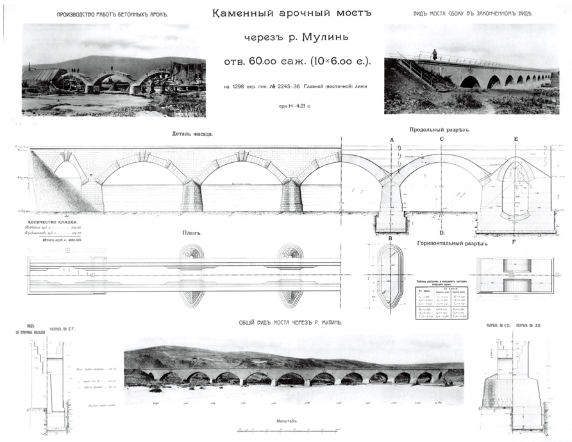


Figure 1. Drawing of the Muling River Bridge (Китайско-Восточная ж. д, 190AD).


Figure 2. Status of the bridge in the summer of 2024.

This study consists of two major components. The first involves the construction of a unified, source-consistent dataset. This was achieved through the collection and analysis of historical archival documents, a preliminary field survey conducted in 2022, and the development of a geographic information database. The second component includes a follow-up field survey and drone-based photogrammetric documentation conducted in 2024, followed by the creation of an HBIM model using two complementary methods: forward modelling, based on original design drawings and archival data, and reverse modelling, derived from point cloud data reflecting the bridge’s current condition.

The second part of this study evaluates three HBIM–GIS integration approaches using the unified dataset in ArcGIS®, QGIS, and InfraWorks®. A comparative analysis is then conducted based on five key criteria: (1) the complexity of the integration process, (2) the range of data types supported, (3) the visualization quality of the 3D models, and (4) remote accessibility of data for the public.

2. Muling River Bridge along the CER Main Line

The Muling River Bridge was designed and constructed by Russian engineers between 1897 and 1901, and upon completion, became the first stone arch railway bridge in China. According to the original design, the total length of the bridge was 174.34 meters, comprising ten arches, each with a span of 12.80 meters. The bridge deck was originally designed to be level, with a vertical clearance of 9.67 meters from the deck to the riverbed. The foundations of the abutments and piers were designed with a height of 3.20 meters.

Each abutment supported an additional arch with a span of 4.26 meters. Below the springing point of these arches, a trapezoidal void extended downward to the riverbed, within which a masonry wall was constructed. The opening measured 4.26 meters across the top, which matched the arch span, and 3.95 meters across the bottom. The vertical height was 4.99 meters. A counter-arch was constructed beneath each void.

The exterior of the concrete arches was clad with neatly cut, smooth-faced rectangular ashlar blocks. At the crown and springing points of the main arches, larger decorative stones with rougher surfaces were used for visual emphasis. A downspout was installed above the springing point on one side of each main arch, with the upper end connected to the lowest level of the internal superstructure. This drainage system enabled rapid water discharge and helped prevent frost heave in the roadbed (Fig. 3).

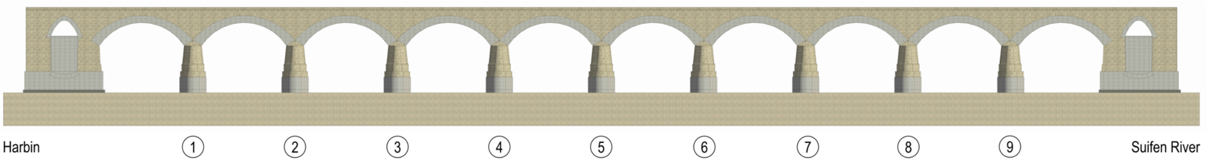


Figure 3. Reconstructed elevation of the bridge at completion, based on original design drawings.

Over the course of the past century, the bridge has suffered partial damage. During World War II, Arches No. 2 [(1)] and No. 3 were destroyed by an explosion. In 1965, the external layers of Arches No. 6 through No. 9 were damaged due to flood-induced erosion (Fig. 4) (The Compilation Committee of the Mudanjiang Railway Admission, 1999). In 1989, the bridge was repurposed as a road bridge. Field investigations revealed that subsequent repairs and reinforcements carried out by the railway company were relatively rudimentary, involving only concrete.

The reconstructed sections from the two major repair phases employed materials different from those used in the original structure, and both featured plain concrete façades. The 1945 restoration was considerably more refined than the 1965 one. In the former, even the masonry joints were carefully replicated on the concrete surface to imitate the original appearance. In contrast, the 1965 reconstruction included joint detailing only on the arches, while the remaining surfaces were left undecorated.

[(1)] In this study, the numbering of the bridge's structural elements begins from the Harbin-facing side. The arches located on the abutments at both ends are designated as Arches No.1 and No. 12, while the main arches are numbered consecutively from No. 2 to No. 11. The piers are numbered from No. 1 to No.9.

A detailed comparison of the original design drawings with field data collected in 2024 revealed that the bridge deck now exhibits a slope, beginning from the Harbin-facing side and descending approximately 2.02 meters toward the opposite end. This results in a longitudinal gradient of approximately 1.16% (Fig. 5).

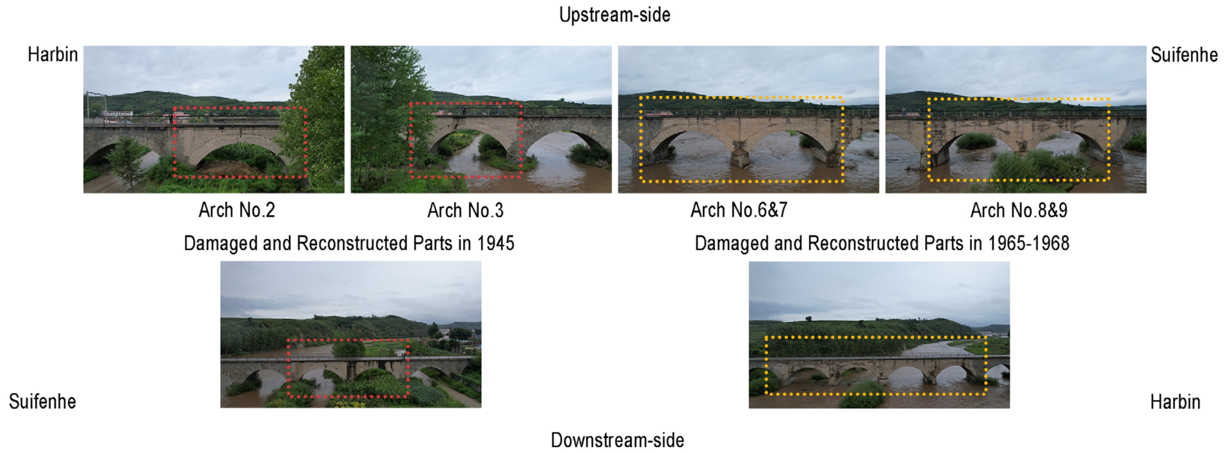


Figure 4. Reconstructed parts of the bridge after damage in 1945 (highlighted in red) and 1965 (highlighted in yellow).

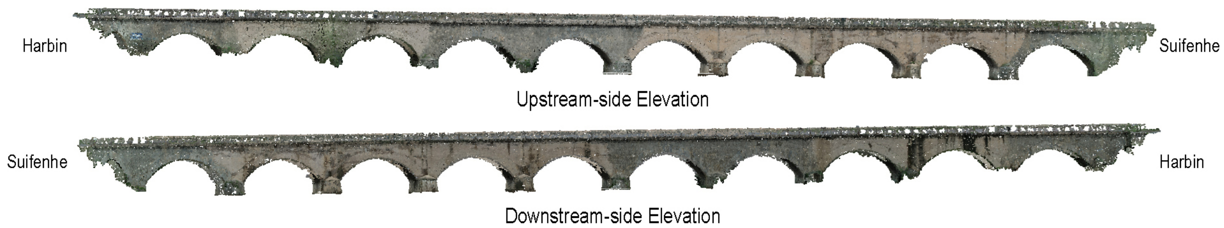


Figure 5. Raw point cloud data illustrating the elevation profiles in both directions of the bridge.

3. Methodology

To evaluate the operability and effectiveness of HBIM/GIS integration, this study applied the process through three different pathways: two established GIS platforms including one commercial (ArcGIS® Pro) and one open-source (QGIS), and InfraWorks®. Historical images and archival data spanning from 1897 to 1989 were collected, while the current condition of the site and bridge was recorded through a drone-based photogrammetric survey conducted in the summer of 2024. The overall methodology consists of five key stages: (1) Archival collection and analysis, (2) GIS database development, (3) Documentation and data processing, (4) HBIM modelling, and (5) HBIM/GIS integration through three approaches. Figure 6 illustrates the workflow, and the subsequent sections provide a detailed explanation of each stage.

3.1 Archival collection / GIS database development

To support multi-phase HBIM modelling and visualize the historical evolution of the bridge, extensive archival research was conducted. Sources included both Russian and Chinese publications such as: *Album of Structures and Standard Drawings of the Chinese Eastern Railway* (Китайско-Восточная ж. д, 190AD), *Album of views of the Chinese Eastern Railway* (Anon., 1901), *Historical Records of Chinese Railway Bridges* (The Compilation Committee of the Historical Records of Chinese Railway Bridges, 1987), and *Historical Records of the Harbin Railway Admission* (1896-1995) (The Compilation Committee of the Harbin Railway Admission, 1999).

Based on these materials, GIS databases were built on both ArcGIS® Pro and QGIS platforms. The databases used shared shapefiles, including point data, railway alignments, supplementary information, and geo-referenced historical photographs.

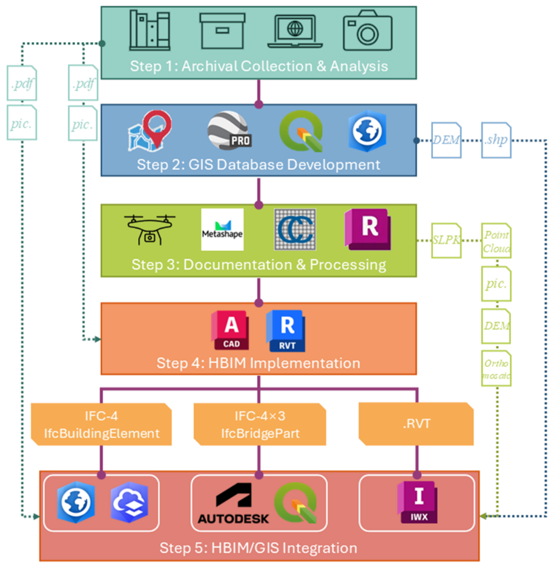


Figure 6. Workflow of the HBIM/GIS integration in this study.

3.2 Point Cloud Data Acquisition and Processing

Geometric data were acquired using drone-based photogrammetry with a DJI AIR 2S drone equipped with an FC3411 8.38 mm lens. Images were captured at a resolution of

5472 × 3078 pixels, producing a ground sampling distance of approximately 2.63 µm per pixel. The bridge was photographed from both nadir (overhead) and oblique (side) perspectives, at an average altitude of 42.2 meters above the bridge deck. A total of 98 nadir and 106 oblique images were collected (Fig. 7). All images were georeferenced using the *WGS 84 (EPSG:4326)*.

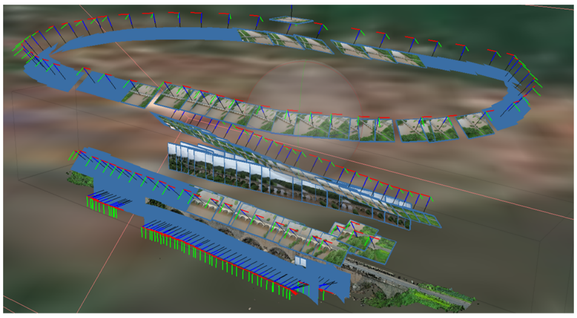


Figure 7. Drone photo acquisition trajectory during the 2024 field survey.

Point cloud generation followed a Structure-from-Motion (SfM) and Multi-View Stereo (MVS) photogrammetric workflow (Granshaw, 2018) , using Agisoft Metashape® (Version 2.2.0) (Agisoft LLC., 2024). The resulting bridge model contained approximately 5.57 million points after MVS processing. The point cloud was exported in *.las* format and imported into CloudCompare (Version 2.14.alpha) (CloudCompare, 2025) for further refinement—slicing, denoising, filtering, and elevation-based colorization.

For HBIM modelling, the processed point cloud was converted into a format compatible with Revit® (Version 2025) (Autodesk, Inc., 2025a) using Autodesk Recap® (Version 25.1.0.307) (Autodesk, Inc., 2024) (Fig. 8). Simultaneously, tiled 3D models were generated in Scene Layer Package (SLPK) format to support integration and visualization within ArcGIS® Pro (ESRI, 2024) (Fig. 9).

Figure 8. Processed point cloud prepared for HBIM development in Recap®.

Figure 9. Tiled 3D model in Scene Layer Package (SLPK) format with RGB-based colouring from photogrammetry.

3.3 HBIM Implementation

The HBIM development process in this study consists of two primary phases: (1) Forward modelling, based on archival research and historical documentation (Brumana et al., 2018) and (2) Reverse modelling, derived from the interpretation and processing of point cloud data.

The integration of forward and reverse modelling enables a comprehensive understanding of the bridge’s historical transformations, particularly in revealing structural damage, deformation, and material alterations over time. Both modelling workflows adhered to LOD 300 standards (Autodesk, Inc., 2025b) and followed the IFC data structure. Due to cross-platform compatibility considerations, two IFC schema versions were used: *IFC 4*, employing the *IfcBuildingElement* entity (buildingSMART International, 2019), and *IFC 4×3* (buildingSMART International, 2024), utilizing *IfcBridgePart* entities for infrastructure-specific representation.

This study defines five historical phases of the bridge, each corresponding to a major construction or transformation milestone: (1) March 1897 – January 1901: Initial Construction, (2) 1945: First Phase of Structural Damage and Repair, (3) 1965 – 31 December 1968: Second Phase of Structural Damage and Repair, (4) 1989: Structural Additions Related to Functional Transformation, and (5) July 2024: Surveying and Mapping of the Current Condition (Table 1).

Past		
No.	Name	Description
1	1897.03-1901.01: Initial Construction	Designed and built by Russian engineers, the bridge was constructed with the help of Chinese workers and made using concrete and stone.
2	1945: First Phase of Structural Damage and Repair	Structures destroyed by the Imperial Army during the WWⅡ.
3	1965 – 31 December 1968: Second Phase of Structural Damage and Repair	Structures damaged by flooding and reconstructed with concrete by the China Railway Administration.
4	1989: Structural Additions Related to Functional Transformation	Converted for road traffic.
5	July 2024: Surveying and Mapping of the Current Condition	Surveying and scanning with drone.
Future		

Table 1. Five historical phases of the bridge’s HBIM.

3.3.1 Forward modelling: The HBIM corresponding to the first milestone was reconstructed based on original design drawings and archival sources. It was developed through the following three key steps: (1) reconstruction of the riverbed, (2) creation of parametric families for structural components, and (3) assembly of the complete model using the created families. This approach allowed for an accurate digital reconstruction of the bridge as it appeared at the time of its completion and commissioning in 1901 (Fig. 10).

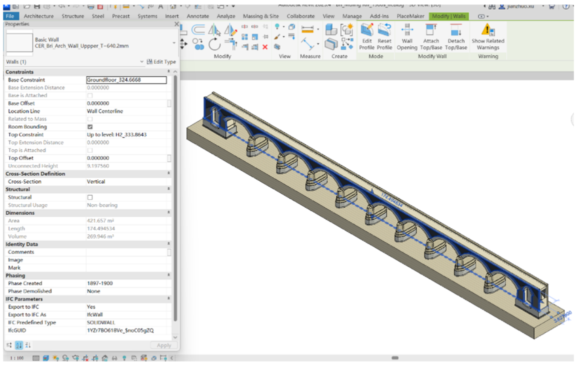


Figure 10. HBIM constructed through forward modelling.

3.3.2 Reverse modelling: During the 2024 field investigation, it was observed that the original bridge deck had been completely overlaid with a newly added asphalt surface. Furthermore, due to two historical episodes of structural damage, identifying and delineating structural elements repaired or reconstructed with different materials became critical for documenting the current state of the heritage structure.

In the CAD® environment, RGB-coloured point cloud data were used to visualize and approximate the boundaries of distinct structural segments. These boundary lines served as references for reconstructing the existing portions of the bridge in BIM (Fig. 11).

The elevation of the bridge deck was established by referencing both the RGB-enhanced point cloud and the extracted structural outlines. Owing to a height discrepancy between the two ends of the current structure, the bridge deck now features a longitudinal slope descending from the Harbin-facing side toward the opposite end. To accurately represent this gradient, multiple custom-built volumes were introduced into the model.

Each structural element within the HBIM was individually annotated in the attribute table, with associated metadata indicating both its historical phase and IFC classification.

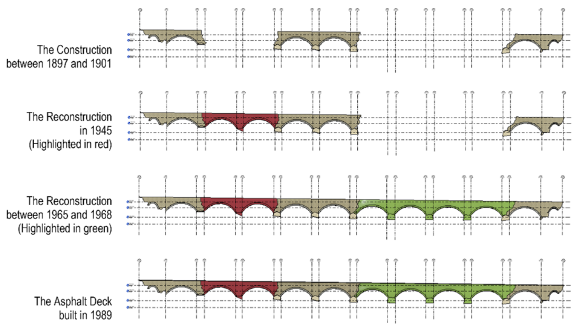


Figure 11. Bridge structures repaired or added during different historical periods.

3.4 HBIM/GIS Integration

Three integration platforms were employed in this study: (1) a commercial GIS solution (ArcGIS®), (2) an open-source GIS solution (QGIS), and (3) a BIM-GIS integration and infrastructure planning platform (InfraWorks®).

3.4.1 Integration in ArcGIS®: A global 3D scene was created in ArcGIS® Pro, followed by the sequential loading of 2D and 3D layers. Building upon the established GIS database, additional 2D layers were imported, including railway and bridge shapefiles, a DEM generated from point cloud data, and an orthophoto. The 3D layers included elevation-mode visualized point cloud data, two BIM models (in *IfcBuildingElement* format) representing different historical phases, and a Scene Layer Package (SLPK) model (Fig. 12).

The integrated scene was then published using the WebScene functionality. After publication, layer adjustments were performed within the online environment. ArcGIS® Online supports the Top-Up feature, which enables the direct loading of historical photographs even in the absence of geospatial metadata (Fig. 13).

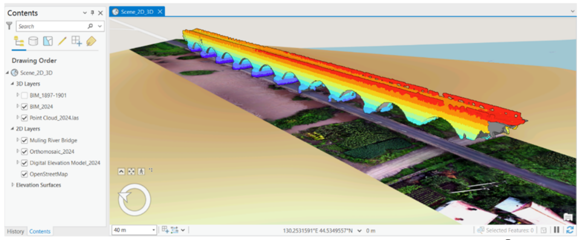


Figure 12. Visualize the integrated results in ArcGIS® Pro.

Figure 13. Visualize the integrated results in ArcGIS® Online

3.4.2 Integration in QGIS: The procedure for integrating 2D layers in QGIS is largely consistent with that in ArcGIS®. However, the management of historical photographs differs. In QGIS (Desktop 3.30.2) (QGIS, 2023), georeferenced historical photographs can be imported using the ImportPhotos plugin (Version 3.0.7) (Marios S. et al., 2025). Geographic coordinates for each image were acquired using Google Earth® Pro (Version 7.3.6.10201) (Google, 2025), and embedded into the images via GEOSETTER (Version 3.5.3) (GEOSETTR, 2019).

Point cloud data in LAS/LAZ format were imported using the Point Data Abstraction Library (PDAL) and visualized in 3D within the QGIS environment (Fig. 14). BIM models were accessed via IFC file links embedded in the bridge’s attribute table, enabling users to open and interact with the models through the Autodesk® Viewer® (Autodesk, Inc., 2025c).

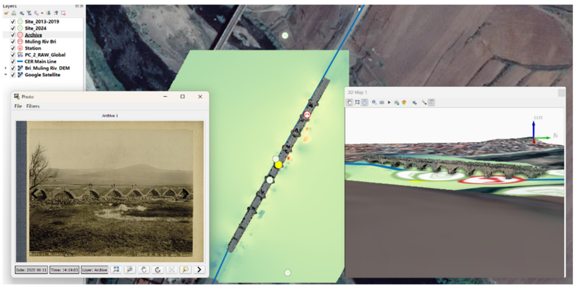


Figure 14. Visualize the integrated results in QGIS.

3.4.3 Integration in InfraWorks®: InfraWorks® enables direct reading of both Revit® files and point cloud data, facilitating the realistic simulation and visualization of the built environment. However, it has limited capabilities for managing image-based content: historical photographs must be added individually and cannot be integrated as a unified data layer (Fig. 15).

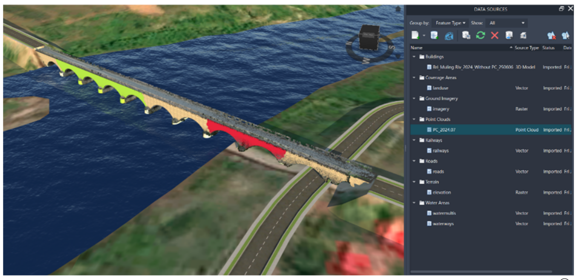


Figure 15. Display of point cloud data and the bridge’s Revit® model in InfraWorks®.

4. Comparation the Three Integration Approaches

The comparison of the three HBIM–GIS integration approaches is conducted across five key criteria: (1) the complexity of the integration process, (2) the types of data supported by each platform, (3) the visualization quality of the 3D models, and (4) public remote data accessibility.

4.1 The complexity of the integration process

From the perspective of integration complexity, InfraWorks® demonstrates the highest level of convenience. As a product developed by the same company as Revit®, it can directly import native Revit® files without the need for conversion into IFC format, thereby streamlining the integration process. This direct compatibility eliminates the additional step of assigning IFC classes and identifiers to individual bridge components, significantly improving modelling efficiency.

In contrast, both the ArcGIS®-based, and QGIS-based approaches require the use of IFC as an intermediary to enable BIM–GIS integration. Furthermore, the QGIS workflow entails an additional georeferencing step for historical images, as spatial coordinates must be assigned manually using external tools, which increases the overall complexity and time cost.

4.2 The types of data supported by each platform

In terms of data compatibility, Table 2 summarizes the types and formats supported by each platform. Among the three, the ArcGIS®-based solution supports the broadest range of data formats, including IFC (*IfcBuildingElement*), LAS/LAZ point clouds, SLPK models, shapefiles, orthophotos, DEMs/DSMs, and historical documents. However, it cannot directly import RVT files, relying instead on IFC for BIM data integration. Although InfraWorks® supports the loading of images in various formats, the images can only be overlaid as flat textures within the model and do not support interactive browsing.

Data Type	ArcGIS® -based	QGIS -based	Infraworks®
HBIM (RVT)	×	×	√
HBIM (IFC)	√ (IFC-4 IfcBuilding Element)	√ (IFC-4×3 IfcBridgePart)	√
Point Cloud	√ (LAS/LAZ)	√ (LAS/LAZ)	√ (LAS/LAZ/RCP)
SLPK	√	×	×
DEM	√	√	√
DSM	√	√	×
Shapefile	√	√	√
Picture (JPG)	√	√	√
Picture (PNG)	√	√	√

Table 2. Supported data types and formats of the three integration approaches.

4.3 The visualization quality of the 3D models

Both GIS-based approaches share a common limitation in 3D visualization: IFC models do not retain the customized material textures embedded within HBIM environments (Fig. 16). As a result, their 3D visualization quality is generally inferior to that of InfraWorks®. However, ArcGIS® partially compensates for this deficiency by supporting the import of SLPK models, which can represent the current state of the heritage site based on recently acquired data. Nonetheless, this capability does not extend to earlier historical phases.

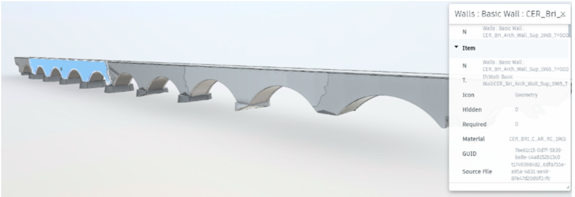
Although InfraWorks® provides relatively detailed 3D simulation scenes, it is unable to accurately reproduce the actual environmental conditions surrounding the heritage site at the time of data acquisition.

4.4 Remote accessibility of data for the public

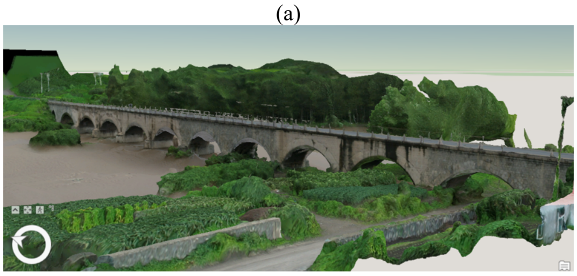
Among the three integration approaches, ArcGIS® offers the most convenient solution for public remote access. In ArcGIS® Online, users can generate shareable links simply by modifying the access permissions of individual layers. Through these links, the public can remotely view the integrated results directly in a web environment. Visitors can remotely access heritage-related information, historical archives, and digital models via a shared link (https://arcg.is/1189jG0) on their computers.

In contrast, QGIS requires additional configuration for public sharing. Remote access must be enabled through plugins such as qgis2web (Andrea et al., 2025), which allow for the creation and deployment of web maps but involve more manual setup and customization.

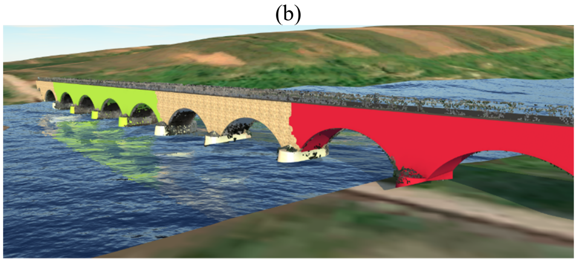
InfraWorks® does not provide a native solution for public remote access. Instead, it relies on the ArcGIS® platform for external access, which is limited to 2D map views. As a result, it does not support remote visualization of 3D models—ironically, one of InfraWorks®’s key strengths lie in its 3D simulation capabilities.



(a)



(b)



(c)

Figure 17. Comparison of the current 3D visualizations of the Muling River Bridge produced by the three integration approaches: (a) QGIS, (b) ArcGIS®, and (c) InfraWorks®.

5. Conclusion and Future Work

This study presented a comparative analysis of three HBIM and GIS integration approaches. These included commercial GIS using the ArcGIS® platform, open-access GIS based on QGIS, and the BIM/GIS integration platform known as Autodesk® InfraWorks®. The analysis was conducted using a unified dataset developed for the Muling River Bridge, which serves as a representative example of infrastructure heritage along the Chinese Eastern Railway. The dataset comprised a historical archive database, a geographic information database, and an HBIM model constructed through a combined strategy of forward modelling (based on historical documents and design drawings) and reverse modelling (based on point cloud data acquired via drone-based photogrammetry in 2024).

The three integration methods were assessed across four key aspects: (1) the complexity of the integration process, (2) the types of data supported, (3) the quality of 3D visualization, and (4) the accessibility for public remote access. The results reveal distinct strengths and limitations among platforms, providing practical insights into platform selection for different heritage conservation and dissemination needs. The study contributes not only to the development and management of digital databases for infrastructure heritage but also to improving strategies for sharing digital conservation results with the public.

Future research will further explore the completeness of HBIM information within each integration approach and refine the evaluation criteria across the four proposed dimensions. These efforts aim to enhance the methodological robustness and practical applicability of HBIM/GIS integration in the digital conservation of cultural heritage.

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