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Building Information Modeling (BIM) and Geographic Information System (GIS) Integrations: a Holistic Review

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Abstract

The purpose of this literature review is to conduct a critical examination of the integration of Building Information Modeling (BIM) and Geographic Information Systems (GIS). This analysis aims to explore the potential synergies that exist between two transformational technologies within the architecture, engineering, and construction (AEC) sector. Building Information Modeling (BIM) and Geographic Information Systems (GIS), both powerful tools for handling intricate architectural information and geographic data, are being increasingly acknowledged for their synergistic ability to transform project processes. The present paper provides an analysis of the fundamental concepts behind Building Information Modeling (BIM) and Geographic Information Systems (GIS), emphasizing their unique functions and setting the stage for a comprehensive examination of integration approaches.

The research examines the many aspects of interoperability standards, data exchange protocols, and the changing landscape of collaborative frameworks. It highlights the issues that arise due to discrepancies in data formats and organizational obstacles, which impede the smooth integration of systems. The effectiveness of integrating Building Information Modeling (BIM) with Geographic Information Systems (GIS) in many fields such as urban planning, infrastructure management, coastal management and facility maintenance is shown by real-life case studies. These practical examples showcase the practicality and usefulness of BIM-GIS integration in several domains.

Keywords: Building information modeling, Geographic Information System, Architecture Engineering and Construction, Coastal management

INTRODUCTION

Integration of Building Information Modeling (BIM) and Geographic Information Systems (GIS), two significant domains in the fields of geospatial and building technology, has received considerable attention in recent years. This literature review offers a comprehensive examination of the integration of Geographic Information Systems (GIS) with Building Information Modeling (BIM), presenting a synthesis of the primary discoveries, objectives, advantages, and obstacles as documented in current scholarly works.

The convergence of Geographic Information Systems (GIS) and Building Information Modeling (BIM) is gaining recognition as a highly promising strategy that amalgamates the spatial data management and analytical functionalities of GIS with the intricate three-dimensional modeling and information-rich components of BIM. The collaboration across different disciplines in the study of the built environment improves the depiction and comprehension of this field, enabling a more holistic approach to the planning, design, building, and administration of infrastructure. According to studies, combining GIS with BIM allows for more thorough understanding of a project's physical and geographical context, which in turn leads to more educated decision-making. This helps in streamlining the building process, cutting down on mistakes, and saving money [1]–[3].

Several articles discuss how GIS enhances BIM with sophisticated spatial analytic tools. For example, overlap, neighborhood analysis, and spatial searches are geographic processes that can be useful for building infrastructure and planning cities. The combination of Geographic Information Systems (GIS) with Building Information Modeling (BIM) has been emphasized in literature about managing facilities, maintenance planning, and monitoring of assets. Streamlining of procedures is achieved via the creation of a uniform platform for continuous building operations and maintenance. Integration, according to experts, reduces data duplication and inconsistencies, allowing all parties involved to use the most recent and correct information to provide better results. The use of Geographic Information Systems (GIS) and Building Information Modeling (BIM) in conjunction has been seen by researchers to provide notable enhancements in building and maintenance operations. This integration offers the advantage of error reduction, workflow streamlining, and resource allocation optimization. Literature shows that the combined method helps find possible risks early on in a project's lifecycle, which leads to effective risk management strategies and lower costs. Sustainable urban development is emphasized as an area where the integrated approach may be particularly helpful, with researchers citing the benefits of optimizing land use, infrastructure location, and environmental impact evaluations. The literature shows that integrating GIS and BIM is crucial for quickly identifying damaged regions during catastrophes and designing efficient response methods. Researchers emphasize the need of a streamlined data transmission between building information modeling (BIM) and geographic information system (GIS) systems, which calls for standardizing information formats and mechanisms. Interoperability: The lack of interoperability across the many platforms of software utilized for GIS and BIM is recognized as a common difficulty, which calls for the creation of tools and processes that are compatible with one another. The integration of GIS and BIM in coastal management ensures a holistic approach to understanding, designing, and managing coastal environments, promoting sustainability and resilience in the face of environmental challenges [4].

The research suggests that those participating in the process of integrating GIS and BIM would benefit from possessing specific expertise and receiving appropriate training in order to properly use both technologies. The study explores data-level BIM-GIS integration. Building Information Modeling (BIM) offers comprehensive three-dimensional representations of buildings, catering to the needs of the Architectural Design, Engineering and Technology, and Construction Facility Management (AECFM) sector. On the other hand, Geographic Information Systems (GIS) are used for the examination and visualization of location-based issues within the realms of geospatial science and environmental science. Both Building Information Modeling (BIM) and Geographic Information Systems (GIS) have seen significant advancements, as shown by the projected growth of the worldwide GIS industry to reach 17.51 billion by 2023 and the anticipated expansion of the global BIM market to 7.64 billion by 2022. This study emphasizes the growing interest in the integration of Building Information Modeling (BIM) and Geographic Information Systems (GIS), as shown by the escalating number of citations pertaining to this subject matter [5]–[8].

The objective of this study is to ascertain the pertinent data models used in the integration of Building Information Modeling (BIM) and Geographic Information Systems (GIS), comprehensively analyze their respective merits and drawbacks, examine alternative data models, and provide guidance for the future advancement of Revit/GIS data integration. This study identifies the pertinent data models used in the integration of Building Information Modeling (BIM) and Geographic Information Systems (GIS) and evaluates their respective merits and drawbacks. The findings of this research contribute to informed decision-making in the context of data integration procedures.

LITERATURES

The amalgamation of Geographic Information Systems (GIS) and Building Information Modeling (BIM) facilitates the optimization of maintenance operations via the provision of comprehensive data pertaining to the precise positioning, altitude, and characteristics of the pipes. The convergence and assimilation of diverse technologies is often seen as an unavoidable trajectory for the effective management of construction projects.

The amalgamation of Geographic Information Systems (GIS) and Building Information Modeling (BIM) facilitates the acquisition of intricate and all-encompassing data pertaining to the amalgamated human-environmental activity area. This integration proves to be well-suited for effectively managing the many phases of the building's life cycle. Putting GIS-BIM integration technology to use in building engineering could lead to even bigger improvements in how people and systems share information. Integration of GIS and BIM technology makes building management more intelligent, efficient, and effective by improving its automation, information sharing, and use of data (Figure 1). It gets around the problems that come with managing just one building by combining the management of multiple buildings into a single system. This makes it easier to work together and coordinate. GIS-BIM technology makes it easier to control and analyze construction processes by combining geographic information data with building information modeling. This helps people make better decisions and use their resources more wisely. When used in building management, GIS-BIM technology can save money, make projects safer, allow teamwork, and speed up the sharing of data. When paired with other information technologies such as the World Wide Web (WEB), the GIS-BIM integration technology offers real-time data visualization, cooperative management of the construction process, and increased quality control. These benefits are achieved via the use of integrated technology. [9]

Both Building Information Modeling (BIM) and Geographic Information Systems (GIS) are inter-disciplinary areas that integrate and display project data to help with decision-making and administration of projects. Bridge design, construction, and operation all stand to benefit from the use of BIM, which has the potential to make these processes more effective and efficient. It makes it possible to create digital mock-ups, improve designs, and better the efficiency of building procedures. The application of GIS helps to save expenses while also contributing to an increase in accuracy in the creation of transportation infrastructure [10]. Architecture, Engineering, and Construction (AEC) professionals are putting a premium on producing 3D parametric models to improve the construction process, particularly in the context of energy efficiency and minimizing energy waste. The Horizon 2020 program from the European Commission wants to turn current towns into "Smart Cities" so that they use less energy. To do this, they need to be able to handle a lot of data from many buildings for energy models and tracking. Geographic Information System (GIS) and Building Information Modeling (BIM) both offer 3D data models that show details about buildings and their surroundings. However, it is very hard for BIM and GIS to work together [11].

BIM is a digital library with a lot of information about buildings, and GIS is a way to manage information that is linked to places. Both fields share basic ideas, but they are also different in ways that make merging difficult. Syntactic data exchange is what most existing methods do, but semantic merging is needed for complex analysis and searches [12]. Improved communication, addressing of mindset-related difficulties, overcoming of institutional hurdles, sharing of knowledge and experiences, decreased costs, increased accessibility, and promotion of standards and interoperability are all ways in which collaboration may boost BIM adoption [13]. The Building Information Modeling (BIM) database offers object-oriented parametric information for buildings that are represented in a 3D model, whilst the Geographic Information System (GIS) database provides topological data that enables 3D and geographical analysis [14]**.** Both steady and dynamic large amounts of data are needed for smart city uses. BIM and GIS are used to handle and use this data. Using BIM and GIS together is still just being investigated, and we need to learn more about this new area[15].

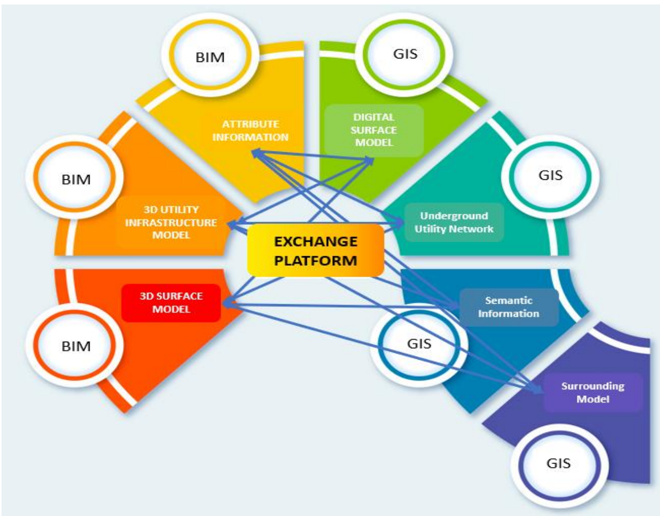

Figure 1. Integrated BIM-GIS Platform

BIM/GIS in Flood Damage Assessment

In flood-prone locations, conducting a Flood Damage Assessment, also known as FDA, is essential for efficient risk management and decision-making. Due to the restricted amount of data that can be entered, the FDA's existing methodologies do not have the capability to examine structures on a case-by-case basis, nor can they take into account the unique characteristics of buildings. The combination of Building Information Models (BIM) with Geographic Information Systems (GIS) offers the possibility of resolving some of the issues that are caused by the constraints of traditional approaches. The process entails coming up with a brand-new data model in the form of a GML profile and determining how successful it is via the use of a case study. The combination of BIM and GIS can offer specific information about the damage to buildings, which may help stakeholders make decisions that will improve the community's resistance to floods. Building Information Models (BIM) and Geographic Information Systems (GIS) are integrated in the data model that is presented in order to allow a thorough evaluation and 3D visualization of flood damage to structures (Figure 2). This is done in order to overcome the constraints that are present in the approaches that are currently used for Flood Damage evaluation (FDA). The currently available approaches do not take into account the unique characteristics of buildings and are unable to do case-by-case analyses of individual structures.

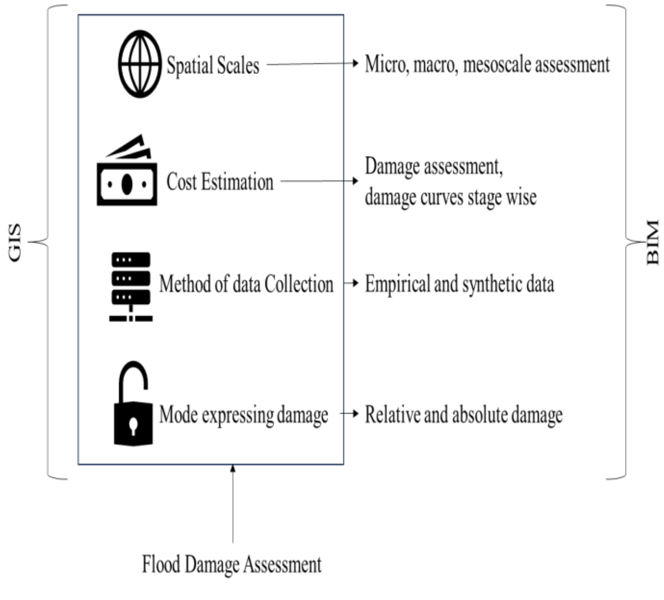

Figure 2. Flood Damage Assessment

The combination of building information modeling (BIM) and geographic information systems (GIS) makes it possible to store precise building information with flood parameters in a unified and consistent manner, which satisfies the criteria for micro-level FDA. A systematic foundation for combining BIM and GIS data is provided by the data model, which was built as a profile of GML (Geography Markup Language). This ensures that information can be efficiently stored and retrieved. The suggested data model, which combines BIM and GIS, makes it possible to include extensive building information as well as data on floods. This, in turn, makes it easier to conduct correct analysis and decisions about risk management and design review. Current techniques have limitations, but the suggested data model integrates building information modeling (BIM) and geographic information systems (GIS), providing a platform for future study and improvement in the area of flood damage assessment. [16].

BIM/GIS in Utility Mapping

Underground utilities are important parts of towns because they carry important services like water, gas, power, and phone lines. Service interruptions, property damage, personal injuries, and even fatalities are all possible results of incompetent utility administration. The primary challenges in utility management are attributed to the absence of a digitalized information model, a unified representation of utility information. It has been suggested that the Building Information Modeling (BIM) and Geographic Information System (GIS) might be combined into a single integrated system to increase the effectiveness of utility management. When BIM and GIS are combined, it can be easier to find services that are buried underground, do 3D analysis and rendering, and keep the models up to date. A standard utility data model is created to show all kinds of utility data, like utility network, component, shape, state, and other types of data. Integration of Building Information Modeling (BIM) with Geographic Information System (GIS) enables correct location of subsurface utilities and offers 3D visualization and analysis. BIM stands for Building Information Modeling, while GIS stands for Geographic Information System. BIM facilitates the generation of adaptable models and the seamless integration of information pertaining to utility components, whereas GIS enables the visualization of city-level data and the precise identification of utility networks using design, project planning, management of asset, master planning and monitoring techniques (Figure 3).

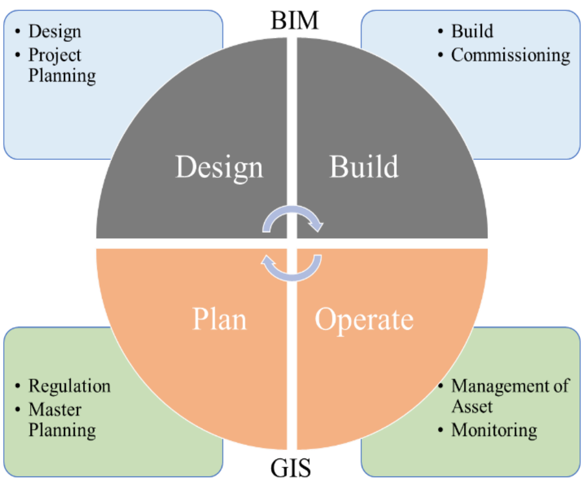

Figure 3. United BIM-GIS in Utility Planning

The convergence of Building Information Modeling (BIM) and Geographic Information Systems (GIS) enables streamlined utility management through enhanced data exchange, optimized utility management processes, and informed decision-making. The integrated BIM-GIS platform that has been developed provides a multitude of functionalities including model updating, clash detection, data visualization, querying, and visualization. These functionalities greatly enhance the efficiency of utility management. To further enhance utility management effectiveness, the framework's unified utility data model provides utility information holistically, encompassing utility network, component, geometry, condition, and other data [17]**.** The potential areas of collaboration between Building Information Modeling (BIM) and Geographic Information Systems (GIS) may be identified. The administration of facility operations inside expansive building complexes. The process of generating replicas or representations of extant or historical structures. Integration may occur at several levels, including the data level, semantic level, or inside a web service. The use of Geographic Information System (GIS) technologies in Building Information Modeling (BIM) activities, specifically in the domain of facility management for the University Campus Bohunice of Masaryk University, is executed via the application of ArcGIS. Experts in the fields of GIS and geomatics engage in the active monitoring of the domain of Building Information Modeling (BIM) in order to be abreast of forthcoming advancements and innovations. This paper aims to highlight the significance and benefits of Geographic Information Systems (GIS) within the domain of Building Information Modeling (BIM). The paramount concern is in guaranteeing the safety and security of Building Information Models (BIMs), with particular emphasis on their use in the preservation of heritage structures and protection of sensitive institutions (Tobiáš, 2015). The suggested framework for integrating BIM and GIS data in facility management for smart city services, known as the BIM/GIS-based Data Integration Framework (DI), demonstrated advantages such as reusability and flexibility. The BG-DI process is a system that facilitates the automated mapping of components across diverse data models, hence promoting standardization in data integration and aiding in the validation of data integrity. The research also discussed the use of ETL (extract, transform, and load) operations as a means of efficiently extracting, transforming, and loading data that is handled by FM [12]**.**The use of three-dimensional (3D) visualization techniques in the representation of pipelines provides a heightened level of clarity in comparison to two-dimensional (2D) formats. This enhanced visual perspective facilitates a more comprehensive comprehension of the subterranean environment, hence benefiting excavation and maintenance personnel. The process encompasses the use of ArcGIS, Revit, and AutoCAD Civil 3D for the purpose of importing, modifying, and visualizing the integrated model, which encompasses both the Building Information Modeling (BIM) model and the Geographic Information System (GIS) dataset [12]**.**

BIM/GIS in Building Construction Information System

The integration of Building Information Modeling (BIM) with Geographic Information System (GIS) facilitates precise identification of subsurface utilities and offers three-dimensional viewing and analytical capabilities. Building Information Modeling (BIM) facilitates the production of adaptable models and the updating of information pertaining to utility components. Conversely, Geographic Information Systems (GIS) aids in the display of city-level data and the identification of utility networks in terms of their location. The amalgamation of Building Information Modeling (BIM) and Geographic Information Systems (GIS) enables the optimization of utility management via enhanced information exchange, increased utility management efficacy, and improved decision-making processes. The integrated BIM-GIS platform that has been built provides a range of services including model updating, conflict detection, data visualization, and querying. These features contribute to the improvement of efficiency in utility management. The framework's development of the unified utility data model encompasses a complete representation of utility information. This includes utility network, component, geometry, condition, and other information which promotes master planning, regulation and permitting, design that exist in preliminary stage, pre and post construction activities record, enforcement monitoring and it stimulates revenue generation (Figure 4). As a result, the efficiency of utility administration is further enhanced [19]. The existing methods used for quality control on construction sites are characterized by a significant investment of time and a heavy reliance on repetitive data entry. These methods include several activities such as on-site inspections, data gathering, analysis, and communication with project stakeholders to address any identified issues. The timely identification of flaws throughout the building process is of paramount importance for ensuring quality control, since delayed detection might result in unnecessary expenditures in construction.

Figure 4. GIS-BIM in Construction Management System

Building Information Modeling (BIM) and Light Detection and Ranging (LiDAR) are two examples of up-and-coming technologies that have the potential to enhance quality control in the building industry. Throughout the whole of a construction project's lifespan, BIM enables the creation, sharing, and exchange of information, as well as its management. Point clouds in three dimensions may be generated using LiDAR, an optical remote sensing method. The limits of conventional methods to construction quality control may be overcome with the use of BIM and LiDAR integration, which allows for real-time onsite quality information gathering and processing [20].

The conventional two-dimensional Geographic Information System (GIS) lacks the capability to accommodate applications that need information on the height or elevation of objects. This particular requirement may be fulfilled by using three-dimensional modeling techniques. Building Information Modeling (BIM) models, which retain pertinent information about a building over its entire lifespan, may be used as a valuable data resource for the creation of three-dimensional (3D) Geographic Information System (GIS) city models [7]. Tower cranes play a vital role in the construction industry by facilitating the lifting and transportation of heavy loads at building sites. However, determining the ideal quantity and placement of these cranes may be a complex task owing to the presence of overlapping work zones and other limitations. The integration of Geographic Information Systems (GIS) and Building Information Modeling (BIM) presents a viable approach to the task of tower crane selection and placement. GIS offers the capability to analyze spatial data, while BIM allows for the visualization of structures prior to their actual construction. The combination of Geographic Information Systems (GIS) and Building Information Modeling (BIM) enables the determination of viable sites for tower cranes by considering their proximity to relevant places of demand and supply, taking into account geometric factors. The resulting data may be represented in three-dimensional models, facilitating the detection of possible conflicts and the optimization of crane placement. The integration of Geographic Information Systems (GIS) with Building Information Modeling (BIM) necessitates the establishment of semantic interoperability at the application level. In order to achieve this, the

Architecture, Engineering, and Construction (AEC) sector has undertaken many initiatives to increase interoperability. The suggested application's use of the Industry Foundation Classes (IFC) as a data store for geometry, relations, and characteristics is hindered by a deficiency in compatibility between Geographic Information Systems (GIS) and Building Information Modeling (BIM). Consequently, it is imperative to investigate alternate options [21].

BIM/GIS in Historical Buildings Management

The drawings used in the field of architectural conservation often lack clear and unambiguous semantic and structural characterization, hence posing challenges in interpreting and evaluating data beyond its geometric attributes. The use of information management systems plays a pivotal role in the effective management of architectural historical information and the formulation of suitable conservation plans. The management of architectural historical information in the digital realm is a multifaceted task, necessitating the integration of several forms of data representation. Building Information Modeling (BIM) has the potential to effectively manage architectural heritage information by seamlessly incorporating born-digital material into a BIM environment. This integration allows for the creation of parametric objects that are derived from the distinctive qualities of historical buildings. This approach aids in the preprocessing of data and the digital portrayal of cultural artifacts inside a three-dimensional virtual environment. Geographical Information Systems (GIS) has significant potential in the examination of spatial linkages, hence offering advantages in the management of architectural heritage data. Nevertheless, the capacity for 3D representation in this context is relatively constrained. The use of Building Information Modeling (BIM) and Geographic Information Systems (GIS) has the potential to enhance the integration and administration of diverse data associated with a complex three-dimensional model. This integration may lead to a deeper comprehension of historic data and facilitate the formulation of effective conservation plans. [22]

This study focuses on the use of shared digital archives for the purpose of collecting and organizing diverse data inside historical city centers. It also presents a proposed workflow that relies on the interoperability between Geographic Information Systems (GIS) and Building Information Modeling (BIM) to establish a spatial relational database using CityGML. The process comprises four distinct stages: initial data gathering, informative modeling using either GIS or BIM techniques, subsequent translation to CityGML format, and final integration into the relational database. The database has the capability to be queried using a range of tools for the purposes of consultation, visualization, or analysis. It is possible to export the database's data in the KMLCOLLADA file format, which makes it possible to navigate databases using web applications [23]**.** The case study of Villa Klonaridi (Figure 5) illustrates that degradation processes inside an information system may be systematically analyzed, categorized, and evaluated by using knowledge about the structure's history. The integration of multidisciplinary data from a cultural heritage asset into GIS and HBIM systems enables the identification of the precise causes of degradation. This is achieved by utilizing the comprehensive qualitative and quantitative information stored in their respective database systems, which operate in both 2D and 3D environments [24].

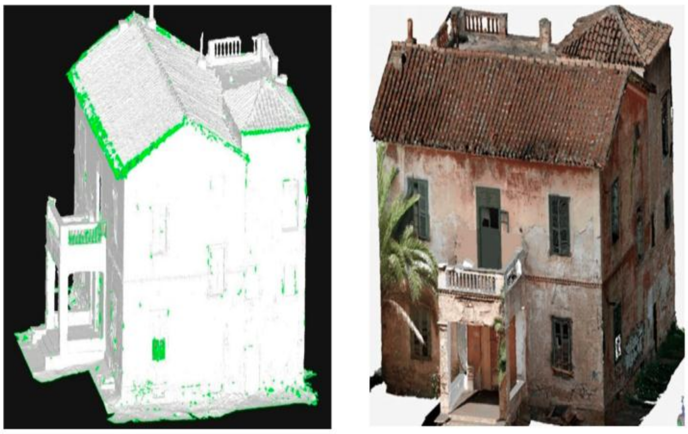

Figure 5. Villa Klonaridi a Historical Building – BIM Plot [24]

In order to allow the rehabilitation and environmentally responsible restoration of historic buildings, it is necessary to enable the interdisciplinary integration of data inside 2D and 3D information systems such as GIS and HBIM. This integration should include data on historical buildings, architectural buildings, building materials, and geometric data. This integration makes it possible to acquire, classify, and manage a variety of multisensory data. It also enables the production of GIS thematic maps and an HBIM, which together provide full information for the evaluation of the structural integrity of a historic structure. Additionally, the semantic enrichment of the HBIM is a part of the technique. This involves combining information from the state of preservation research, historical documents, and structural analysis to provide a comprehensive model of the structure. The combination of GIS with HBIM makes it possible to create maps of building materials, the level of degradation, and the extent of decay, which is helpful for the monitoring and preservation of historic structures. Making it possible to map and visualize building materials as well as the degree of degradation and extent of decay in historic structures, so giving useful information for monitoring the structural integrity of these buildings. This is accomplished by the integration of data from several disciplines into GIS and HBIM systems, which makes it possible to model, record, and conduct an analysis of the amount to which building materials have decayed. This work aims to enhance the semantic content of Historic Building Information Modeling (HBIM) by establishing connections between data derived from the state of preservation assessment, historical documentation, and structural analysis. The enhanced model offers a detailed depiction of the structure, facilitating the monitoring and evaluation of its state. Enabling the incorporation of non-destructive testing (NDT) data, including diagrams, pictures, and 3D point clouds, into the geographical information systems (GIS) and historic building information modeling (HBIM) systems. The integration of this technology allows for the analysis and evaluation of the condition of the building, specifically focusing on the assessment of the masonry structure and the calculation of deterioration levels. This platform facilitates the creation of thematic maps and the analysis of geographical information, hence augmenting the monitoring capacities of historical structures. This encompasses the process of cartographically representing the constituent elements of the structure and evaluating the degree of deterioration, fissures, distortions, and empty spaces [25]**.** The integration process presents several challenges, such as those related to data compatibility, discrepancies, and the possible disappearance of semantic information. The successful integration of Geographic Information Systems (GIS) with Building Information Modeling (BIM) is widely regarded as a significant accomplishment in addressing challenges across several industries, including Architectural Design, Engineering, which is Development, Facilities Management, and Disaster Prevention and Management [26].

BIM/GIS in Railway Projects

The railway sector is now undergoing a period of revitalization, necessitating ongoing enhancements to align with technical improvements, environmental shifts, and evolving consumer expectations. The use of Building Information Modelling (BIM) and Geographic Information Systems (GIS) has promise for enhancing efficiency and fostering cooperation within railway projects. The integration of Building Information Modeling (BIM) with Geographic Information Systems (GIS) may provide a comprehensive understanding of a project, since BIM primarily concentrates on the building aspects, while GIS offers geographic data. The absence of well-defined protocols for cooperation across the various stages of the railway project lifecycle, along with the need for further investigation in this domain, underscores the significance of combining Building Information Modeling (BIM) with Geographic Information Systems (GIS). The amalgamation of Building Information Modeling (BIM) and Geographic Information Systems (GIS) has the potential to augment decision-making processes, improve operational efficiency, and boost overall effectiveness across all stages of railway projects. There exists a need to establish a connection between the integration of Building Information Modeling (BIM) and Geographic Information Systems (GIS) within the railway industry, with the aim of enhancing cooperation and facilitating informed decision-making processes [5]. With the ability to rapidly model and update data, the combination of oblique photogrammetry and 3D laser scanning information can be utilized to construct an accurate 3D surface model that accompanies the Metro line. This facilitates the acquisition of the 3D scene model of the city's environment.

CONCLUSION

In summary, the amalgamation of Geographic Information Systems (GIS) and Building Information Modeling (BIM), as substantiated by the extant scholarly works, has substantial prospects for transforming the building and geospatial sectors. By integrating the advantages of these two technologies, professionals may enhance their decision-making process, enhance operational effectiveness, and explore novel opportunities for promoting sustainable urban development, emergency response, and infrastructure initiatives. Nevertheless, in order to achieve effective implementation, it is essential to tackle the obstacles related to data integration, interoperability, and talent development. The present literature analysis establishes a foundation for a more comprehensive investigation into this dynamic and growing domain, underscoring the significance of ongoing research and advancement in the integration of Geographic Information Systems (GIS) and Building Information Modeling (BIM).

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