The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume XLVIII-4/W11-2024
19th 3D GeoInfo Conference 2024, 1–3 July 2024, Vigo, Spain

Integration of HGIS/HBIM to Reveal and Reconstruct the Vanished Metal Bridge Heritage of the Chinese Eastern Railway Main Line

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Keywords: Metal Bridge Heritage, Conservation, HGIS, HBIM, Integration, Chinese Eastern Railway (CER).

Abstract

Integration of HGIS (Historical Geographic Information Systems) and HBIM (Heritage Building Information Modelling) constitutes a high-precision, efficient, and sustainable method for conserving cultural heritage (CH), particularly in instances characterized by large-scale distribution and spanning multiple historical periods, with extensive archival material. HBIM not only aids in the preservation of remaining structures but also facilitates the revelation and reconstruction of invisible elements. The Chinese Eastern Railway (CER), a key industrial and linear cultural heritage site in northeast China, has a variety of metal bridge heritage, many of which are documented and seen solely in historical archives until now. These bridges, designed and constructed by Russians at the outset of the 20th century, serve as crucial components of the CH along the CER while also showcasing the technological advancements and application developments in metal structures along the railway. We propose a method of integrating HGIS/HBIM to conserve the integrity of the heritage and this methodology has been validated through two case studies. A historical database was established for collection and exhibition archives in QGIS®. Concurrently, Autodesk® Revit was employed to reconstruct bridge models, incorporating material information and GPS coordinates based on the Industry Foundation Classes (IFC). Subsequently, we utilized FME® Workbench to bridge the gap between BIM and GIS. This approach promises to enhance the richness and integrity of the CH along the CER, offering a sustainable solution for its preservation and management.

1. Introduction

As a type of linear cultural and industrial heritage, historic railway conservation has many dilemmas, especially for the infrastructure heritage, including bridges, tunnels, culverts, and spiral lines. Cultural heritage (CH) consists of its physical body and invisible elements. The invisible element includes vanished parts such as the heritage destroyed by natural erosion and human reasons and knowledge, including construction engineering, design methods, etc. As a significant component of the CH, revealing the invisible part is also a basement and essential step to keep the integrity of the heritage. Moreover, the railway company and the public always pay more attention to the infrastructure operation values far more than their artistic value and heritage characteristics. The appearance of the heritage has changed a lot due to reinforcement works and renovation. Furthermore, compared to the architectural heritage, large-scale and remote distribution of the infrastructure heritage makes it hard to manage and collect data.

The conservation of the bridge heritage, which has a metal upper structure, along the Chinese Eastern Railway (CER) has faced all the above dilemmas (Li et al., 2023). As the easternmost part of the Great Siberian Railway, the CER has played a key role in economic, cultural, and societal development in northeastern China and has experienced several renovated constructions in the past hundred years (Fig. 1). On the one hand, there are very few remaining examples along the line. Numerous metal bridges have vanished for many reasons such as the original design, metal fatigue, human demolishment, new lines operation and so on. Moreover, many cutting-edge design and construction methods at the time vanished after the line operation, such as the caisson of the pier's basement of the large-span metal bridge (see Fig. 2). We can only find most of their documentation in historical archives (К.А. Фишера, 1903; Китайско-Восточная ж. д, 190AD; фот. Хосита, 1901), which are the basements of the digital reconstruction work. On the other hand, large-scale distribution and multiple types of heritage create a series of difficulties in management and digitalisation.

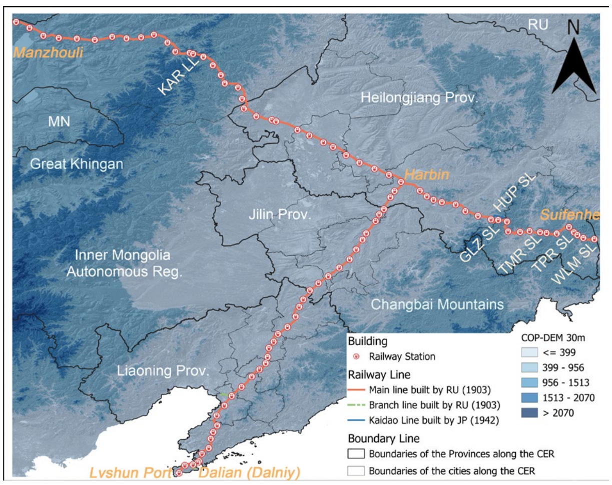

Figure 1 The Chinese Eastern Railway direction.

All bridges with metal upper structures consist of at least one standardised span unit: the steel plate girder bridge (BSP) and the steel truss bridge (BST). The application of this method helps the railway line to cross multi-scale and countless rivers and valleys along the railway and increases construction speed. Integration of HBIM/GIS is a high-precision, efficient, and sustainable way to conserve the CH, especially for the linear railway heritage (Barazzetti, 2021; Garramone et al., 2022; Garramone and Scaioni, 2023, 2022). Heritage Building Information Modelling

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(HBIM) cannot only be applied to the remaining architectural/infrastructure heritage with point clouds but also be used to reconstruct invisible heritage such as the metal upper structure and caissons along the CER (Morganti et al., 2019; Rio et al., 2020; Vecco, 2010). Historical Geographic Information System (HGIS) is a management tool for the large-scale distribution of heritage and a modelling tool, applied for reconstructing large-scale heritage scenes (Bitelli et al., 2016; Brumana et al., 2023; Fiorini et al., 2022; Gatta and Bitelli, 2020; Krejčí and Cajthaml, 2022). Compared to the remaining infrastructure heritage, applying digitalisation to the vanish part is an important and appropriate method to enrich the CH along the CER (Garramone et al., 2023).

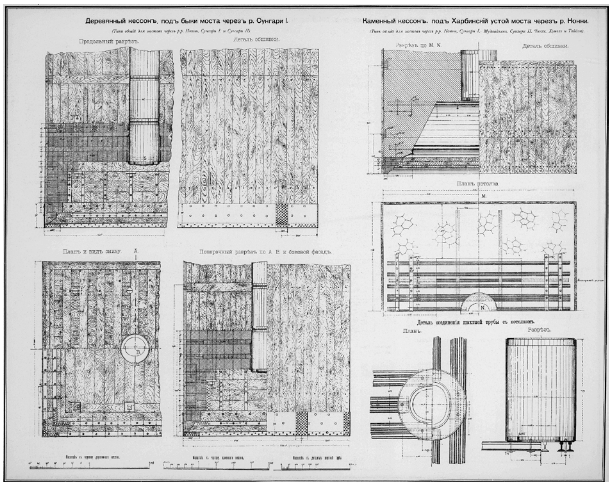

Figure 2. Two types of the caissons of the CER construction (Китайско-Восточная ж. д, 190AD).

The objective of this study is to propose a methodology for the integration of HBIM/HGIS tools to metal structures of the infrastructure heritage along the CER with the aim of revealing invisible part, reconstructing vanished part and heritage management. This model will integration of historical archives from multiple sources and digital models based on the original drawings. The proposed method will be applied to the case study of two vanished small/medium-scale metal bridge: the Yalu River Bridge Ⅱ (Yalu, Inner Mongolia) and the Heshi Lake (or called Hailang River) Bridge (Hailin, Heilongjiang).

2. Methodology

The methodology consists of five main steps that can be repeated in different periods, which are: (1) HGIS database construction, (2) Modelling of the elements and structure, (3) File format conversion of information documents, and (4) Integration based on the platform of GIS.

These steps would be:

(1) HGIS database construction: First, collecting and organising historical archives. This would be the phase of collection of the multiple types of historical documents from the museums and institutions located in China, Japan, Russia, and other countries. Moreover, encoding each infrastructure heritage with a 12-digit ID code for study, recognition, and management. This ID code comprises the following six parts: location of the section/line, heritage classification, designer, mileage on the section, serial number, and remaining status (Table 1). Furthermore, organizing and classifying the historical archives such as drawings and photographs for each case and adding geographic information to them. Finally, importing all the historical documentation into QGIS®.

Character No.	Meaning of the character	Abbreviation and meaning
1 ~ 2	The section/line on which the heritage is built.	EL/WL - East/west section of the mainline SL - South branch line BL - Other Branch Lines
3 ~ 5	The heritage's classification.	The Infrastructure Heritage: 1) BCI - Iron-rail Concrete Bridge 2) BCR - Reinforcing-Iron Concrete Bridge 3) BIT - Iron Truss Bridge 4) BIP - Iron Plate Girder Bridge 5) BSA - Arch Stone Bridge 6) BTB - Timber Beam Bridge 7) BTT - Timber Truss Bridge 8) BTt - Timber Trestle Bridge 9) BTS - Timber Strut-framed Bridge 10) CCA - Concrete Arch Culvert 11) BCA – Concrete Arch Bridge 12) SLP - Spiral Line Permanente 13) SLT – Spiral Line Temporary 14) TSS – Stone Tunnel with the Straight plan 15) TSC – Stone Tunnel with the Curve Plan The Affiliated Architectural Heritage: 1) STA - Station 2) GAR - Locomotive Garage 3) TWR - Water Tower 4) WSP - Maintenance Workshop 5) FTY - Railway Factory
6	Identity of the heritage's designer.	R - Russian J - Japanese
7 ~ 10	Mileage location of the heritage along the CER in Russian units (1 verst = 1.067 km).	WL - 0000 ~ 0894 EL - 0894 ~ 1415 SL - 0000 ~ 0911
11	Serial number of the heritage within the same classification in the same verst.	A^Z
12	The heritage's remaining status.	F - Full remaining P - Partly remaining V - Vanished E - Waiting to explore

Table 1 The encoding rule and the meaning of characters of the infrastructure/affiliated architectural heritage's ID code.

(2) Modelling of the elements and structure: First, a family should be created for each element of the metal structure, for example, a family of T beams, railings, sleepers, etc. The cross-section of each element is defined when creating these families. Meanwhile, each case has its geographic coordinates set. All models apply LOD (Level of Development) 300 and IFC4 (buildingSMART International, 2019) in Autodesk® Revit.

(3) File format conversion of information documents: Importing the IFC files to the FME® Workbench for transforming shapefile (shp) and csv documents which can be recognised in QGIS®. The "GeometryProperty" information was extracted from the IFC4 file, and then exporting "AttributeExposer" for csv file and "GeometryFilter" (including "Surface" and "Solid"). Finally, two files called "BuildingElementProxy" which can be recognized by GIS were generated.

(4) Integration of HBIM/HGIS in GIS environment: Importing the files generated in last step into QGIS.

3. Technical Characteristics of the Small/Medium-scale Metal Bridge along the CER

The infrastructure along the CER employs two important design methodologies: (1) standardized design and modular construction; and (2) the individual/universal design for different scale infrastructures. Small/medium-scale bridges include steel plate girder bridges (BSP) and steel truss bridges (BST). All bridges combine multiple standardized span-length units, decreasing the construction and preparation time.

The BSP has 6.40 m (3 саж, "саж" is short for "сажень", Russian traditional length unit, 1 саж =2.134 m), 8.54 m (4 саж) and 10.67 m (5 саж) three the most popular span-length units along the line, and their weight is 4144.32 kg (253 пуд, "пуд" borrowed Late Latin "pondo", from Classical "pondus", Russian traditional weight unit, 1 пуд = 16.3807 kg ("Russian units of measurement," 2024), 6519.52 kg (398 пуд) and 8960.24 kg (547 пуд). They have similar appearances, but the dimensions of their primary supporting structures differ. Except for the middle timber board of the second deck panel located at the centreline of the transverse section, all other components of the upper structure are symmetrically arranged. From the side to the middle, there is a railing, an edge bridge deck panel constituted by three timber boards, a guardrail, a rail, and the first board of the second bridge deck panel set. Railings are supported by vertical posts anchored to the sleepers at the bottom. A single-span main beam is composed of three to five box girders, with each box girder having cross-shaped truss supports on the top and bottom surfaces and two transverse end faces. Meanwhile, the longitudinal faces are covered with steel plates, which are equipped with reinforcing ribs in the middle part. The ends of the main beam are riveted to the bearing pads placed on the abutments/pier caps (Fig. 3).

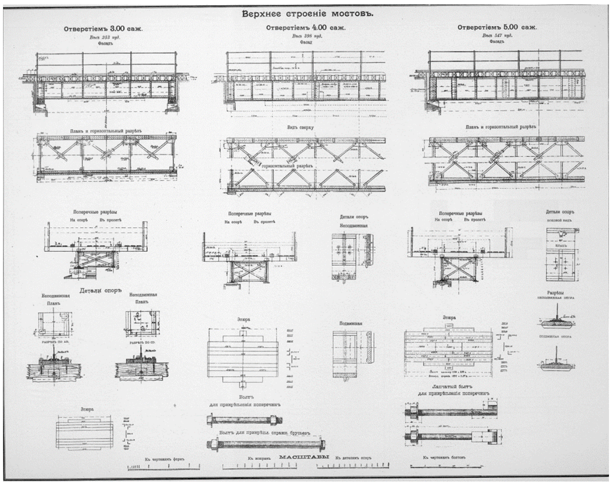

Figure 3. The original design drawing of three small-scale steel plate girder bridge units of 6.40m, 8.54m, and 10.67m (Китайско-Восточная ж. д, 190AD).

The medium-scale BST span-length units includes a 21.34 m (10 саж) deck truss unit and two half-through truss units at 21.34 m and 32.01 m (15 саж). Their weights are as follows, in sequence: 29,305.07 kg (1789 пуд), 40,755. 18 kg (1488 пуд), and 66,947.92 kg (4087 пуд). The half-through trusses set trapezoidal main trusses on both sides which have cross-braced web members in the middle part. The cross-section of the diagonal beams at both ends of the main girder consists of two pairs of T-beams placed one above the other with their flanges facing each other, while the top and bottom chord members are composed of T-beams and steel plates. The cross-section of the vertical members is a cruciform beam, which is riveted together from two T-beams. Three sets of horizontally aligned box girders support the bridge deck. Each small box girder is reinforced with cross-diagonal struts at the top, bottom, and ends to enhance load-bearing capacity. The deck truss consists of steel box girders at both ends and a truss in the middle. Its cross-section is similar to that of the steel plate girder bridge (Fig. 4 and 5).

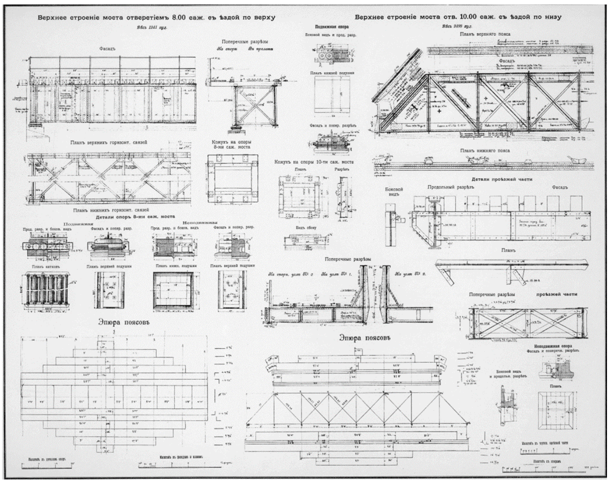

Figure 4. The original design drawing of a 21.34m half-through steel trusses unit (Китайско-Восточная ж. д, 190AD).

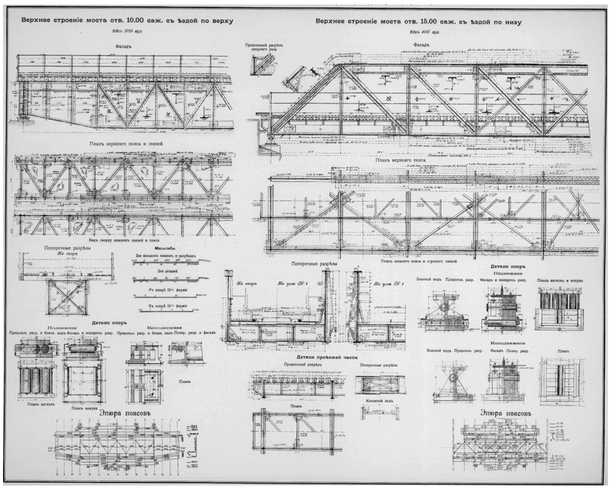

Figure 5. The original design drawing of two steel trusses units (a 21.34m deck truss and a 32.01m half-through trusses) (Китайско-Восточная ж. д, 190AD).

4. Case study

This study applies the methodology in two vanished cases: the Yalu River Bridge Ⅱ (ID code: WLBSPR0421AV) and the Heshi Lake (or called Hailang River) Bridge (ID code: ELBST1204AV). Following a comprehensive review of historical archives in different institutions, meticulous documentation of the cases has been undertaken from two albums, *The Album of Constructions and Standard Drawings of the Chinese Eastern Railway* (Китайско-Восточная ж. д, 190AD) and *The Album of Construction of the Chinese Eastern Railway* (К.А. Фишера, 1903) , which including original drawings and photos at the time.

WLBSPR0421AV locates on the west section of the main line at 421 верста (верста, a Russian tradional unit, 1 верста = 1.067 km). It is the second bridge to supporting the line passing through the Yalu River. This BSP consists of three 10.67 m-unit. ELBST1204AV consists of five 21.34 m-unit of the steel half-through truss bridge. It locates on the 1204 верста near Hailin town. Through recognising the geometry information under the reference system of "EPSG:4326 – WGS 84", two bridges were imported into GIS through the "add spreadsheet layer" to create point layers. Moreover, the detailed information was connected to the point as its attribute table, such as ID code, name, length, operation/closure time, slope, etc. Furthermore, all geographic information is connected to historical archives though the open-source software GeoSetter®. After that, the historical documentation is imported into QGIS® as the point layer (Fig. 6).

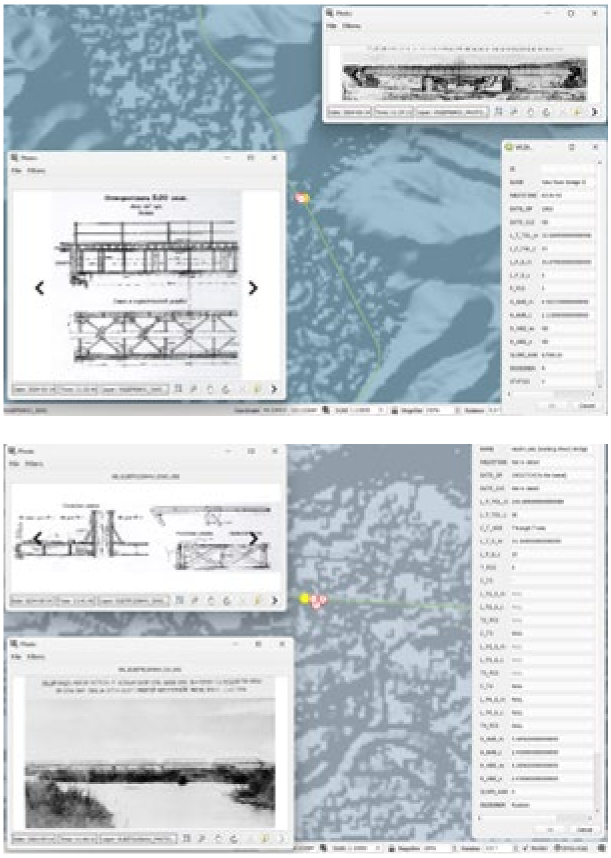

Figure 6. The Yalu River Bridge Ⅱ and the Heshi Lake Bridge with historical archives in HGIS.

At the beginning of modelling, it's an important step to confirm the location and select the geographic coordinate system for each site in Autodesk Revit®. The geographic coordinates were acquired from the Google Earth® and then import into through the "Location" in "Manage". Applying the plugin called "Environment" to search for a suitable geographic coordinate system and select. After that, loading satellite imagery around the site via the plugin "PlaceMaker" to ensure the correct orientation of the models (Fig. 7). Moreover, multiple types of the family of the elements were created and gradually improved to reconstruct the standardized structure and special-design elements of the bridge with the metal structure. Meanwhile, the type of each element was selected based on the standard of IFC4 for buildings. All digital models were reconstructed base on the original drawings and are all in metric units though various dimensions were used in the original drawings published at the beginning of 20th Century. Fig. 8 and 9 show the final modelling results.

Subsequently, the 3Dmodel in IFC format was exported to the FME® Workbench for format transformation. Under the workflow mentioned in the methodology, the transformed files with the formats of *.shp and *.csv were imported into QGIS for the following integration. In this exchange several problems of data identification and reading were detected, for example, that model positioning error occurred. All the information is stored and available for the future exhibition online.

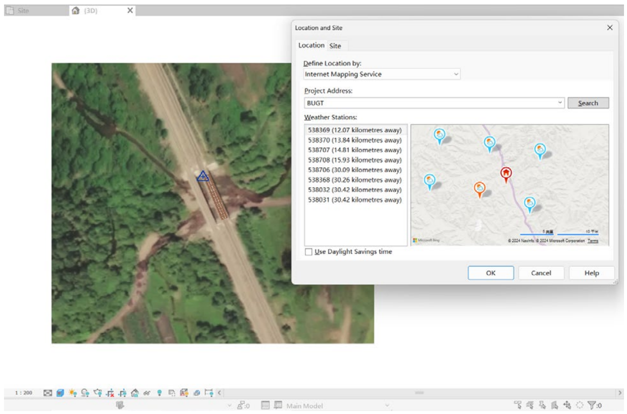

Figure 7. Using the plugin for directional reference in Revit.

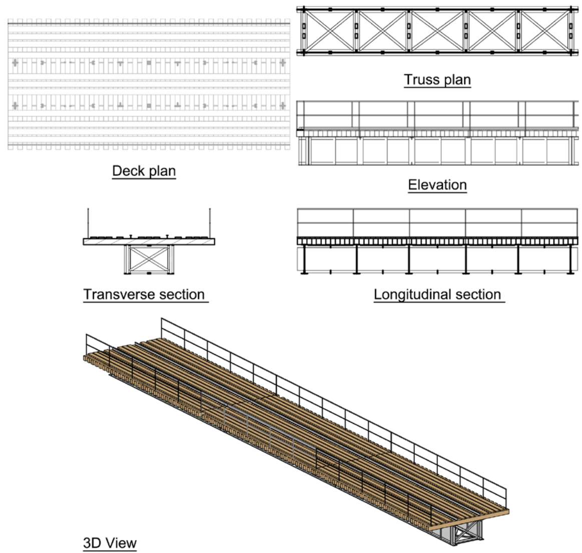

Figure 8. The detailed model of the Yalu River Bridge Ⅱ and its span-unit.

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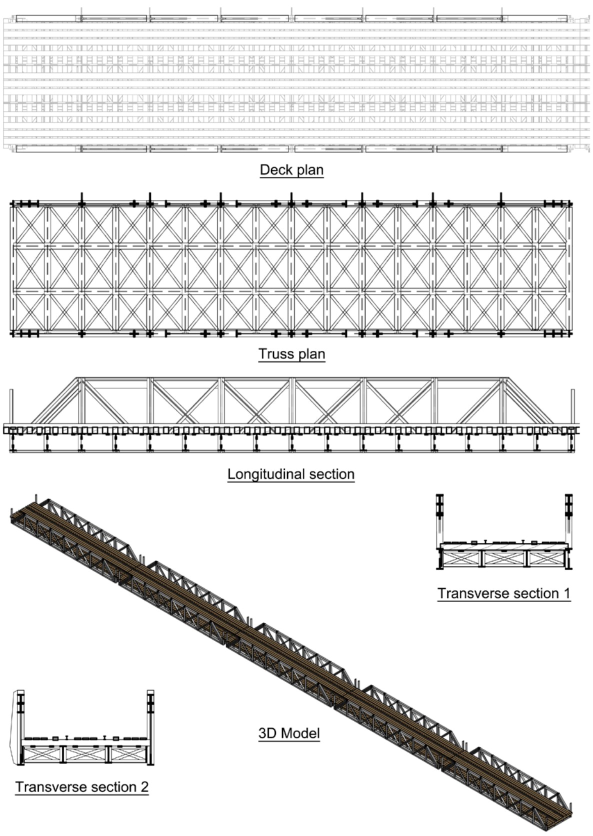

Figure 9. The detailed model of the Heshi Lake Bridge and its span-unit.

5. Conclusion

Integrating of Historical Geographic Information Systems (HGIS) and Heritage Building Information Modelling (HBIM) is a developing methodology in the conservation of cultural heritage. These heritage sites often feature complex structures, diverse construction materials, and vast amounts of historical archival documents. This methodology has been tested as a tool for the sustainable conservation of the vanished metal bridges along the Chinese Eastern Railway (CER) main line.

HGIS allows building a database for encoding each heritage and collecting their historical archives. HBIM allows modelling and creating the family of each element based on the historical drawings and relating the geometry of the building with its components and properties. FME® Workbench supports the transformation from the IFC file to the files with the format of shp and csv, which can be recognized in GIS environment to help accomplish the final integration.

This methodology allows us to reveal and reconstruction the vanish part and invisible elements, as well as preserving the integrity of the cultural heritage along the CER. In the following work, the integration results will be reviewed online through the WebGIS.

Acknowledgement

The work reported in this paper was supported by the China Scholarship Council (No. 202206120044). Many thanks to the supports from the Copernicus DEM, QGIS®, FME® by Safe Software and GeoSetter®.

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