

A SYSTEMATIC LITERATURE REVIEW OF BUILDING INFORMATION MODELLING (BIM) APPLICATION ON RAILWAY ASSET MANAGEMENT

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Abstract

Building Information Modelling (BIM) has become a prominent trend in the built environment. Despite numerous countries mandating the adoption of BIM in this context, its integration into transportation infrastructure, notably railways, has progressed gradually. Asset Management (AM) continues to be emphasised in transport infrastructure. This study offers an understanding of BIM-based AM in railways via a systematic literature review (SLR). Although some studies delve into railway BIM-based applications across various life cycle phases, previous research has predominantly centred on the operation and maintenance phases. This paper presents a comprehensive view and proposes further research direction.

Introduction

Building Information Modelling (BIM) has a unique characteristic and can be found in the definitions from the standard, academic and industry fields. Nonetheless, a common thread across these definitions underscores the significance of features such as process, information, and life cycle considerations (British Standards Institution, 2013; International Organization for Standardization, 2018; National Building Specification, 2021). BIM is acknowledged in the academic field for its numerous benefits. Wang *et al.* (2013) arranged the BIM's various advantages: decreased costs, reduced errors, improved estimation, improved coordination, identifying conflicts and enhanced clients' and end-users understanding. Shin, Jung and Kim (2022) and Shin, Kim and Liao (2024) found meaningful benefits through their research on BIM implementation in the design and construction phase of the railway sector, such as cost and management aspects. Based on these advantages, governments across the globe, regardless of their geographical location, are opting to mandate the use of BIM in the built environment. Among them, the United Kingdom is positioned as a leading country globally in the application of BIM (Jaskula and Papadonikolaki, 2021).

Nevertheless, BIM is still slowly being adopted in transportation infrastructure, especially linear transportation infrastructure (e.g. railways, roads, gas pipelines, power lines, rivers and canals). Unlike buildings or other entities, transportation infrastructure's considerable size and intricacy contribute to the relatively recent initiation of BIM adoption. Notably, the application of BIM in railways is often referred to as being in its infancy (Han *et al.*, 2018).

As previously mentioned in the definition of BIM and its ultimate purpose, it is noted that it considers the lifecycle. The BIM lifecycle simply refers to the product lifecycle process, which consists of the concept, design, construction, operation, demolition and disposal (Gajera, 2017). Additionally, the term "sustainability" is a crucial global focus. Through the announcement of SDGs Goal 9, the United Nations emphasises the sustainability of infrastructure. In this paper, the perspective of sustainability is examined through an Asset Management (AM) approach. First, PAS 55- 1 defined the AM definition as 'systematic and coordinated activities and practices through which an organisation optimally and sustainably manages its assets and asset systems, their associated performance, risks and expenditures over their life cycles for the purpose of achieving its organisational strategic plan' (British Standards Institution, 2008, p.2). AM is not a novel concept, but AM is considered a relatively new discipline in the transportation infrastructure field because of the recent need to perform the lifecycle management is necessary for this domain (Garrazone, Tonelli and Scaioni, 2022). Alnaggar and Pitt (2019) emphasised that BIM has a big potential in the AM sector.

Among linear transportation infrastructures, railways are environmentally friendly with low carbon emissions. They possess numerous advantages, including the ability to transport a large number of people at once and minimal traffic congestion. Consequently, they continue to garner significant global attention as transportation. Hence, the purpose of this paper is to explore a comprehensive perspective on railway infrastructure asset management using BIM.

This paper mainly comprises four sections. First, the introduction part consists of background information and general understanding. Second, the research methods part demonstrates this paper's systematic literature review (SLR) process. Third, the results and discussion section includes the SLR results and explains them. Finally, the conclusion summarises the overall contents of this paper.

Research Methods

This paper aims to investigate the BIM-applied railway infrastructure AM from a comprehensive point of view. To achieve this, this study conducted a systematic literature review (SLR), which adopted the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) methods, as illustrated in Figure 1.

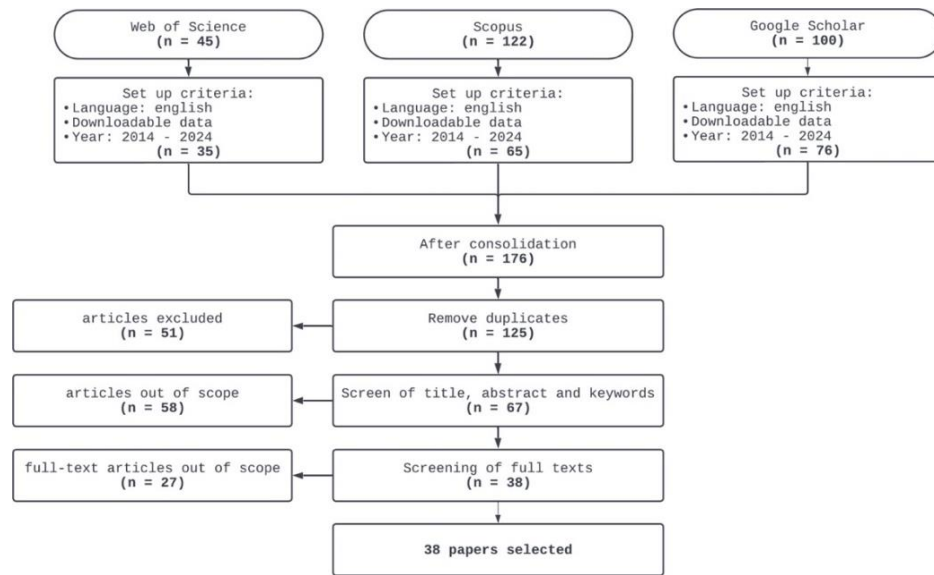


Figure 1: SLR flow chart (adopted the PRISMA method).

First, the authors decided on the keywords for BIM-based rail infrastructure AM. This study's main keywords are BIM, railway and AM. The keywords for searching in the database are set in Figure 2. The reason why the keyword "life cycle" is used not only the keyword AM, because the extended area of AM contains the consideration of the life cycle. Therefore, this review includes the term life cycle to cover all aspects of AM rather than just one specific part of it.

(BIM OR "building information modelling" OR "building information modeling" OR "building information model") AND (AM OR "asset management" OR "life cycle") AND (rail OR railway OR railroad)

Figure 2: Keywords.

This review selected three databases: Web of Science, Google Scholar and Scopus. At first, a total of 267 papers were found from three selected databases. Several criteria were used in SLR in this study. First, the language used is limited to English. Second, the article only includes the downloadable data. Third, the range of years is between 2014 and 2024. BIM is deeply related to cutting-edge technology. Hence, the literature's publication dates are only considered for the past 11 years. These years include the years when BIM exploded in popularity. Fourth, this SLR includes the grey literature (such as conference papers, books and proceeding papers). Including grey literature in this study is important because it allows us to include more current trends and ongoing research. By applying the criteria, approximately 176 papers were selected from the first 267 papers.

The combined search outcomes of three databases, as per four specific criteria, yield a total of 176 scholarly articles. After identifying 51 duplications among the 176 aggregated papers, the resultant set comprises 125 non-duplicated papers. From this point onward, authors examined titles, abstracts, and keywords to filter out relevant papers. In this procedure, 67 papers were

identified after excluding the out-of-scope of 58 papers. This study examined all 67 identified documents in the last phase, verifying their relevance. Consequently, the final 38 papers align with the included scope.

Results and Discussion

Results

The 38 identified documents focus on the scope of asset management in railway infrastructure with the implementation of BIM. This SLR investigated papers from 2014 to 2024. Figure 3 shows a gradual increase in the number of papers published. The papers in this review were not published in 2015 or 2024. The years 2021 and 2023, in particular, saw a sudden drop in the published literature than the previous year. The most recently published papers were in 2023, totalling six papers.

In this SLR study, beyond the exclusive analysis of journal articles, this review encompasses grey literature, including conference papers and conference proceedings. The conference category includes both conference papers and proceedings. Specifically, there are 21 journal articles, comprising 55% of the total, and 17 conference papers, representing 45%. An observation is that more proportion of the papers analysed in this review originated from journals.

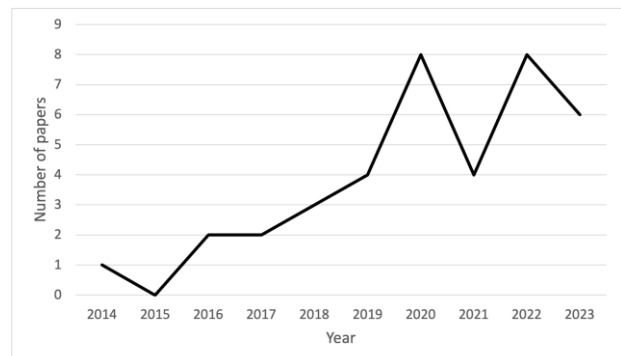


Figure 3: Trend of the published year.

Figure 4 illustrates the percentage of paper types by year. This figure consolidates the observations from published papers years, which are illustrated in Figure 3, and the types of papers published. It visually represents the proportion of papers published each year by type.

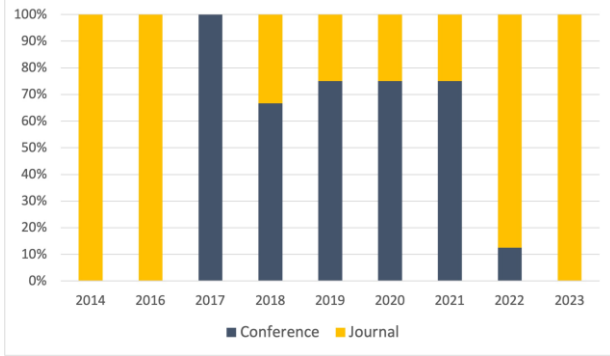


Figure 4: Percentage of paper types by year.

Conducting an SLR on Railway AM with the application of BIM, diverse applications of BIM were witnessed in Figure 5. This included not only the exclusive use of BIM but also the integration of other intelligent technology with BIM, OpenBIM, the application BIM with Industry Foundation Classes (IFC) and System Information Modelling (SIM), the combination with Geographic Information Systems (GIS), the extended application of BIM like the Digital Twins (DT) and the application of BIM in other infrastructure.

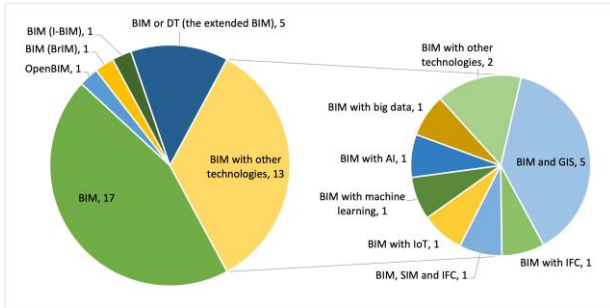


Figure 5: Used BIM classification.

Figure 6 presents a diagram designed to investigate the areas within railway infrastructure where BIM has been applied. The most extensively covered segment, accounting for 38% of instances, involves 12 papers providing a railway. The category of railway-related buildings is closely followed, representing 7 papers. Five papers delve into the application of BIM to railway bridges. Additionally, railway lines, tracks, tunnels and transportation infrastructure are investigated by applying BIM in each of the 2 papers. Lastly, the railway signal, turnout system, and light rail system were studied in one paper with BIM for AM, respectively.

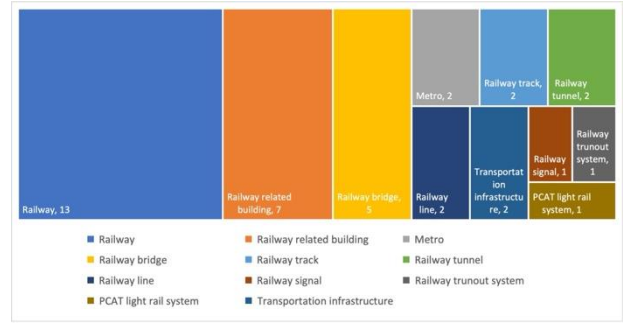


Figure 6: BIM-applied objects.

Next, an exploration was undertaken to identify the stages or points where BIM has been applied, as depicted in Figure 7. A notable observation is that around 13 papers focused on utilising BIM for AM during all stages of the life cycle. A total of 22 papers were studied related to the design phase, and a total of 17 papers were researched in the construction phase. The operation & maintenance (O&M) phase conducted the AM based on the BIM around 27 studies. Two papers considered the rehabilitation stage.

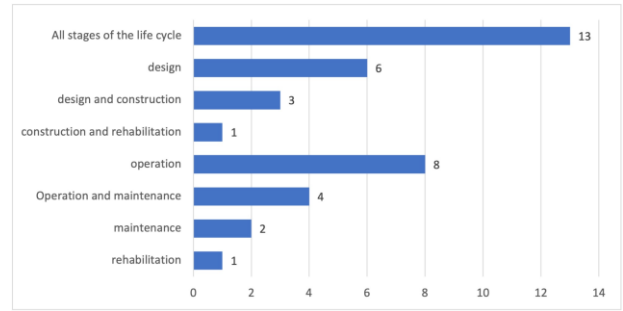


Figure 7: BIM used phases.

The papers analysed in this SLR aimed to implement BIM in railway infrastructure to facilitate AM. The different methods performed to manage AM are summarised in the literature according to the phase in which BIM is applied, as shown in Table 1. The literature shows that there are many different ways to perform AM by each phase.

Table 1: Studies employed to attain the objective at each stage.

Asset Management		
All stages of the life cycle	Propose the BIM-based approach	(Dan, 2021; Zheleznov, 2021; Alqatawna et al., 2023)
	Investigate the current situation of BIM and provide the countermeasures	(Kurwi, Demian and Hassan, 2017; Han et al., 2018; Belcher and Abraham, 2023)

Design stage	Propose the new applications of DT (extended BIM)	(Kaewunruen and Lian, 2019)
	Suggest the application of BIM	(Cheng <i>et al.</i> , 2019; Kaewunruen, Peng and Phil-Ebosie, 2020; Wang <i>et al.</i> , 2022)
	Propose the data exchange model	(Gu <i>et al.</i> , 2022)
	Combine the application of BIM with other technologies	(Gebken, Drews and Schirmer, 2019; Wan <i>et al.</i> , 2020)
	Propose the BIM-based approach	(Lv, 2018; Efanov, Shilenko and Khoroshev, 2020; Pasetto <i>et al.</i> , 2020; Liu, 2022)
	Investigate the current situation of BIM and provide the countermeasures	(Sanchez <i>et al.</i> , 2014; Akponeware <i>et al.</i> , 2020)
	Introduce safety design, risk evaluation system and related theories of BIM	(Xiahou <i>et al.</i> , 2022)
	Suggest the application of BIM	(Chen, Hu and Tang, 2016)
	Provide the insight of BIM/GIS interoperability	(Floros, Ruff and Ellul, 2020)
	Propose the BIM-based approach	(Großauer <i>et al.</i> , 2022; Liu, 2022)
Construction stage	Provide the insight of BIM/GIS interoperability	(Floros, Ruff and Ellul, 2020)
	Suggest the application of BIM	(Chen, Hu and Tang, 2016)
	Develop the BIM-based methodologies	(Wang <i>et al.</i> , 2020; Ciccone <i>et al.</i> , 2022)
Operation and Maintenance stages	Investigate the current situation of BIM and provide	(Liu <i>et al.</i> , 2023)

Rehabilitation stage	the countermeasures	
	Develop a suitable platform based on BIM	(Hartung, Senger and Klemmt-Albert, 2019; Hartung <i>et al.</i> , 2020)
	Introduce the new approach to digital asset management	(Love <i>et al.</i> , 2018)
	Combine the application of BIM with other technologies	(Boyce, Ellul and Irwin, 2017; Sresakoolchai and Kaewunruen, 2021, 2023; Garramone, Tonelli and Scaioni, 2022)
	Propose the new applications of DT (extended BIM)	(Kaewunruen, Sresakoolchai and Lin, 2021; Kaewunruen <i>et al.</i> , 2023)
	Develop a real-time lifecycle assessment-capable paradigm digital twin framework	(Borjigin <i>et al.</i> , 2022)
	Propose a solution within the existing CAD/BIM/GIS application	(Bartonek <i>et al.</i> , 2023)
	Suggest the application of BIM	(McKenna <i>et al.</i> , 2017)
	Propose the BIM-based approach	(Großauer <i>et al.</i> , 2022)

Discussion

1) Current

Figure 3 captures related research trends that seem to be increasing overall. The lack of published papers in 2024 is likely due to the fact that the papers have not yet been published at the time of this review. Although the change is not dramatic and fluctuates between 2020 and 2023, it still showed a rising interest in the relevant keywords in recent years. In other words, the escalating quantity of published papers can be interpreted as a meaning of an intensifying interest in the associated keywords, signifying rising scholarly attention to these subjects. Figure 4 demonstrates the proportion of published paper types by year. The research was found to be ongoing, with a balance of journal articles and conferences being published. Figure 5 shows the current research on BIM type. While the use of only BIM remains prevalent, a

noticeable adoption of BIM in more complex integrations has also been observed. For example, BIM for infrastructure, open BIM, BIM with SIM and IFC, BIM/GIS, extended BIM (DT) and BIM with other technologies. There were noteworthy attempts to expand its applications through various methods.

In the AEC sector, architecture is widely known as the domain where BIM has been most effectively applied and advanced. It was assumed that the reviewed studies would primarily focus on building research. However, Figure 6 revealed that BIM is utilised in a much more comprehensive range of areas. Likewise, the expectation was that most research would be confined to design and construction; however, it was observed to be applied across various domains, especially O&M. Figure 7 illustrates the diversity of BIM application phases. This indicates its diverse application from design to redecoration and its multifaceted implementation across multiple stages, not only the O&M phase. This illustrates the potential of BIM's diverse field of applications, further extending to all stages of the lifecycle.

Table 1 highlights the BIM-based AM. Each study was conducted using various methods at each stage to achieve its objectives. The design and construction phases have been studied in common research: suggest the application of BIM, investigate the current situation of BIM and provide countermeasures, propose the BIM-based approach, and provide insight into BIM/GIS interoperability. In the O&M phase, there were also studies such as the BIM-based approach, investigating the current situation of BIM and providing the countermeasures, but also the development of BIM with other technologies, platform construction, and DT (extended BIM) related studies were characterised differently from other phases. The methods used in all stages of the life cycle use most of the methods used in other stages. BIM application and a BIM-based approach were proposed for the rehabilitation phase. A common method used throughout the entire phase to apply BIM for AM was the proposed BIM-based approach. It can be seen that a lot of research has been done to study BIM-based approaches.

On the other hand, the challenges have been noticed in papers. In general, while the authors explained that they needed to improve their study, scholars emphasised the limitations of their studies, such as the specific performance of the application of BIM (Chen, Hu and Tang, 2016), information exchange (Floros, Ruff and Ellul, 2020; Kaewunruen, Peng and Phil-Ebosie, 2020), limitation of standards (Floros, Ruff and Ellul, 2020) and limitation of guidelines (Love *et al.*, 2018). In order to perform AM using BIM on a railway, there are obvious difficulties in terms of performance, but it is especially difficult to exchange information.

2) Future

The findings of Table 1 describe the different approaches that BIM has been used in railway infrastructure to

achieve the AM. This can be connected with future research directions that are frequently mentioned in the literature's future research section. First, many of the authors described the need to develop their studies more deeply. Therefore, future research seems to study the methods that were used more deeply, as mentioned in Table 1. Second, future studies could be proposed on the combination of Table 1 methods and the literature's mentioned limitations and future research suggestions. The keywords that are mentioned as limitations of the studies are the specific performance of the application of BIM, information exchange, and limitations of standards and guidelines. In several papers, keywords frequently mentioned in concluding remarks regarding future research directions include developing the strategy, effectiveness, efficiency, intelligence, and interoperability. In order to develop these keywords, future research might be conducted using the methods mentioned in Table 1. For example, investigating the current status of related keywords and finding the problem and countermeasure, developing a BIM-based approach, combining the application of BIM with other technologies, proposing the data exchange model, developing a new approach to digital asset management or developing the insight of interoperability.

Figure 5 demonstrates that many studies are currently conducted on BIM alone and BIM with other technologies. This indicates the potential for future applications of BIM in infrastructure AM. This shows the BIM potential of BIM integration with other complex technologies. Especially in BIM or DT and intelligent BIM, there is an emerging theme advocating for the advanced application of BIM, extending into dimensions such as 4D, 5D, 6D, and 7D, alongside the integration of various intelligent technologies. The occurrence of DT in asset management indicates a significant change towards higher integration, especially with BIM technology. This combination emphasises the need for further investigations on BIM within the context of DT. Research efforts like this are crucial for discovering innovative technologies and gaining useful knowledge about asset management. This, in turn, promotes the creation of more advanced and efficient asset management systems.

Conclusions

This paper aims to investigate the current trend and provide a comprehensive view of BIM-applied rail infrastructure AM. This paper adopts the SLR review, which includes the grey literature and uses three databases. As a result, 38 papers were selected for review. While conventional BIM applications are prevalent, research combining BIM with other technologies is also diverse. Moreover, BIM applications are conducted beyond the general railway context, encompassing a variety of targets such as buildings, bridges, systems, signals, and more. Although the majority of BIM applications for AM are concentrated in the O&M phase, they are also performed in various areas. With the current

prominence of these keywords, the research trend is expected to continue, with the anticipation of further studies. Based on the studies that have been conducted, limitations of the studies and suggestions for future research are discussed. In future research, not only research focusing on the single use of BIM but also BIM integration research incorporating various intelligent technologies is expected. Furthermore, this is expected to employ real-time data integration to implement DT, enabling holistic Asset Management.

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