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Application of BIM technologies in transportation infrastructure: current practices, barriers, and future directions

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<p>Received: 20 June 2025 Peer-reviewed: 26 August 2025 Accepted: 15 December 2025</p>	<p>Abstract Transport infrastructure plays a critical role in supporting sustainable socio-economic development; however, increasing demand and the aging of assets necessitate the adoption of more efficient, data-driven management approaches. This paper presents a comprehensive systematic review of scientific publications and applied reports on the implementation of Building Information Modeling (BIM) in transport infrastructure, including roads, bridges, tunnels, and railways. The reviewed studies are classified according to model types, lifecycle stages, application domains, and integration with other digital technologies. The findings indicate that BIM is most maturely implemented in bridge and road projects, primarily at the design and construction stages. In contrast, its application in operation, maintenance, and asset management remains limited. Key barriers include insufficient interoperability, the lack of standardized data models for linear infrastructure, and institutional constraints. At the same time, significant potential is identified in integrating BIM with Geographic Information Systems, monitoring technologies, and digital twin concepts. The results provide a structured understanding of current practices, highlight existing research gaps, and define promising directions for future BIM-driven digital transformation of transport infrastructure.</p> <p>Keywords: Building Information Modeling; transportation infrastructure; lifecycle management; digital transformation;</p>
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Көлік инфрақұрылымында BIM технологияларын қолдану: қазіргі тәжірибелер, кедергілер және болашақ даму бағыттары¹ Бенедетто А., ²Ердаулетқызы Ф.¹ Рим Тре университеті, Рим қаласы, Италия² Л.Б. Гончаров атындағы Қазақ автомобиль-жол институты, Алматы қ, ҚазақстанХат алмасу үшін автор (корреспондент-автор): verdauletqyzy.antal@gmail.com

<p>Мақала келді: 20 маусым 2025 Сараптамадан өтті: 26 тамыз 2025 Қабылданды: 15 желтоқсан 2025</p>	<p>Түйіндеме Көлік инфрақұрылымы елдің тұрақты әлеуметтік-экономикалық дамуын қамтамасыз ететін негізгі факторлардың бірі болып табылады. Алайда көлік қызметтеріне сұраныстың артуы және инфрақұрылымдық активтердің тозуы оларды басқарудың неғұрлым тиімді, деректерге негізделген тәсілдерін енгізуді талап етеді. Осы мақалада автомобиль жолдары, көпірлер, тоннельдер және теміржолдар сияқты көлік инфрақұрылымы объектілерінде BIM технологиясын қолдануға арналған ғылыми жарияланымдар мен қолданбалы есептердің жүйелі шолуы ұсынылған. Зерттелген деректер ақпараттық модельдердің түрлері, өмірлік цикл кезеңдері, қолдану салалары және басқа цифрлық технологиялармен интеграциясы бойынша жіктелді. Нәтижелер BIM технологиясының ең жоғары даму деңгейі көпір және жол жобаларында, негізінен жобалау мен құрылыс кезеңдерінде байқалатынын көрсетті. Пайдалану, техникалық қызмет көрсету және активтерді басқару кезеңдерінде BIM әлеуеті толық іске асырылмаған. Негізгі кедергілер ретінде деректердің өзара үйлесімсіздігі, сызықтық инфрақұрылымға арналған стандартталған модельдердің болмауы және ұйымдастырушылық шектеулер анықталды. Сонымен қатар BIM-ді ГАЖ, мониторинг жүйелері және цифрлық егіздермен біріктірудің жоғары әлеуеті айқындалды. Алынған нәтижелер ғылыми олқылықтарды анықтауға және болашақ зерттеулер бағыттарын негіздеуге мүмкіндік береді. Түйін сөздер: Building Information Modeling; көлік инфрақұрылымы; өмірлік циклді басқару; цифрлық трансформация;</p>
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Применение BIM-технологий в транспортной инфраструктуре: текущие практики, барьеры и перспективы развития

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<p>Поступила: 30 Июнь 2025 Рецензирование: 26 Августа 2025 Принята в печать: 15 Декабря 2025</p>	<p>Аннотация Транспортная инфраструктура играет ключевую роль в обеспечении устойчивого социально-экономического развития, однако рост нагрузки и износ активов требуют внедрения более эффективных и цифровых подходов управления. В данной статье представлен систематический обзор научных и прикладных источников, посвящённых применению BIM-технологий в транспортной инфраструктуре, включая автомобильные дороги, мосты, тоннели и железные дороги. Публикации проанализированы по типам информационных моделей, стадиям жизненного цикла, областям применения и интеграции с другими цифровыми инструментами. Установлено, что наибольшая зрелость внедрения BIM наблюдается в мостостроении и дорожных проектах, преимущественно на этапах проектирования и строительства. В то же время стадии эксплуатации, технического обслуживания и управления активами остаются недостаточно охваченными. Среди ключевых барьеров выделены проблемы интероперабельности, отсутствие унифицированных стандартов данных для линейной инфраструктуры и организационные ограничения. Вместе с тем выявлен значительный потенциал интеграции BIM с геоинформационными системами, технологиями мониторинга и цифровыми двойниками. Полученные результаты способствуют систематизации знаний, выявлению научных пробелов и формированию направлений дальнейших исследований.</p>
	<p>Ключевые слова: Building Information Modeling; транспортная инфраструктура; управление жизненным циклом; цифровая трансформация;</p>
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1. Introduction

Transportation infrastructure plays a key role in the functioning of any state, as the reliable, safe, and efficient movement of people and goods directly affects the pace of economic growth and the level of social development. Under conditions of steady population growth, combined with the physical and functional deterioration of a significant share of transportation facilities, there is an increasing need for the adoption of more efficient and economically justified technologies and methods aimed at the construction, operation, monitoring, and rehabilitation of infrastructure assets [1]. In response to these challenges, the transportation sector has experienced intensified efforts toward the development and implementation of innovative solutions, with many technologies and approaches that have previously proven effective in the building industry being adapted for use in infrastructure projects. One of the most effective technologies that has demonstrated substantial benefits in the building sector is Building Information Modeling (BIM) [2].

According to the definition proposed by the U.S. National Building Information Model Standard Project Committee, BIM represents a digital representation of the physical and functional characteristics of a facility and serves as a single, reliable source of information for decision-making throughout all stages of its life cycle, from initial conception to decommissioning [3]. The common misconception of BIM as merely a three-dimensional geometric model leads to a distortion of its fundamental essence, as the core value of BIM lies in the information itself, while the three-dimensional model is only one of the possible means of representing that information. The widespread adoption of centralized approaches to data creation, storage, and sharing has driven a paradigm shift in the Architecture, Engineering, Construction, and Operations (AECO) industry, transforming traditional design practices into information-centric and interdisciplinary collaboration processes. In both academic and professional contexts, BIM is interpreted in multiple ways—as a digital product, a collaborative process, and a lifecycle management tool [4]. The original intent of BIM was to comprehensively capture and structure all information related to the design and construction of a facility in order to support its effective operation and maintenance (O&M) phases.

Although BIM has been actively applied in the design and construction of buildings for several decades, its adoption in transportation infrastructure has been characterized by slower progress and limited practical implementation [5]. In recent years, both the academic community and industry practitioners have increasingly focused on adapting BIM to civil infrastructure assets beyond vertical construction. However, to date, a comprehensive and specialized review dedicated specifically to transportation infrastructure has been lacking. Previous review studies have addressed the application of BIM to existing buildings [6], managerial aspects of BIM implementation [7], the use of BIM as a collaborative platform and data management tool [8], civil infrastructure in a broader sense, infrastructure projects from a contractor's perspective, as well as bibliometric and scientometric analyses of global BIM research [9]. While these studies provide a broad overview of the development of BIM technologies, a systematic analysis of their application to transportation assets—such as bridges, highways, and road networks—remains insufficiently represented in the literature.

In this context, the present paper aims to develop a comprehensive and up-to-date review of studies focused on the application of BIM in transportation infrastructure. The main objective of the study is to provide a critical analysis of existing research directions and practical implementations of BIM in order to identify key trends, challenges, and unresolved issues, as well as to determine perspectives for future research and applied developments. The paper examines current application domains of BIM, the digital technologies employed, their advantages and limitations, and the identified research gaps and emerging needs of the industry. In addition, the study seeks to establish a coherent direction for future research and interdisciplinary collaboration that can enable a more effective exploitation of the potential of digital technologies that have already been successfully implemented in the building sector. A significant outcome of this paper

is the synthesis of the current state of research, the identification of critical constraints, and the delineation of promising technological directions required to develop more efficient and economically viable solutions for the modernization, development, and expansion of transportation infrastructure.

2. Materials and Methods

The methodological foundation of this study is a systematic review of scientific publications and applied reports addressing the application of Building Information Modeling (BIM) technologies in transportation infrastructure. The analysis covers studies in which BIM is examined in the context of highways, bridges, tunnels, railway infrastructure, as well as other linear civil infrastructure assets.

The study employed qualitative content analysis and thematic classification methods to examine the selected publications. The reviewed materials were analyzed according to several key criteria, including the stage of the asset life cycle (planning, design, construction, operation, and maintenance), the type of transportation asset, the digital technologies used and their integration methods, as well as the identified benefits and limitations of BIM implementation. Particular attention was given to studies in which BIM was considered not merely as a three-dimensional visualization tool, but primarily as an instrument for information and process management throughout the entire life cycle of transportation infrastructure assets.

The first stage of the study involved identifying scientific journals and information databases that potentially contain publications relevant to the scope of the review. Leading journals in the fields of architecture, construction, civil infrastructure, transportation engineering, information technologies, and related disciplines were examined, along with proceedings of international conferences. Given that a substantial portion of research and pilot projects related to BIM in transportation infrastructure is conducted outside the academic environment, the analysis also included publications from governmental departments, public agencies, professional associations, and industrial organizations.

At the second stage, a comprehensive search for publications addressing BIM in transportation infrastructure was conducted. Due to the diversity of terminology and concepts used in this field, an extended list of keywords and their combinations was developed. The search included not only direct references to BIM, but also related concepts such as Bridge Information Modeling (BrIM), Civil Integrated Modeling (CIM), Civil Information Modeling (CiM), three-dimensional infrastructure modeling, computer-aided design (CAD) for linear assets, and other digital technologies applied in transportation infrastructure. Both academic and applied databases (SCOPUS, EBSCO, Google Scholar) and general-purpose search engines were used. A top-down search strategy was adopted, whereby the process began with broad queries followed by filtering of relevant publications, enabling the identification of studies that may not explicitly use contemporary BIM terminology but are nevertheless pertinent to the subject area.

The third stage involved the collection, filtering, and systematic organization of the selected publications. To minimize the risk of overlooking relevant sources, priority was given to compiling a broad body of literature, followed by the exclusion of non-relevant materials. After the initial screening, the abstracts and keywords of the publications were examined to assess their relevance to the research topic. For publications deemed relevant, an in-depth analysis was conducted, accompanied by the preparation of a concise analytical summary outlining the content, scientific and practical significance, and key findings.

To manage and analyze the large volume of publications, a dedicated application based on Excel VBA (Visual Basic for Applications) was developed to automate the storage, retrieval, and analysis of bibliographic data. The application's functionality included the input and classification of publications, assignment of thematic categories and keywords, export of references, and execution of analytical procedures. In addition, an import/export function was implemented to enable seamless exchange of bibliographic information with EndNote.

Within the scope of the review, the abstract, keywords, and citation data were recorded for each publication, along with detailed characteristics, including the BIM application domain, life-cycle phase, type of transportation asset, applied technologies and data schemas, as well as the identified benefits and limitations. To analyze the textual data, automated sorting and classification algorithms were developed, along with methods for extracting keywords from abstracts and full-text publications. In total, 478 unique keywords were identified across the analyzed sources and subsequently used for thematic analysis.

It should be noted that, due to the adopted methodology, the review is limited to published and officially accessible materials and does not include ongoing studies whose results have not yet been published. At the same time, given the leading role of industry and governmental bodies in advancing BIM for transportation infrastructure, the review also incorporates reports from projects funded by governmental, professional, and industrial organizations, provided that such reports were officially published.

3. Results

As a result of the conducted systematic review, 189 publications addressing the application of Building Information Modeling technologies in transportation infrastructure were analyzed, including journal articles, conference proceedings, and published reports. The analysis revealed a steady growth of interest in BIM within the transportation sector, particularly after 2012, indicating a gradual transition from experimental and conceptual studies toward practice-oriented applications.

The analysis of publications by information model type revealed a substantial diversity of approaches to data representation and utilization in transportation infrastructure. As shown in Table 1, conventional BIM models and specialized forms such as Bridge Information Modeling (BrIM), which are specifically oriented toward bridge structures, are the most widely adopted. A significant share of the studies focuses on numerical, parametric, and product models, indicating researchers' efforts to adapt BIM to engineering analysis, computational procedures, and the specific characteristics of linear assets. Less prevalent but promising directions include multi-scale models, digital terrain models, and the integration of BIM with Virtual Design and Construction (VDC), reflecting the current stage of BIM maturity in infrastructure projects.

Table 1. Publications regarding BIM for transportation infrastructure based on model type.

Model type	Publication
As-built	[5, 10]
Bridge Information Modeling (BrIM)	[11, 12]
Building Environment Information Modelling (BEIM)	[13]
Building Information Modeling (BIM)	[5, 11, 14]
CIM	[15, 16]
Civil Information Modeling (CiM)	[9, 17]
Digital Terrain Model (DTM)	[18, 19]
Finite elements	[20, 21]
Geometric modeling	[22, 23]
Multi-scale model	[24, 25]

Model type	Publication
Numerical modeling	[20, 26]
Parametric models	[22, 23]
Product model	[27, 28]
Tunnel information model	[20, 29]
VDC	[20, 30, 31]

The results of the analysis also showed that a substantial proportion of the publications focus on bridges and highways as the most capital-intensive and critical components of transportation infrastructure. This confirms that these asset types serve as the primary “pilot” domains for BIM implementation, including during the design, construction, and operation phases. In contrast, the application of BIM to railway infrastructure, tunnels, ports, and airports is less extensively represented, indicating the presence of both research and practical gaps in these areas.

The analysis of BIM application areas presented in Table 2 indicates that the primary uses of the technology include planning and schedule simulation (4D), cost estimation (5D), clash detection, data management, visualization, and decision support. A considerable number of publications also address asset management, structural condition monitoring, and inspection processes, highlighting the significant potential of BIM during the operation and maintenance phases of transportation infrastructure.

Table 2. Publication of applications and uses of BIM for transportation infrastructure

Application or use	Publication
Accelerated bridge construction (ABC)	[9, 32]
Adoption	[33, 34]
Advantages and disadvantages	[9, 19]
Analysis	[9, 22]
Appraisal	[33, 35]
Appraisal and assessment	[9, 33]
Asset Management	[9, 33]
Automation	[9, 35]
Best practices	[9, 33]
Bill of Quantities (BOQ)	[9, 36]
Bridge Management System (BMS)	[9, 37]
Cash Flow	[9, 33]
Clash detection	[38, 39]
Collaboration	[40, 41]
Constructibility	[9, 22]
Cost Estimation (5D)	[33, 42]

Application or use	Publication
Data management	[18, 33]
Environmental impact	[43, 45]

At the same time, the results indicate that the application of BIM extends beyond traditional design and construction tasks. In several studies, BIM is used as a tool for risk management, safety assurance, resilience analysis, and environmental impact assessment. A distinct group of publications focuses on issues of interoperability, regulatory frameworks, and organizational aspects of BIM implementation, reflecting a transition from isolated technological experiments toward systematic and institutionalized adoption of BIM within the industry.

The aggregated results of the analysis confirm that the current development of BIM in transportation infrastructure is characterized by fragmentation and heterogeneity. On the one hand, there is active advancement of applied solutions and a widening range of tasks addressed through BIM. On the other hand, a continued dependence on specific asset types and software platforms, along with the lack of universal standards and neutral data formats, limits the scalability and interoperability of BIM-based solutions in transportation infrastructure.

4. Discussion

The results of the conducted review confirm that the application of BIM technologies in transportation infrastructure is at an active stage of development and adaptation, which differs significantly from the level of BIM maturity achieved in vertical construction. Despite the steady growth in the number of publications and the expansion of practical applications, BIM adoption in the transportation sector remains fragmented and characterized by heterogeneous implementation approaches.

The dominance of bridge structures and highways within the research landscape, as identified through the analysis of Table 5, reflects both the engineering complexity of these assets and their critical importance in terms of safety, operational costs, and life-cycle performance. The strong focus on Bridge Information Modeling (BrIM) and conventional BIM models indicates that the development of BIM in transportation infrastructure largely relies on the adaptation of existing tools originally designed for buildings. At the same time, the relatively limited number of studies addressing railway infrastructure, tunnels, ports, and airports highlights a substantial potential for expanding the application of BIM within these segments.

The analysis of BIM application areas summarized in Table 6 shows that design activities, schedule planning, cost estimation, and visualization are the most widely addressed tasks. This confirms that BIM in transportation infrastructure is primarily used as a tool to enhance the management and coordination of design and construction processes. At the same time, the significant number of publications focusing on operation, maintenance, condition monitoring, and asset management indicates a gradual shift in the attention of researchers and practitioners toward the full life cycle of infrastructure assets, which is consistent with the original BIM concept as an information foundation for decision-making throughout the entire service life of structures.

One of the key issues identified through the analysis is the problem of interoperability and the lack of neutral data exchange formats tailored to the specific characteristics of linear assets. The diversity of model types, data schemas, and software solutions presented in Table 5, on the one hand, demonstrates an active search for optimal approaches, while on the other hand, it highlights the absence of unified standards capable of ensuring seamless data integration across life-cycle stages and among different project stakeholders. This limitation significantly constrains the scalability of BIM solutions and hinders their widespread adoption at the industry level.

Additional barriers to BIM implementation in transportation infrastructure are institutional and organizational factors. The predominance of public-sector clients, complex contracting procedures, and regulatory constraints often slow down the adoption of innovative digital

technologies. At the same time, the results of the review show that the active involvement of governmental authorities and publicly funded pilot projects plays a crucial role in advancing BIM within the infrastructure sector, underscoring the need for strategic governmental support for digitalization initiatives.

An important outcome of the analysis is the identification of a close relationship between BIM and the development of related digital technologies, such as geographic information systems, laser scanning, photogrammetry, sensor-based monitoring systems, and virtual and augmented reality technologies. The integration of these technologies with BIM creates the prerequisites for a transition from static information models to dynamic digital twins of transportation infrastructure. However, the practical implementation of such integrated solutions requires further research, the development of advanced computational platforms, and the improvement of methods for processing large volumes of data.

Overall, the discussion of the results indicates that BIM in transportation infrastructure has significant potential to enhance the efficiency of design, construction, and operation processes; however, its implementation is currently constrained by technological, regulatory, and organizational barriers. Overcoming these limitations is possible through the development of open standards, improvement of interoperability, and strengthened collaboration among the scientific community, industry, and governmental institutions. This provides a foundation for future research aimed at developing sustainable and scalable BIM solutions for transportation infrastructure.

5. Conclusions

This paper presents a systematic review and analytical synthesis of contemporary research and applied developments related to the use of Building Information Modeling technologies in transportation infrastructure. The analysis demonstrates that BIM technologies show a sustained trend toward expanding their application scope and are gradually transforming from auxiliary design tools into a comprehensive information foundation for managing the life cycle of transportation assets.

The results of the study indicate that the highest level of BIM maturity has been achieved in the context of highways and bridge structures, where BIM and Bridge Information Modeling (BrIM) technologies are actively applied during the design and construction stages and are increasingly being introduced into operation, monitoring, and asset management processes. At the same time, the application of BIM to other types of transportation infrastructure, including railways, tunnels, ports, and airports, remains limited, indicating the presence of significant research and practical gaps.

The key factors constraining the wider adoption of BIM in the transportation sector include the lack of unified standards and neutral data exchange formats, insufficient interoperability among software platforms, and institutional and organizational limitations associated with the specific characteristics of infrastructure project delivery. Nevertheless, the results of the review confirm the strong potential of BIM for integration with geographic information systems, remote sensing technologies, laser scanning, and structural health monitoring systems, thereby creating the prerequisites for the development of digital twins of transportation infrastructure.

Overall, it can be concluded that the further development of BIM in transportation infrastructure requires a comprehensive and interdisciplinary approach, including the improvement of regulatory and methodological frameworks, the advancement of open standards, and active collaboration among the scientific community, industry, and governmental authorities. The implementation of these measures will enable the full realization of the potential of BIM technologies and support the transition toward more efficient, sustainable, and economically sound management of transportation infrastructure in the context of the sector's digital transformation.

Conflict of interest. The correspondent author declares that there is no conflict of interest.

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