A BRIEF FEASIBILITY ANALYSIS OF HBIM/GIS INTEGRATION IN THE INFRASTRUCTURE HERITAGE CONSERVATION: THE CASE OF THE CHINESE EASTERN RAILWAY(CER) MAIN LINE

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KEY WORDS: Chinese Eastern Railway (CER), Heritage Conservation, HBIM, GIS, Integration, Railway Infrastructure.

ABSTRACT:

Large-scale infrastructure is typically regarded as a symbol of technological and engineering development during its construction time. This phenomenon is particularly evident in the infrastructure heritage along the Chinese Eastern Railway (CER) Main Line. However, the conservation of this crucial component of the CER, which is an important cross-culture and linear heritage in China, has received little attention, with conservation methods remaining relatively traditional. Due to threats posed by human and natural factors, the remaining infrastructure heritage is at risk of being lost. Additionally, the vanished part, including the infrastructure and technical heritage applied during construction, cannot be revealed. To address this issue, new technologies and management methods, such as BIM/HBIM and GIS, should be introduced to reconstruct the vanished part and record the status quo of what still remains. We propose building a database that integrates HBIM and GIS to facilitate the preservation of this historic infrastructure and analyse the feasibility of this method. Our research aims to establish an accurate, efficient, and collaborative method for integrating historical data and preserving the infrastructure heritage along the Main Line of the CER.

1. INTRODUCTION

According to the Nizhny Tagil Charter for the Industrial Heritage (TICCIH, 2003), the *infrastructure heritage* is an important component of the industrial heritage. More and more stakeholders such as the sector, the public, and the public administration are becoming concerned about the conservation of this type of Cultural Heritage (CH). This process occurs for the following reasons. On one hand, infrastructure heritage has its unique value consisting of the following factors: (1) technological and scientific value in the history of manufacturing, engineering, and construction; (2) aesthetic value for the quality of its architecture, design, or planning; and (3) memorable value for its surrounding residents and those people who had visited it. On the other hand, heritage infrastructure has had important use value for transport lines such as roads, railways, and canals. The infrastructure is crucial to support the line to travel past diverse terrains such as rivers, mountains, ravines, and ridges and connect both sides of the geographical barriers. Because of this, most infrastructure heritage was built in remote and sparsely populated areas. It has led to difficulties in conservation as well as surveying and mapping. In the meanwhile, numerous and scattered distributions of the heritage also may cause problems with reuse, management, and monitoring.

In recent years, advanced Geomatics techniques and methods such as point clouds from photogrammetry and laser scanning, and Unmanned Aerial Vehicles (UAV) have become more popular in architectural heritage conservation (see Barazzetti et al., 2009; Altuntas et al., 2016; Barazzetti et al., 2020; Chiabrando et al., 2017). Their application improves the efficiency and accuracy of mapping and recording a large amount of manpower and materials. These features were the key-points of the fundamental surveying of the isolated and remoted infrastructure heritage. From the conservation perspective of a single object, with the large-ranging application of the abovementioned techniques, the remaining heritage or partly remaining heritage could be mapped, recorded, or reconstructed in the Heritage/Historic Building Information model (HBIM) environment. In the meanwhile, the vanished heritage, which was demolished or destroyed by human and natural actions, can be also reconstructed based on the original drawings or research results by using HBIM. For the needed protection objects, which locate in heritage groups or distribute along the linear heritage, introducing Geographic Information Systems (GIS) is helpful for future management and monitoring. Moreover, integrating HBIM/GIS in the infrastructure heritage conservation works may build a conservation system. The system can co-collaborate and collect contributions of all stakeholders, provide and display the historic data and the situation of the heritage in its whole life cycle, and efficiently update the protection progress and changes for the heritage.

As the eastmost part of the Great Siberian Railway (GSR), the Chinese Eastern Railway (CER) is composed of a Main Line and a South Branch Line. The Main Line starts from Manchuria and extends via Harbin to the east border station (today called Suifenhe). However, this line selection option is the most economical and minimal construction difficulties method to link the Far East and the East Terminal of the GSR of Russia among the three plans. The other two plans were abandoned due to the tough surveying and mapping, longer payback cycle, and further distance. One runs along the north bank of the river to Vladivostok with the same start point as the CER, and another one starts at the Ulan-Ude station on the GSR, via Kjachta (Russia) and Zhangjiakou (China) and ends at Beijing (China) (Liu D. et al., 2020). Diverse classifications and scales of the infrastructures, which include bridges, tunnels, culverts, and spiral/loop lines, were originally designed and built to overcome

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the terrain obstacles such as rivers, gorges, ravines, and mountains (see Figure 1). After the 1930s, the South Manchuria Railway (SMR), a Japanese corporation, built some new infrastructures, which enriched the diversity of the heritage classifications and contents, after they took over the railway line. The new infrastructures include the Ducao Tunnel, the Hufeng Spiral Line, six reinforced concrete arch bridges, and steel plate girder bridges (See Figure 2).

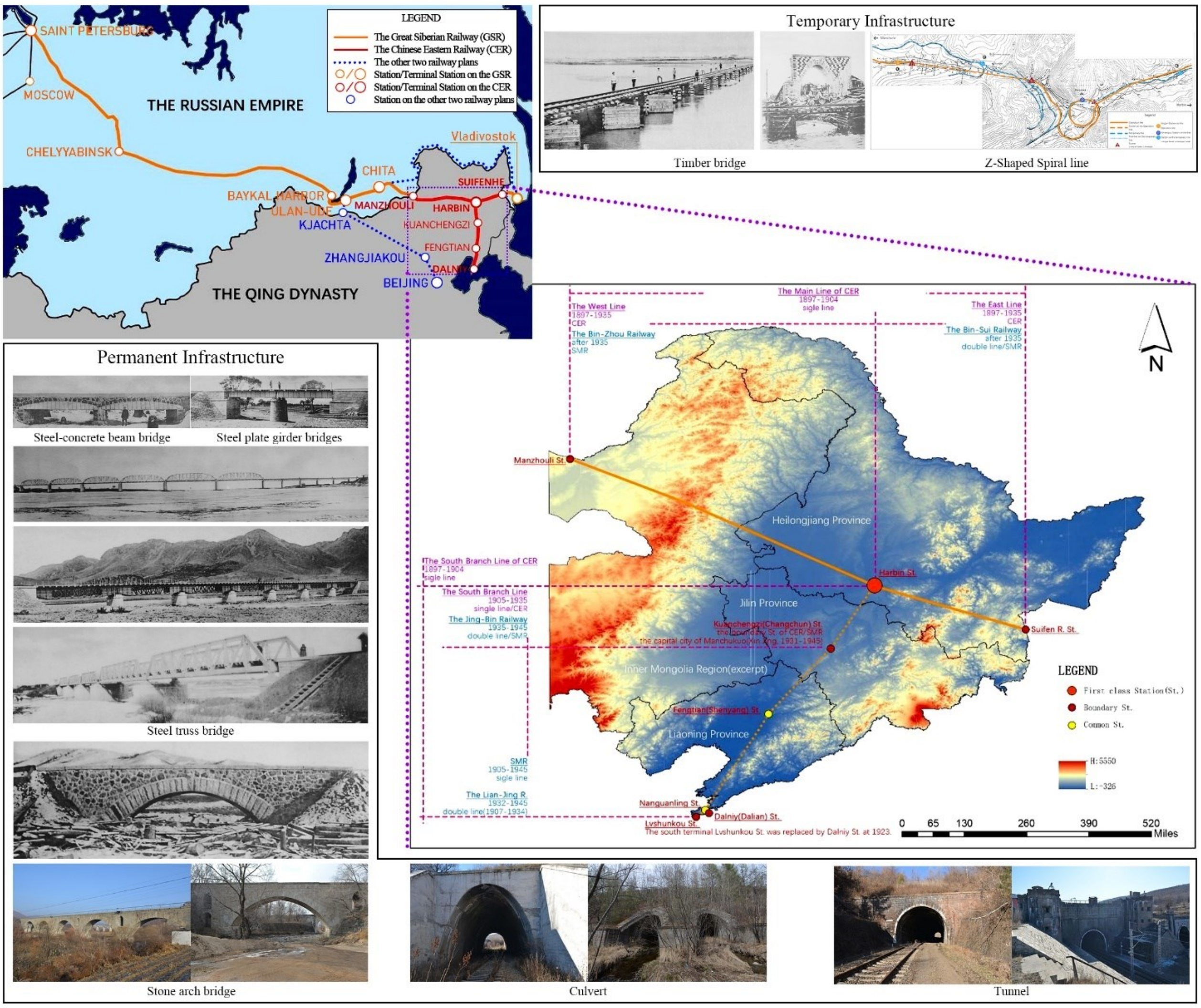

Figure 1. The railway line and infrastructure were designed by the Russians along the Chinese Eastern Railway (CER).

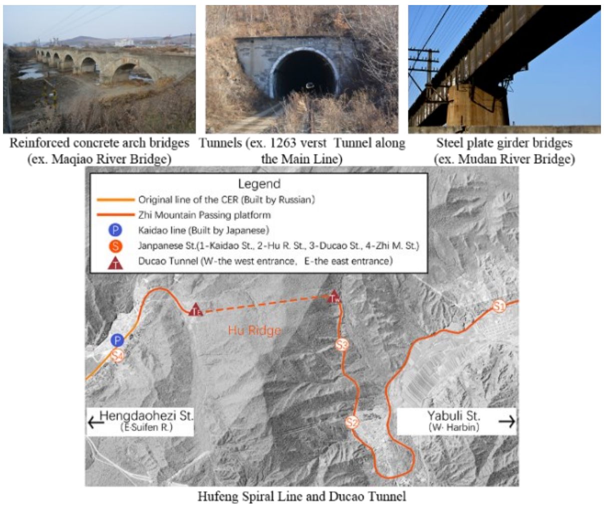

Figure 2. Classifications of the new infrastructure were built by the Japanese along the CER Main Line.

As one of the most important linear cultural and industrial heritage groups of the 20th century in China, the architectural heritage along the CER was awarded in the list: the sixth, seventh, and eighth batches of the Major Historical and Cultural Sites Protected at the National Level (MHCSPNL) (since 2006, 2013 and 2019) and the first batch of the China Industry Heritage Protection List (since 2018). Moreover, it is representative of the highest technical achievements of the CER. The administration, the researcher, and the public always pay the most attention to the conservation and restoration of the architectural heritage along the CER in China. Since 2006, they have awarded a total of 241 historic buildings in seven cities, which include public buildings (churches, schools, courts, consulates, and so on), railway-affiliated buildings (stations, water towers, factories, locomotive garages, office buildings, and so on), and staff residences (villas and dormitories), protected at the Nation Level. Unfortunately, in contrast to the architectural heritage with high attention, there are only three infrastructures which include the Khing'an Tunnel, the King'an Loop Line, and the Songhua River Bridge were awarded on the MHCSPNL (see Fig. 3). For a too long time, the authorities have focused only on their using value for the railway operation, neglecting the technical, aesthetic, and commemorative value of the heritage, and thus the conservation of the heritage has lagged that of the architectural heritage along the line. The mentioned system was needed to build for the heritage in poor states of conservation.

The King'an Tunnel The King'an Loop Line The Songhua River Bridge

Figure 3. Infrastructures and their identification plates at the National Level along the CER Main Line.

2. CONSERVATION DIFFICULTIES OF THE INFRASTRUCTURE HERITAGE ALONG THE CER

Buildings and towns, which were built and established by the CER, have not been identified as heritage for a long time after they were finished at the beginning of the 20th century. In 2006, the situation started to change, since some buildings in the Heilongjiang Province were awarded to the list. Four years since 2013, large-scale fieldwork on the cultural heritage along the Main Line had been carried out by the research program (No. 51278139) (see Table 1). Meanwhile, related research on the heritage's illustration characteristics and conservation methods has been established. Subsequently, a series of research that applied multiple methods was selected to be financed by the National Natural Science Foundation of China (NSFC) (see Table 1). By analysing the completed research on architectural heritage conservation along the CER, most topics are focused on two key points: (1) architectural heritage characteristic illustration, conservation strategies and renovation techniques, (2) construction of a basic database of the architectural heritage distributed in cities along the line. Since the restriction of the conservation technical development and supporting funding at that time in China, most results were achieved with the help of traditional and man-powered surveying and mapping methods. Fortunately, advanced analysing, management, and acquiring tools such as GIS (Geographic Information System) were applied in two programs to build databases of the CER's architectural, urban, and rural heritage. Based on published papers from the implementing program No.52078238 – i.e., the first research program funded on this topic –, which applied BIM in heritage conservation along the CER, point clouds have been collected to record the status quo of some remaining small-scale architectures. Examples include the Former Site of the Russia Military Officer Camp in Changchun City, the Yaomen (now called Dehui) station, and the architectural heritage in Gongzhuling City. Then they reconstructed digital models only using current point-cloud data and BIM (see Chang and Mo, 2022; Liu and Mo, 2022; Jia and Mo, 2022). In Figure 4 some buildings investigated in this program are reported.

Compared to the architectural heritage along the line, especially for those parts located in urbanized areas, the research and conservation of infrastructure heritages along the CER only received little attention from the cultural heritage conservation sector and the public administration. This fact may be caused by the following three reasons: (1) the isolated and remote location of the heritage causes difficulties in mapping, surveying, and protection; (2) the re-use and functional transfer of those heritages are less profitable than that architectural heritage with interior spaces; and (3) the research involves pieces of knowledge of the cross-linguistic and interdisciplinary such as Russian and Japanese, the design and construction methods of the civil engineering in both countries and so on.

No.	Research Program	PI/Univ.	Category	Amount	Duration	Keywords	Method/
5127 8139	Research on the Cultural Characteristics of the Modern Architecture of the Chinese Eastern Railway and its Conservation from the Perspective of Cultural Route	Prof. Liu Daping HIT	GP	800K CNY	2013/ 2016	Modern Architecture of the CER, Cultural Route, Cultural Characteristics, Heritage Conservation	Mapping and Surveying, Value evaluation, conservation Strategies
5127 8141	Research on the Industrial Cultural Heritage Corridor of the CER	Prof. Shao Long HIT	GP	760K CNY	2013/ 2016	CER, Industrial Cultural Landscape, Heritage Corridor, Living Protection	Space syntax, GIS
5130 8144	Research on the Construction of a Basic Database of Cultural Heritage Along the CER (Heilongjiang Section)	Prof. Zhu Haixuan HIT	YP	250K CNY	2014/ 2016	CER, Cultural Heritage, Value Evaluation Database, GIS	GIS
5137 8137	Research on Frost Damage to Heritage Buildings in Cold Areas and Their Conservation and Renovation Techniques	Prof. Liu Songfu HIT	GP	800K CNY	2014/ 2017	Cold Area, Historic Building, Frost Damage, Conservation, Renovation Techniques	Fieldwork, Mapping and Surveying
4147 1128	Research on the Evaluation of the Value of the CER in the Perspective of the Industrial Heritage Corridor	Prof. Cui Weihua DUFE	GP	820K CNY	2015/ 2018	CER, Industrial Heritage Corridor, Value evaluation, CVM, Heritage Geographic	Contingent Valuation Method (CVM)
5207 8238	Research on the Morphological Composition and Conservation Mode of the CER Industrial Heritage Corridor based on Digital Technology	Prof. Mo Wei JAU	GP	580K CNY	2021/ 2024	-	BIM, Point cloud

Table 1. The information of research programs was financed by the National Natural Science Foundation of China since 2013 (the general and youth programs are short as GP and YP; Harbin Institute of Technology, Dongbei University of Finance and Economics, and Jinlin Architecture University are short as HIT, DUFE and JAU) (NSFC, 2023).

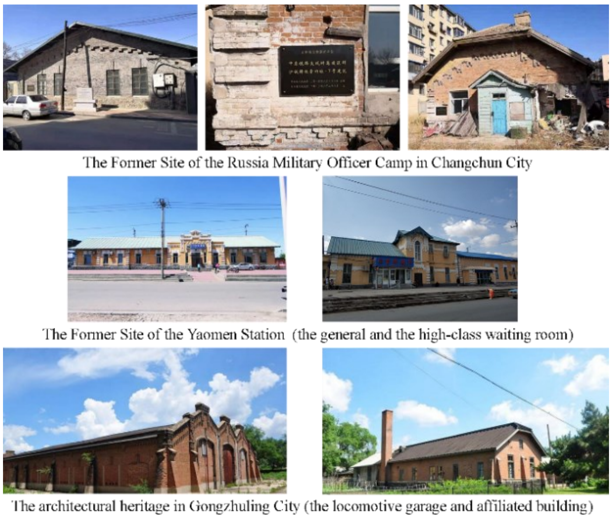

Figure 4. Research objects of the implementing program (No. 52078238) supported by the National Natural Science Foundation of China (NSFC).

3. CURRENT RELEVANT RESEARCH FOUNDATION OF THE CULTURAL HERITAGE ALONG THE CER

With a constant decade effort, the research which focused on the CH of the CER has received considerable progress in the field of characteristic illustration of architectural and landscape heritage. Based on the search result of CNKI® (China National Knowledge Infrastructure) with the topic "Chinese Eastern Railway" and "architecture" or "heritage", we can find three significant institutions which have published papers on these topics. Two of them are in Harbin, where the sole first-classed station and the intersection of the Main Line and the South Branch Line are located, i.e., Harbin Institute of Technology (HIT) and Northeast Forestry University (NEFU). Another institution – Jilin Architecture University (JAU) – is located in Changchun (Kuanchengzi) which was the boundary station of the CER and South Manchuria Railway (SMR) along the track direction. CNKI® has many sub-databases such as China Academic Journals Full-text Database, China Dissertations Database, and so on. This project was co-managed by Tsinghua University and the Ministry of Education, Science and Technology and other administrations of the P.R. China. Meanwhile, we can only find some journal papers (Zhao and Wang, 2012; Zhao and Li, 2012; Li et al.,2022) on the topic of "CER" and "architecture" in the Web of Science® (WoS), and all of them were published by researchers from HIT (see Figure 5).

Up to date, both the quantity and the quality of the research which was principled by the research group led by Profs. D. Liu and Y. Wang from the School of Architecture of HIT, have made a number of significant contributions in this field, such as Liu and Li (2018), Liu and Wang (2018), and Liu et al. (2020).

Compared to the abundance of research fields on features illustration and conservation methods of the architectural and landscape heritage along the CER, the infrastructure heritage has been rarely mentioned except for a few papers and books which only introduce simple types and values (Zhang and Liu, 2020), drawings, and pictures (Liu et al., 2020). Based on my past three-year research, those heritages are not only the temporal typical symbol of advanced design methodologies and construction technologies, but also the representation of culture, art, aesthetic, and science transmission and interchange. Many grand and record-breaking infrastructures were constructed such as the first 3-km-long tunnel (Khingan Tunnel) in Asia and China, the first nearly 1-km-long truss bridge in China (First Songhua River Bridge), and steam rock drill, wooden-iron caisson, and moveable beam girder-erecting machine and other technologies were applied at that time (Xu, 2022; Xu and Wang, 2022).

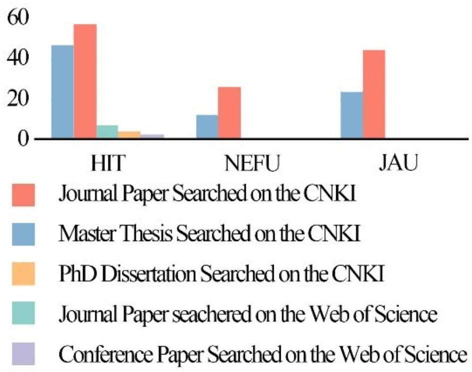

Figure 5. The research results of architectural and landscape characteristics along the CER are based on the CNKI® (China National Knowledge Infrastructure) and the Web of Science® (WoS).

4. DEVELOPMENT AND APPLICATION OF THE HBIM IN CHINA AND EUROPE

During the past decades, the applied scopes, and scenes of BIM (Building Information Modelling) were expanded from the life-cycle management of new buildings to the existing buildings, especially for the CH since it had been coined. In 2008, the first usage of BIM for an existing building was discussed and studied in Arayici (2008). The research provides useful methods on BIM for the structure of those existing buildings and implements in a historic building through the point-cloud data which was captured by laser scanning (Logothetis et al., 2015). Though many researchers and groups are focusing on this field around the world through searching the WoS, the relevant advanced technologies were widely applied and developed in Europe, especially in Italy, which hosts abundant CH resources and the largest amount of world heritage (see Table 2).

Many architects, archaeologists, conservationists, and engineers regard BIM as a disruptive force, changing the way professionals can document and manage a construction project. For developing countries with abundant heritage resources and wide distribution, HBIM (Heritage Building Information Modelling) is an innovative method which will save labour and time costs, replace the traditional investigation ways and improve accuracy in field works. Meanwhile, some different geoinformatics tools and methods have been applied to heritage conservation in both developed and developing countries (Vacca et al., 2018), such as close-range photogrammetry and Terrestrial Laser Scanning (TLS), which have been extensively applied together for detailed 3D modelling of CH artefacts and large sites (Scaioni, 2005). 3D modelling with CAD, by integrating historical sources with present-day 3D data, is also a form of documentation that, once georeferenced as in CityGML models, maintains accurate spatial and geometric features (Dore and Murphy, 2012). Based on current situations, China has to try to enlarge the applied scopes of HBIM for CH conservation and recording from the digitization project of the national symbol monument, the Forbidden City (Chang, 2021), to other key ones such as the

Great Wall and the Foguang Temple. Compared to the digitization research on the conservation of architectural heritage with systematism, network and integration, the methods and technologies which were applied to CER obviously are still in the primary stage, which finished a few small-scale buildings around the station areas along the south branch line only using point clouds and ignoring the historic data and CityGML models (Chang and Mo, 2022; Liu, 2022; Jia, 2022). These methodologies and technologies have not been applied to the recording and conservation practice of the infrastructure heritage along the CER.

Bridges located in multiple terrains supporting the railway to overcome different geographic barriers are a vital part of the whole infrastructure heritage with diverse classifications and a large proportion. BIM for bridges sometimes also was referred to as Bridge Information Modelling (BrIM) (Barazzetti et al., 2016), and applied to record the status quo of a historic bridge as a part of the lifecycle management. Most of the surviving historic bridges in Europe were designed or constructed as arch bridges (León-Robles et al., 2019). However, the modelling of the arches was not simulated accurately since the shortage of Autodesk Revit®, which is a popular commercial BIM platform. Some research groups have started to exploit the NURBS -Based method to solve this lack and successfully applied to some complex objects' reconstruction (Barazzetti et al., 2015; Banfi, 2019). Furthermore, the research on the reconstruction of iron/steel structure of bridges or buildings are almost an unexploited field in both Italy and China, but the group from the University of L'Aquila has tried to exploit and made a workflow for modelling with HBIM (Morganti et al., 2019).

Country	Affiliation	Department	Search results
Spain	University of Sevilla	Inst Architecture & Bldg Sci IUACC; Dept Expres Graf & Ingn Edificac	34
	Universitat Politecnica de Valencia	Sch Art Design & Architecture; Inst Restaurac Patrimonio; Graph Express Dept	10
Italy	Politecnico di Milano	Dept. of Architecture, Built Environment and Construction Engineering	55
	Politecnico di Torino	Dept. Architecture & Design	28
	Marche Polytechnic University	Civil Construction and Architecture Engineering Dept.	15
	The Institute of Heritage Science	Consiglio Nazionale delle Ricerche (CNR)	13
	Politecnico di Bari	Dept. of Civil, Environmental, Land, Building Engineering and Chemistry	12
	University of Florence	Dept. of Civil and Environmental Engineering	12
	Sapienza University of Rome	Dept. Hist Represented & Restored Architecture	11
	University of Naples Federico II	UNINA	11
China	City University of Hong Kong	Dept Math	8
	Tianjin University	Sch Architecture	6

Table 2. The main research groups of HBIM (Heritage Building Information Modelling) in Europe and China are from the WoS.

5. THE INTEGRATION OF EXTERNAL DATA, GIS AND HBIM

HBIM is not only an advanced method and tool which can reveal the historical changes and record the different status of the heritage, but also the foundation of the administrative department's management to protect the heritage sustainable development and exhibition online to feedback to the stakeholders and the public (Vacca et al., 2018). Those rated as important CH objects, including architecture, structures, landscapes, and sites, for a region or country always had experienced many different stages which were divided based on the reasons such as special events and construction activities (Yang et al., 2020). Based on these reasons, as a principal component of the CH, much external data such as the design drawings, pictures, mappings, and relevant research, was produced during the long exchanges. To keep the integrity and sustainable conservation of heritage, those data also should be integrated into the HBIM as same as the recordings of the status quo and the restoration processes of the CH. Meanwhile, sustainable preservation also includes the meaning of preventing the CH from anthropogenic and natural threats such as earthquakes, flooding, fire and urbanization. However, it is regrettable that prevention actions sometimes being the only remedy for those who cherish CH (Agapiou et al., 2015). So, the data from remote sensing which has shown great potential as an important tool for the protection and prevention of monuments and sites also should be integrated with HBIM together.

This aim causes some questions such as the compatibility between the formalization of information in the BIM model, and what limitations are inherent in current software implementations to establish a connection with external resources (Cursi et al., 2022). The research shows that there is no single way to fully "integrate" data across the different resources involved. Different applications and even specific users of the same applications see the same data in different ways, and specific workflows rather than an overall approach can be supported. The large-scale/linear heritage, e.g., canals, railways, ports, and other types of transportation heritage, and the monument located in the risky surrounding environment are always the important research object. In a changing history, those heritage has accumulated abundant historic data, including design drawings, figures, archive records, and relevant research results, which is an essential foundation for their integrity conservation. Meanwhile. collecting heritage geographic information can contribute to protecting heritage integrity, improving protection accuracy in daily work, and enhancing management efficiency. Therefore, it is significant that collect and integrate the historic data and the geographic information together into the HBIM for sustainable conservation and intensity of the heritage. But the way of compressing the data size has constantly disturbed the researchers. Barazzetti (2021) exploits a novel prototype of integrated Historic BIM-GIS able to deal with multi-source, -scale, and -temporal information which combines elements from the cartographic scale to a more detailed level-of-detail towards the objects.

Moreover, in the conservation and management of infrastructure heritage, integrating HBIM/GIS is an effective and appropriate method. Indeed, the HBIM approach allows the reconstruction and modelling of individual elements (see Figure 5), while GIS allows for considering the geospatial extension of the historical railway line (Garramone et al, 2020; 2022). Especially for the infrastructure heritage along the CER with numerous and diverse types of elements, introducing this new method to preserve the heritage will build a solid and cooperative background for both the heritage conservation sector and stakeholders from both sides. From the conservation perspective, almost the heritage stayed in a vulnerable and unprotected situation, and it's urgently required to build a geographical information database for their sustainable conservation. Therefore, we collected geographical coordinates of the heritage, which locates in places that are easy to reach, using on-site GNSS records during the past three years. As well as we collected data on other inaccessible heritage with Google Earth®. There are three main reasons why the on-site collection is not possible: (1) the heritage locates in the Border Management Area such as the five Wanglong Mountain Tunnels; (2) the heritage is controlled by the Administration of Railway, for example, the King'an Tunnel; (3) the heritage locates in a remote area. Completed the mentioned collection, we created a basic database for the remaining heritage using ArcGIS® 10.2 and add historic information (Cursi et al, 2022) based on the systematic collection and collation (see Figure 6). The database consists of the following items of every infrastructure: identification code, region, geographic coordinates, type, structure form, status quo, protection level, current function, status description, technical achievements, design drawings, and historical photos. At the same time, facing such a massive volume of data and the compatibility of different software packages, it is worth exploring problems such as efficient processing data storage and integration of data cross-platform.

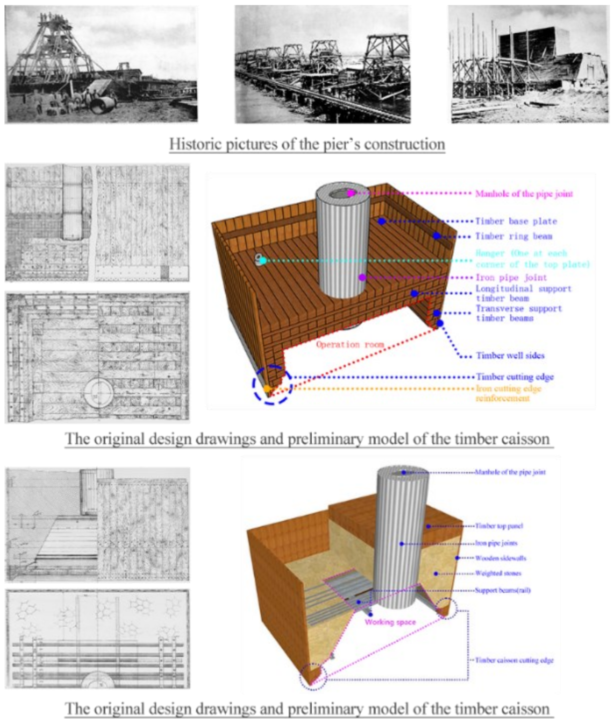

Figure 5. Caisson's details and the reconstructed modelling (Chinese Eastern Railway, 1900).

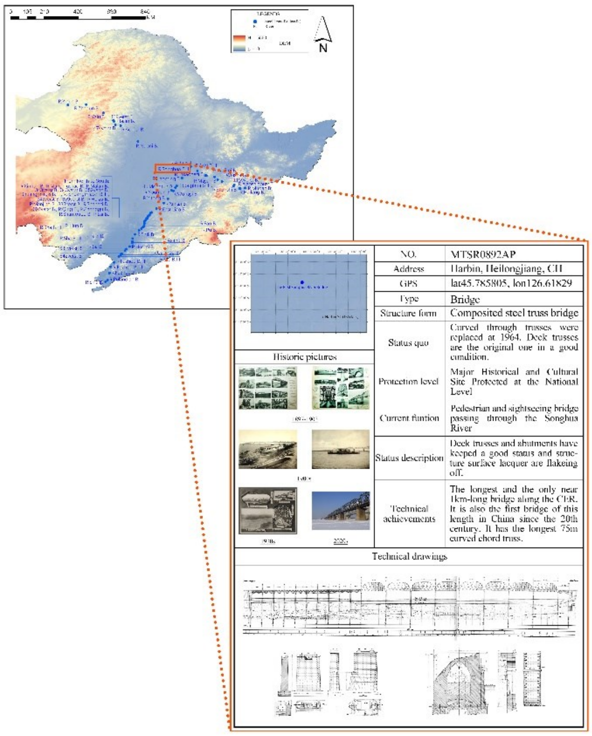

Figure 6. The distribution of the truss bridge built by the CER and the examples of the database in this stage for the first Songhua River bridge.

6. SUMMARY

Combined with the research topic and the current research results, the HBIM for the infrastructure heritage constructed by stone and concrete such as the stone bridges mentioned, has accumulated a great deal of experience with the technologies development of point-cloud acquisition and processing as well as other surveying/mapping techniques. However, the reconstruction methods and practices for the heritage with steel structures have been explored by the researchers. Most of them focus on a single research object or a group having many objects located in a small-scale region. Distinguishing from previous studies, the research object with steel structures in this study has obvious features such as abundant classifications, structural diversity, multiple construction methods, and large-scale distribution.

To summarise, integrating HBIM/GIS to conserve the infrastructure heritage along the CER Main Line is feasible. Meanwhile, some challenges probably need to be addressed in the following study: (1) the digital reconstruction of the infrastructure heritage with complicated structures and structure deformation; and (2) the integration of large volumes of data. For the former, the vanished structure can be reconstructed through the deep comprehension of the design drawings and the knowledge of construction engineering at that time. While the reconstruction of the remaining structure needs to consider the influence of transformations and damages. The infrastructure heritage has accumulated an amount of historic data over the past one hundred years. The following study needs to explore how to integrate those various types of data including historic data, geographic information, and digital modelling for achieving sustainable conservation.

7. CONCLUSIONS AND FUTURE WORK

The paper reviews the current research results on the infrastructure heritage along the Main Line of CER (Chinese Eastern Railway) and analyses the possibility of applying an integration HBIM (Heritage Building Information Modelling)/GIS (Geographic Information System) way to preserve and valorise the crucial infrastructure heritage and its historic data in a sustainable way.

Rarely received attention, the infrastructure heritage along the Main Line of CER is vanishing and being threatened by both human and natural factors. The reconstruction of these remained, vanished, and concealed heritage with BIM (Building Information Modelling)/HBIM required support from advanced technical methods, as well as accurate mapping and surveying. Meanwhile, geographical data collection and the creation of a preliminary database of the heritage in this stage provide a solid basement for heritage management using GIS. Moreover, introducing the integration of HBIM/GIS will become a shared and sustainable platform for conserving the heritage, which is an effective and profound way to integrate all types of historic data.

ACKNOWLEDGEMENTS

The work reported in this paper was supported by the China Scholarship Council (No. 202206120044). Acknowledgement also goes to the China Geospatial Data Cloud. The support of fieldwork and study from Profs. Yan Wang and Daping Liu (Harbin Institute of Technology) are appreciated.

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