Politecnico di Torino

Masters of Science in Building Engineeing
A.a. 2021/2022

Thesis Report For Masters Degree

Integration of BIM and GIS for Smart Construction Management

Supervisor:
Villa Valentina

Candidate:
AHSAN AHSAN

Acknowledgement

I would like to thank ALMIGTHY ALLAH who has given me the strength and health to achieve this goal. Surely, without His will nothing would have been possible.

I extend my heartfelt thanks to the supervisor of my thesis, Professor Villa Valentina for her invaluable guidance, support, and encouragement throughout the research process. Her expertise, insights, and constructive feedback have been instrumental in shaping this thesis.

I am indebted to my family for their unwavering support, understanding, and patience during this challenging journey. Their encouragement has been a constant source of motivation for me.

I am indebted to Politecnico Di Torino for providing all the necessary facilities and resources for conducting this research

Abstract

In recent years, the management of construction projects has undergone a remarkable transformation across their entire life cycles, from initial planning stages through to operation and maintenance. This evolution has been driven by the adoption of cutting-edge technologies such as Building Information Modeling (BIM) and Geographic Information System (GIS), both of which play pivotal roles in supporting construction endeavors. With their distinct advantages, BIM and GIS have revolutionized the utilization of construction project information, particularly by aligning it with the dynamic realities of construction sites, thus demonstrating their critical importance throughout the lifespan of building projects.

Recognizing the immense potential of these technologies in enhancing construction project management, there is an increasing imperative for their seamless integration. This integration marks a significant advancement in smart construction management practices, offering unprecedented opportunities for efficiency and effectiveness.

The primary focus of this thesis is to provide a comprehensive examination of the research and practices surrounding the interoperability of BIM and GIS and its transformative impact on construction management. Through an in-depth exploration, this thesis aims to shed light on the practical applications of integrated BIM-GIS systems in construction management, illustrating their pivotal role across various aspects of project execution. Furthermore, the thesis will present compelling case studies to showcase successful implementations of integrated BIM-GIS systems in real-world scenarios, providing valuable insights into their potential for widespread adoption in the construction industry.

Table of Contents

Index of Tables

Index of Figures

INTRODUCTION

Statement of the Problem: Challenges in Construction Management and the Need for Integrated Solutions

Construction management faces numerous challenges, ranging from logistical complexities to resource allocation and environmental considerations. Traditional approaches to construction management often involve fragmented workflows, disjointed data sources, and inefficient communication channels, resulting in budget overruns, delays, and less than ideal project results. Additionally, there is growing pressure on the construction sector to implement sustainable practices, reduce waste, and raise safety standards..

The construction industry operates in a complex environment, with projects involving various stakeholders, intricate processes, and tight schedules. Traditional management methods often struggle to cope with these challenges effectively. Therefore, there's a growing need for smarter management practices in construction. Smart construction management ensures that construction materials, equipment, and personnel are strategically positioned on the site. This reduces the need for excessive movement of resources, saving time and minimizing disruptions to workflow[1].Smartly planning the sequence of construction activities and allocating resources accordingly, project managers can minimize downtime and maximize productivity. This includes coordinating subcontractors, scheduling tasks, and implementing lean construction principles to manage the construction procedures.[2]Efficient resource utilization leads to cost savings by minimizing waste, reducing overhead expenses, and avoiding unnecessary expenditures.[3]Proper managed construction sites means ensuring that pathways, access points, and emergency exits are clearly delineated, minimizing the risk of accidents and injuries[4] restricted accessibility might result in a 58% drop in efficiency, while a 65% fall in efficiency could come from a crowded workspace[5] Effective resource allocation can cut costs by minimizing pointless trips and backtracking.[6]

Many studies in construction management often assume flat construction sites, disregarding the influence of terrain and topography on travel distances and paths. However, in reality, terrain variations significantly impact construction operations, affecting productivity, fuel consumption, and project costs. Therefore, incorporating terrain considerations into construction site planning is essential for enhancing accuracy and practicality. By integrating terrain data, such as elevation changes and slopes, using Geographic Information Systems (GIS), construction managers can make more informed decisions about site layout and transportation routes.[3]Considering the environment surrounding a construction site and visualizing it in (4D) can provide invaluable assistance to practitioners during the preconstruction phase, this approach allows practitioners to adjust their execution plan and foresee possible scheduling mistakes, missed tasks, geographical feasibility issues, and spatial-temporal conflicts.. By integrating the environmental context into the construction planning process, practitioners gain a broader understanding of the construction process, allowing for more informed decision-making and proactive risk management. [7]Traditional planning and scheduling tools such as bar charts or network analyses have been found to be less effective compared to the method of 4D planning and scheduling, This approach provides a more comprehensive understanding of the construction schedule, allowing practitioners to identify potential issues and optimize project execution more effectively.[2]Placing Temporary facilities carefully at construction site specially in dense urban area can help avoiding hazards that could compromise its functionality, stability, or operation.[8] Representing a 3D model within its surrounding environment, can be very helpful for space planning, which can be done by spatiotemporal analysis using GIS.

Why BIM and GIS?

Building Information Modeling (BIM) and Geographic Information Systems (GIS) have emerged as powerful technologies with the potential to address many of these challenges. However, the standalone use of BIM or GIS may not fully leverage their capabilities or address the multifaceted nature of construction management challenges. Therefore, there is a growing recognition of the need to integrate BIM and GIS to harness their synergies and create more holistic solutions for smart construction management.

Integration of BIM and GIS offers several potential benefits, including improved data interoperability, enhanced visualization capabilities, better decision-making support, and streamlined workflows. By combining the spatial analysis capabilities of GIS with the detailed building information provided by BIM, stakeholders can gain a comprehensive understanding of construction projects and their surrounding environments. This integrated approach enables more informed decision-making throughout the project lifecycle, from initial planning and design to construction execution, operation, and maintenance. The challenges in construction management underscore the urgency of adopting integrated solutions that leverage the strengths of BIM and GIS technologies. By addressing these challenges through integration, construction stakeholders can improve project efficiency, reduce costs, minimize environmental impact, and enhance overall project success. Therefore, this thesis aims to explore the interoperability of BIM and GIS and its transformative potential in addressing the challenges of construction management.

A recent and rapidly emerging trend in research and industrial practice is the integration of BIM and GIS in construction project management. During the building life cycle, BIM offers benefits in terms of rich geometric and semantic data [9], although GIS is a vast field that includes geographic modeling and decision-making based on visualization [10].In today's construction management landscape, merging Building Information Modeling (BIM) with Geographic Information Systems (GIS) marks a significant step towards smarter and more efficient construction practices.

Scope of Study:

This research focuses on exploring the integration of Building Information Modeling (BIM) and Geographic Information System (GIS) technologies within the domain of construction management. The scope encompasses an in-depth analysis of recent advancements, methodologies, challenges, and the transformative potential associated with interoperability of BIM and GIS systems. The goal of the study is to look into the useful applications, benefits, and limitations of this integration across various aspects of construction project management. The study further explores the practical implications of integrated BIM-GIS systems, ranging from optimizing project planning and visualization to enhancing safety measures and fostering sustainability in construction practices.

The objective of this study is to demonstrate the significance of integrating Building Information Modeling (BIM) and Geographic Information Systems (GIS) for construction planning and management. Additionally, it aims to propose a methodology for developing a versatile and adaptable model. This model will enable users to address various construction planning and management challenges efficiently. The model aims to provide quicker, more user-friendly, safer, and conflict-free building site planning by utilizing the interaction between BIM and GIS. The integrated approach aims to assist users in quickly and easily designing construction locations that are safer and closer to conflict-free areas. The underlying idea is to support users in making informed decisions during the construction management process by providing a unified platform for problem-solving.

STATE OF ART

BIM and GIS are prominent tools widely embraced in the construction sector, each bringing unique functionalities to the table. Yet, despite their indispensability, they come with inherent limitations that the other platform can effectively address. GIS, for instance, harnesses georeferenced data, enabling robust 3D analysis, spatial examination, and diverse queries like distance calculations, route planning, logistics optimization, and site selection. These capabilities are pivotal for tackling various construction challenges and facilitating spatial analysis.[11] [12]

On the flip side, When it comes to offering a comprehensive collection of object-oriented parametric information for buildings that is vividly depicted in a 3D model, BIM excels—a capability that GIS noticeably lacks [13]. This sophisticated modeling enables detailed visualization and analysis of building components and their interactions, offering valuable insights to construction professionals. However, despite their respective strengths, seamlessly transitioning, querying, and analyzing data between BIM and GIS remains a significant challenge, primarily due to interoperability issues at a semantic level and other compatibility hurdles. This chapter delves into the literature, examining the similarities and disparities between BIM and GIS, exploring the diverse applications of their integration in the construction domain, and shedding light on the complexities surrounding their interoperability and integration, while also addressing associated challenges and potential solutions.[14]

Introduction to Building Information Modelling:

Definition of BIM :

Building Information Modeling (BIM) is a concept introduced in 1970 by Professor Charles Eastman. He pointed out that traditional drawings at the time lacked the ability to adequately convey the project's visual aspects to stakeholders. BIM has significant implications across various phases of the Architecture, Engineering, and Construction (AEC) industry, including design, life-cycle management, and performance during construction. Its application varies across different stages of construction, including pre-construction, construction, and post-construction phases. BIM has been effectively utilized in construction projects through computerized information management systems since the mid-2000s. The AEC industry has adopted BIM extensively, leveraging computer software and Information and Communication Technology (ICT) tools. BIM acts as a facilitator of interoperability, bridging communication gaps between various stakeholders involved in the AEC industry.[15]

Building Information Modeling (BIM) serves as a sophisticated digital representation of architectural structures or environments, encompassing their inherent characteristics. It constitutes a comprehensive database of intelligent building components or environmental elements, each endowed with specific data attributes and governed by parametric rules. In essence, BIM provides a detailed and organized framework for capturing and managing crucial information about the components comprising a structure or environment.[16]

BIM technology can effectively mitigate common issues encountered in construction projects, such as design errors, deficiencies in design quality, prolonged construction time, and escalating costs. By leveraging parametric 3D models, BIM facilitates better synchronization and exchange of information between project participants, leading to enhanced collaboration and decision-making processes. The findings underscored the potential of BIM to revolutionize the construction industry, prompting widespread adoption and utilization of BIM methodologies and tools over the past decade. [17]

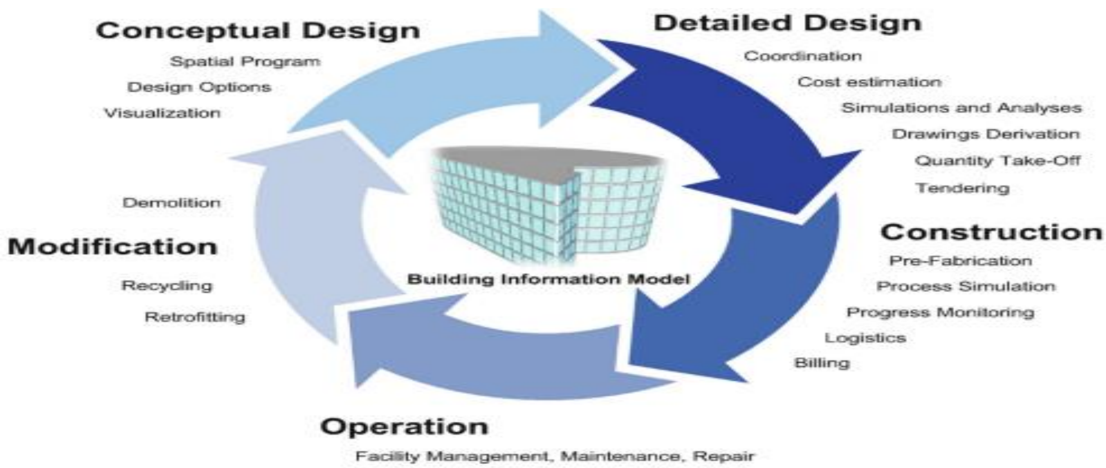

Figure 1 The concept of Building Information Modeling [18]

The ultimate goal of BIM is to generate valuable information that can facilitate decision-making and improve the delivery process of the overall facility. By extracting views and data tailored to the specific needs of various stakeholders, BIM enables informed decision-making at every stage of the project. Whether it's evaluating design alternatives, analyzing constructability issues, estimating costs, or optimizing facility operations, BIM provides a comprehensive platform for collaborative decision-making and performance improvement.[19]

BIM, or Building Information Modeling, represents a methodology for electronically managing both the design and pertinent information of a facility across its entire lifecycle [20].This methodology represents the outcome of the integration of various policies, processes, and technological advancements, enabling a holistic approach to managing facility design and information[21]. It emphasizes the interconnectedness of key elements such as governance frameworks, operational procedures, and innovative tools, cooperatively enhancing facility management across their lifecycle.

Regarded as a groundbreaking technology, BIM enables engineers to create virtual models of digitally constructed buildings, providing owners with the opportunity to visualize the structure before physical construction commences[22]. This capability revolutionizes the traditional approach to building design and construction, offering stakeholders a comprehensive understanding of the project even before ground is broken. Moreover, it represents a revolutionary process that has fundamentally transformed the way practitioners conceive, design, construct, and operate facilities [23].This transformative impact extends spanning a facility's full lifecycle, from initial conception to building to continuous operation and maintenance.

BIM serves as a digital repository of comprehensive facility data, offering owners nearly all the information they need about a structure [24]. While in the architecture, engineering, and construction

(AEC) industry, BIM is often associated with parametric 3D CAD technologies and processes [25], its capabilities extend far beyond mere visualization. BIM introduces additional dimensions to the modeling process, including the fourth dimension (4D) of time, incorporating scheduling information and the fifth dimension (5D) of cost [26]. Given the inherently collaborative nature of the AEC industry, characterized by fragmented workflows and extensive coordination among stakeholders [27][28].

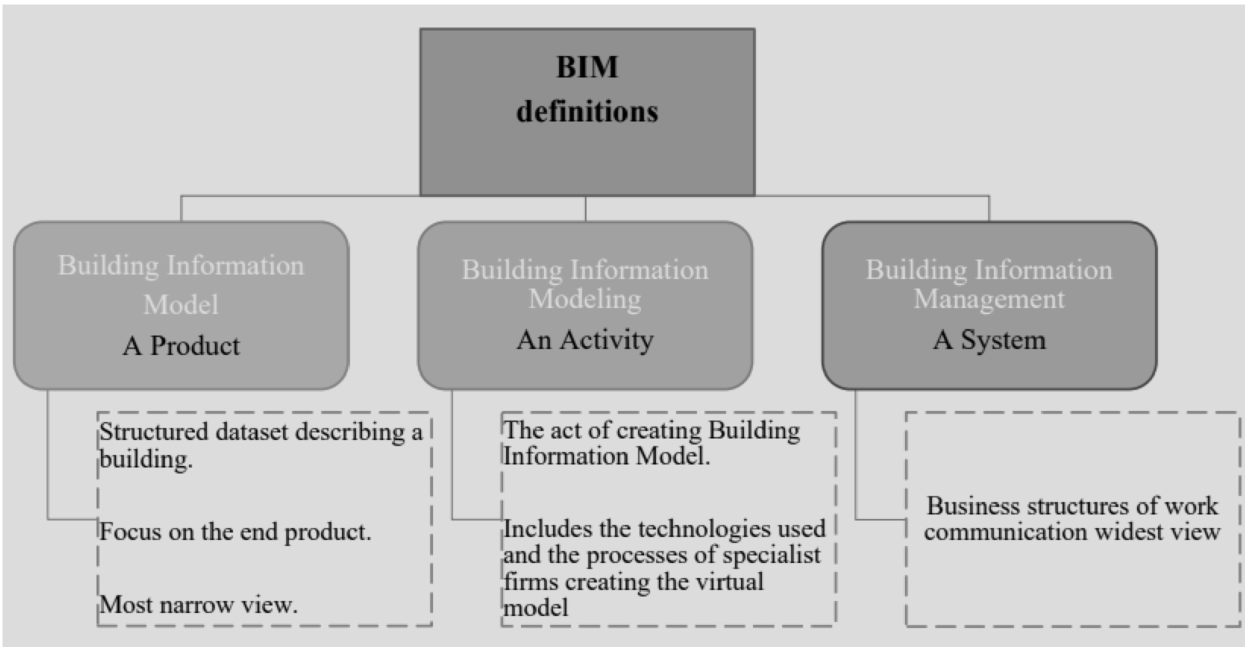

Figure 2 Different definitions of BIM[29]

Building Information Modeling (BIM) is defined by the US National Building Information Model Standard Project (NBIMS-US) Committee as a a facility's computerized depiction of its functional and physical attributes, It serves as a comprehensive knowledge repository, offering insights into a facility's attributes and functionalities, aiding decision-making processes across its entire life cycle, from inception to decommissioning [29].

A Building Information Model (BIM) is more than just a static representation; It is a digital representation of a facility that is dynamic, data-rich, object-based, intelligent, and parametric. This model can be used to extract and analyze multiple views that are suited to the demands of different users in order to gather feedback and improve the facility. design. BIM facilitates collaboration and communication among project stakeholders, streamlining workflows, improving accuracy in design, reducing environmental impact, and optimizing overall lifecycle costs [30]

Building Information Models (BIMs) are digital representations of buildings that are dynamic, data-rich, object-oriented, intelligent, and parametric. They go beyond simple static representations. From this model, diverse perspectives tailored to the specific requirements of different stakeholders can be extracted and analyzed, fostering feedback loops and iterative improvements to the facility design. BIM fosters collaboration and communication among project participants, thereby streamlining workflows, enhancing design precision, mitigating environmental impacts, and optimizing overall lifecycle expenditures [31]

The following are the dimensions specified in BIM [32].

1) 3D – The Shared Information Model or Three-dimensional rendering of the element

- The elements within the BIM environment are rendered in three dimensions, which is represented by this dimension, which is the Shared Information Model.
- It is the most fundamental and commonly utilized dimension in BIM, encompassing both graphical and non-graphical information related to the building elements.
- Graphical data includes the visual representation of architectural, structural, and MEP (Mechanical, Electrical, Plumbing) elements, while non-graphical information comprises attributes such as material properties, specifications, and performance data.
- All information within this dimension is typically stored and shared within the Common Data Environment (CDE), ensuring that it remains accessible and up-to-date throughout the project lifecycle.
- This dimension's primary tasks and results include spatial coordination, model walkthroughs, clash identification, and project visualization.
- At this dimension level, the numerous models from the different project disciplines are merged to create what is called a federated model.
- The federated model, typically achieved at Level 2 BIM maturity or higher, enhances project visualization and fosters communication and collaboration between different disciplines.
- By facilitating early clash detection and resolution, the federated model helps prevent conflicts and errors during later stages of the project, ultimately leading to improved project outcomes and reduced rework.

2) 4D Dimension – Construction Sequence or Duration Analysis:

- The 4D dimension in Building Information Modeling (BIM) adds an essential layer of time management to the project, allowing for the integration of construction sequencing and duration analysis into the digital model.
- The 4D dimension, which specifies the order of construction operations and their durations as the project advances, differs from the 3D dimension's graphical portrayal of building elements in that it places more emphasis on non-graphical qualities ascribed to elements.
- These characteristics can provide a thorough insight of the building timetable and can include lead time, installation time, installation sequence, dependence on other elements, and more.
- Planners may optimize construction schedules, organize material and equipment delivery using a "just-in-time" approach, and see the evolution of construction operations over time by including 4D into the federated model.
- Efficient planning of work sequences not only enhances project safety but also minimizes costs associated with errors and delays.
- In a digital workflow, planners play a crucial role in shaping proposals during the early stages of the project, leveraging the insights provided by the 4D model to make informed decisions.
- Using a digital workflow reduces the risk of data loss and enhances collaboration between designers and construction businesses by streamlining communication and data exchange in contrast to traditional approaches like Gantt charts.

- Discussions surrounding the duration of a construction contract highlight the distinction between "static" and "dynamic" approaches to project scheduling. Embracing a more dynamic approach necessitates the adoption of new methodologies to reduce, manage, and reorganize construction timelines in response to changing project requirements and conditions.

3) 5D Dimension – Cost Estimation:

- Efficient Budget Tracking: BIM streamlines budget tracking and cost analysis processes, offering substantial time savings compared to traditional methods.
- Quantity Takeoff Automation: BIM's parametric modeling capabilities automate the process of quantity takeoff, eliminating the need for manual updates from 2D drawings.
- Automatic Reflection of Changes: Any modifications or updates made to the BIM model are automatically reflected in the quantity of materials required, ensuring accurate cost estimation.
- Cost managers' job is made easier by BIM's provision of comprehensive cost-related data for all model elements, including capital, operating, and replacement costs.
- 3D Visualization of Costs: Associating cost information directly with the model enables 3D visualization of costs, facilitating rapid assessment of the financial impact of changes or updates.
- Integration with Cost Estimating Systems: Various integration methods, such as Application Programming Interfaces (APIs) and Open Database Connectivity (ODBC), enable seamless communication between the BIM model and cost estimating systems, enhancing collaboration and efficiency.

4) 6D Dimension – Project Lifecycle Information or Energy Analysis:

- Three Pillars of Sustainability: Sustainability encompasses environmental, economic, and social aspects, focusing on natural resource protection, economic viability, and societal well-being.
- Shift Towards Long-Term Sustainability: Prioritizing upfront capital expenditures was the norm in the AEC sector; but, with 6D BIM, the focus is now on a project's entire life costs, which include things like energy and CO_2 emissions.
- Early Sustainable Decision Making: Early in the project lifecycle, stakeholders can make more environmentally friendly decisions thanks to the incorporation of 6D BIM, which increases project sustainability overall and lessens its impact on the environment.
- Data Inclusion for Operations and Management: In order to facilitate informed decision-making for durable and sustainable equipment, 6D BIM requires the inclusion of data pertaining to facility operation and management, such as manufacturer details, installation dates, energy performance, and replacement costs.
- Integrated BIM Approach: Also known as Integrated BIM (iBIM), 6D BIM enables designers to evaluate multiple options throughout the project lifecycle, comprehensively understanding the impacts of each option on sustainability and performance.

5) 7D Dimension – Facility Management:

- As-Built Model: The 7D dimension provides the as-built model, which includes information about the initial design as well as any modifications made throughout the construction process, resulting in the final as-built model.
- Operations and Management Data: Information retrieved at the 7D dimension relates to the facility's continuous management and operations, covering a range of topics including

component status, warranties, maintenance schedules, specifications, and other pertinent information.
- Handover to Facility Manager: Upon completion, the data extracted from the 7D dimension is handed over to the facility manager. This data serves as a comprehensive resource for managing the facility effectively during its operational phase.
- Maintenance and Updates: It is crucial to keep the information updated and accurate throughout the facility's lifecycle. Maintenance schedules, component statuses, and other relevant data should be regularly monitored and adjusted as needed to ensure efficient facility management and performance.

Industry Foundation Class (IFC):

In 1993, a pivotal collaboration among leading Architecture, Engineering, and Construction (AEC) firms in the United States initiated a groundbreaking discourse on the integration of modern information technology within the building industry. This watershed moment marked the genesis of the Industry Alliance for Interoperability (IAI) in 1994, aimed at demonstrating the compatibility and synergy among diverse Computer-Aided Design (CAD) and simulation tools prevalent in the industry As IAI gained momentum and expanded its scope globally, it underwent a significant transformation in 1996, transitioning into the International Alliance for Interoperability. This evolution underscored the organization's commitment to fostering interoperability on a global scale, transcending geographical boundaries and industry silos.[33]

Central to the mission of IAI was the development and dissemination of the Industry Foundation Classes (IFC) specification, serving as a standardized framework for information exchange across diverse disciplines throughout the lifecycle of a building project. The adoption of IFC as the basis for information sharing aimed to streamline communication, enhance collaboration, and ensure seamless integration of data across all phases of a project, from conception to demolition. Today, the legacy of IAI lives on through buildingSMART International, the successor organization dedicated to advancing interoperability standards and promoting digital transformation within the AEC industry. The latest iteration of the IFC standard, IFC 4, has attained international recognition, being registered as ISO 16739. This recognition underscores the widespread acceptance and adoption of IFC as a globally recognized standard for digital representation and information exchange within the built environment.[34]

IFC, or integrated built environment, is defined by “BuildingSMART” as a standardized digital description that includes both buildings and civil infrastructure. It functions as an open, global standard that is interoperable with a broad range of hardware, software, and interface platforms and is meant to be vendor-neutral. IFC goes beyond conventional sharing techniques, enabling the smooth transfer of project data between disciplines and applications at any stage of the project lifecycle[18].

In essence, IFC is an object-based file format with an extensive data model designed to improve industry interoperability in the AEC sector. Although primarily based on EXPRESS, IFC also includes an XML-based standard (ifcXML) developed by buildingSMART. While ifcXML offers broader compatibility, its larger file size limits its widespread adoption.[35]

The research emphasize IFC as the cornerstone of Building Information Modeling (BIM), serving as a common language to facilitate communication and data delivery across all phases of a project. By establishing a unified framework for information exchange, IFC enables smoother collaboration, enhances project efficiency, and fosters innovation within the AEC industry (Zh`u et al., 2019). Three major technologies are used by the ISO 10303 Standard for the Exchange of Product Data (STEP) to define Industry Foundation Classes (IFC): Globally Unique Identifiers (GUIDs), the object-oriented data description language EXPRESS, which is used to express the conceptual schema, and STEP physical files as compact exchange files [37].

IFC serves as a catalyst for interoperability across various software applications, transcending domain-specific boundaries in architecture, construction, and facility management. By enabling seamless data exchange with other simulation software, IFC fosters collaboration among approximately 150 software applications that support its format, paving the way for extensive collaboration opportunities. Notably, IFC's neutrality and non-proprietary nature ensure that it remains accessible and adaptable across different platforms [32]. The capacity of IFC to formally express common building materials and their qualities, as well as the connections between them, is one of its distinguishing features. It also offers timetables and budgets for each task [38]. This standardized approach streamlines interoperability in Building Information Modeling (BIM), addressing the challenge of exchanging vast amounts of digital information seamlessly across diverse software platforms[33].

Software programs can interact directly and share information of mutual interest or reference by following IFC standards, which has several advantages. These include cost-free access to facility data, enhanced collaboration between different disciplines, and reduced planning efforts through automated data acquisition from models and external IFC-compliant libraries. However, it's crucial to note that IFC's effectiveness in ensuring interoperability hinges on software vendors' commitment to supporting and complying with the format. As long as software vendors uphold these standards, IFC remains a powerful enabler of seamless data exchange and collaboration in the AEC industry.

According to [39], The IFC schema can be broken down into four layers, as illustrated in figure 3, with multiple modules comprising numerous classes inside each layer.

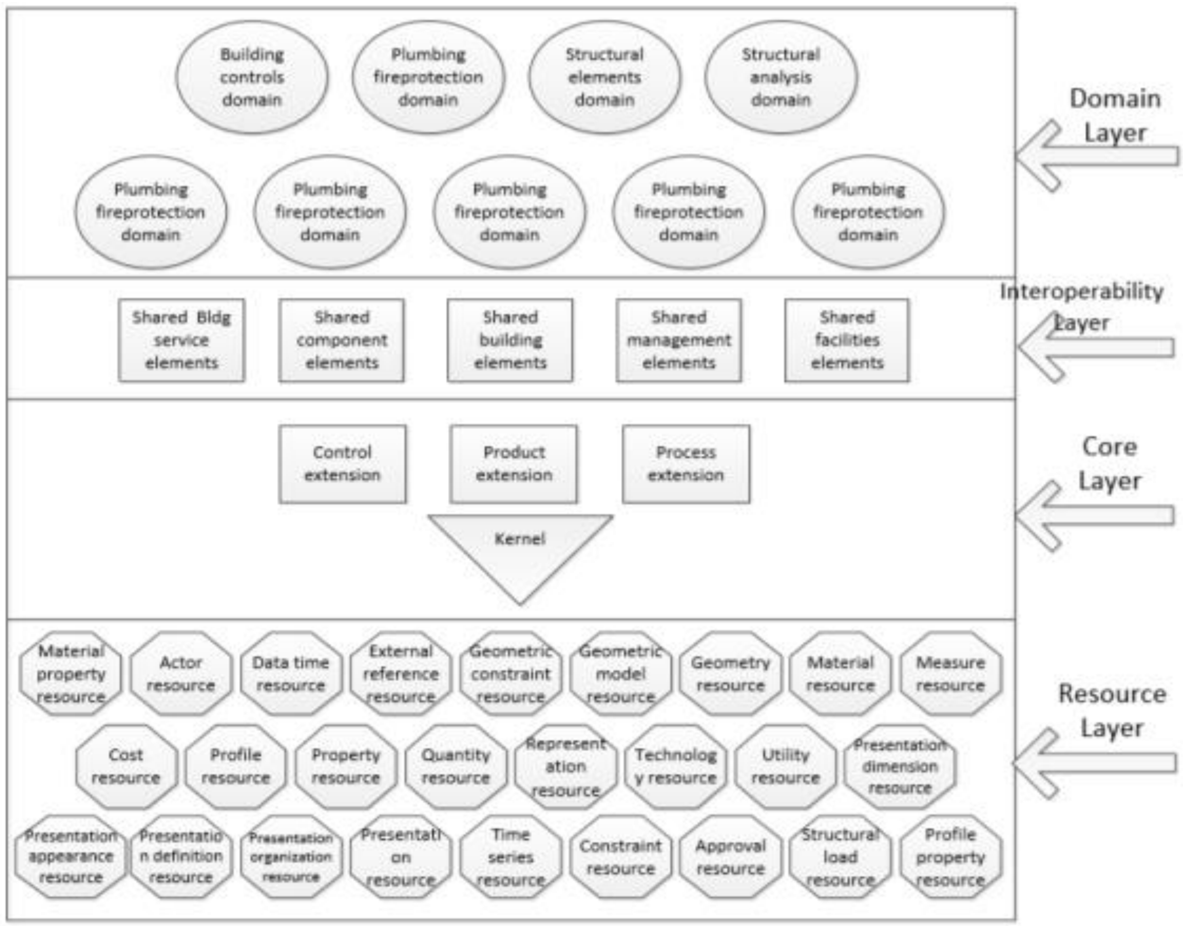

Figure 3 IFC Schema adopted from [39]

In the realm of Industry Foundation Classes (IFC) models, a critical aspect is comprehending an element's position within its local coordinate system (LCS), which spans multiple hierarchical levels including element, story, building, and site.[35] In order to clarify this further, define "local placement system" (LPS) and describe how the parent and child LCS relate to each other in the model.This understanding of LCS enables precise determination of an element's position, facilitating its transformation across different levels of the model hierarchy. By grasping these intricacies, stakeholders can ensure accurate alignment and positioning of elements, thereby enhancing spatial analysis, clash detection, and interdisciplinary coordination throughout the project lifecycle.

Additionally, [40]emphasize the significance of LCS knowledge in enabling seamless coordination between different levels of the IFC model, from individual elements to the broader site context. With a clear understanding of LCS parameters such as origin and axis orientation, stakeholders can effectively translate an element's coordinates from its local context to higher-level LCS, and potentially even to the World Coordinate System (WCS) with proper linkages established. This capability not only enhances the accuracy of spatial representation within the model but also fosters efficient data exchange and interoperability across diverse stakeholders and project phases.

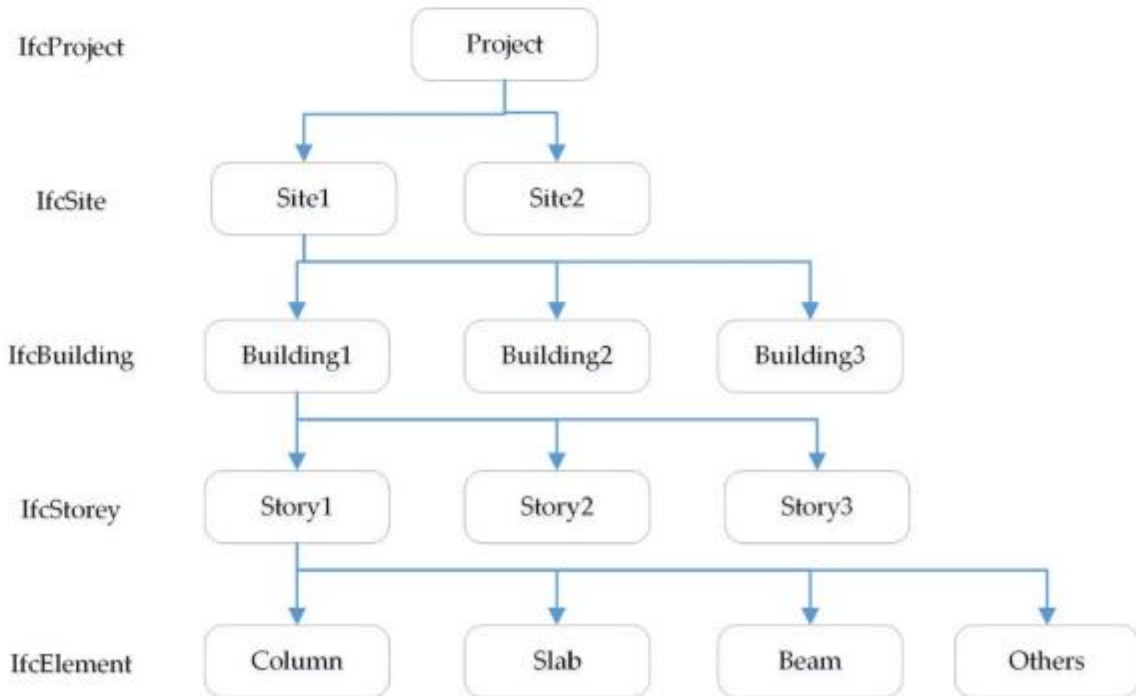

Figure 4 IFC Spatial Structure adopted from [36]

Importance and Applications of BIM in the AEC industry :

A complex digital representation known as a Building Information Model is the end product of the BIM process. This model is a data-rich, object-oriented, intelligent, parametric representation of the facility rather than merely a static 3D model.[17]

Data-Rich: The BIM model contains a wealth of information about every aspect of the facility, including its geometry, materials, structural elements, mechanical systems, and more.

Object-Oriented: BIM organizes information based on objects or components within the facility. Each object in the model represents a specific element of the facility, such as walls, windows, doors, HVAC systems, etc.

Intelligent: BIM objects are intelligent, meaning they have associated attributes and parameters that describe their properties, behavior, and relationships with other objects in the model. For example, a door object may contain information about its dimensions, material, swing direction, fire rating, etc.

Parametric: BIM objects are parametric, meaning they are defined by a set of parameters or rules that govern their behavior and appearance. This allows stakeholders to easily modify and adapt the model to reflect changes in design or construction requirements.

BIM technology can be leveraged during the project planning phase to facilitate options analysis and support decision-making regarding building layout selection. By integrating BIM-based cost estimation into the design process, stakeholders can evaluate the economic implications of different design options more effectively, ultimately leading to more informed and strategic decision-making in cost estimation planning.[23]

Introduction of Geographic Information System:

Definition of GIS:

Geographic Information Systems (GIS) have evolved significantly, driven by ongoing advancements in technology and research. Originally introduced by Goodchild in 1992, GIS has transitioned from being solely a tool for mapping and spatial analysis to a comprehensive science and technology discipline known as Geographic Information Science (GIScience), GIS emphasizes its multidisciplinary nature and its application across various fields, encompassing disaster response, public health, environmental management, and urban planning. In order to handle complicated spatial challenges, the field of GIScience focuses on using computer technology to process, store, extract, manage, and analyze geographical information.[41]

The findings regarding Geographic Information Systems (GIS) underscore its multifaceted utility as a comprehensive system for managing spatial data.GIS offers a robust platform for capturing, storing, analyzing, and presenting various forms of geographical data, enabling users to discern patterns, relationships, and trends.GIS's role as a decision-support system, possessing are essential qualities for effective information management [42].[43] further delineate the architecture of GIS within an information system framework, elucidating its organizational structure and functional components.

Within the AEC industry, GIS offers innovative solutions to address diverse challenges influenced by location-specific factors, as emphasized by [7]. Factors such as site conditions, terrain, and material quantities are pivotal in identifying suitable storage locations, a capability effectively harnessed through GIS. Additionally,GIS enhances BIM and 4D CAD by offering geographic analytics that are essential for site planning and logistics. [7].

The integration of GIS enhances the construction process by providing comprehensive spatial analysis and facilitating route and logistics planning, as affirmed by [44]and [45]Additionally, GIS datasets encompass vital environmental data such as ambient temperature and pollution levels, augmenting decision-making processes related to construction site management [45].Overall, the utilization of GIS within the AEC industry demonstrates its efficacy in enhancing spatial understanding, facilitating informed decision-making, and optimizing project management processes.

Components of Geographic Information System (GIS):

Hardware: Physical equipment such as computers, servers, GPS devices, scanners, and printers used to collect, store, and process geographic data.

Software: Applications and programs designed for data collection, storage, analysis, and visualization, including GIS software like ArcGIS, QGIS, and Google Earth.

Data: Spatial data including maps, satellite imagery, aerial photographs, and attribute data such as demographic information, land use, and infrastructure details.

People: Skilled personnel including GIS analysts, technicians, and cartographers who manage and interpret geographic data, as well as end-users who utilize GIS outputs for decision-making.

Methods: Procedures and techniques for data collection, analysis, and interpretation, including spatial analysis, remote sensing, and geo statistics.

Data Representation	Description	Details
Vector Data	Represents geographic features as discrete points, lines, or polygons.	Points: City locations, landmarks. Lines: Roads, rivers. Polygons: Countries, land parcels.
Raster Data	Depicts geographic data as a grid of cells, with a value assigned to each cell.	Grid Cells: Elevation models, satellite imagery. Continuous Surfaces: Temperature, precipitation maps.
Attribute Data	Contains descriptive information about spatial features, often stored in tabular format.	Tabular Data: Feature attributes such as names, classifications, populations.
Image Data	Incorporates visual representations of the Earth's surface, such as satellite imagery or scanned maps.	Satellite Imagery: High-resolution aerial photographs. Scanned Maps: Historical maps, land use maps.
3D Data	Represents spatial features and surfaces in three dimensions, adding height or depth information.	3D Vector Data: Buildings, terrain models. 3D Raster Data: Digital elevation models, 3D terrain surfaces.

Table 1 Data Representation in GIS

Uses of Geographic Information System (GIS):

Geographic Information Systems (GIS) play a crucial role in managing and analyzing location-based data, known as geodata. Geodata encompasses a wide range of information, including roads, land use, elevation, vegetation, waterways, and more. The power of GIS to make this data usable and accessible from any location in the globe is what makes it so powerful. But problems occur when some local manuals and catalogs are not machine-readable, making it difficult to share data between various systems. To address this issue, the concept of semantic interoperability has been introduced, enabling seamless data exchange between disparate systems. The applications of GIS can be described as [46].

Mapping and Cartography: Mapping and cartography are fundamental uses of GIS, allowing for the creation of accurate maps essential for various purposes such as urban planning, land management, and navigation. Thematic maps, a product of GIS, visually represent data trends and patterns like population density or vegetation cover, providing valuable insights for decision-making processes in different domains.

Resource Management: GIS plays a crucial role in monitoring and managing natural resources such as forests, water bodies, and wildlife habitats. It facilitates environmental impact assessments and aids in planning conservation efforts by leveraging spatial data analysis to understand the dynamics of resource utilization and distribution.

Urban Planning and Development: In urban planning and development, GIS assists in evaluating land use suitability, assessing infrastructure needs, and planning transportation networks, utilities, and public services. By analyzing spatial data, urban planners can make informed decisions about the allocation of resources and the design of sustainable urban environments.

Emergency Management: GIS is instrumental in predicting and mitigating natural hazards such as floods, wildfires, and earthquakes. It enables emergency managers to coordinate response efforts effectively, manage resources efficiently, and plan for disaster resilience by leveraging spatial data analysis to understand vulnerability and risk.

Business and Marketing: Businesses utilize GIS for analyzing market demographics, consumer behavior, and competitor locations to target advertising and sales strategies effectively. Spatial data analysis informs site selection for retail stores, restaurants, and other businesses, optimizing their market presence and enhancing decision-making processes.

Healthcare and Epidemiology: In healthcare and epidemiology, GIS aids in mapping disease outbreaks, analyzing their spatial distribution, and identifying risk factors for public health interventions. It assists in planning healthcare facilities and services based on population demographics and healthcare needs, improving healthcare delivery and response.

Agriculture and Forestry: GIS is extensively used in agriculture for monitoring crop health and productivity, managing farm resources, and optimizing agricultural practices. In forestry, it supports the management of forest resources, including timber harvesting, biodiversity conservation, and wildfire prevention, through spatial data analysis and satellite imagery.

Transportation Planning: Transportation planners rely on GIS for designing efficient transportation networks, optimizing route planning for vehicles and public transit systems, and analyzing traffic patterns and congestion. GIS-based insights enhance road infrastructure planning and traffic management, improving overall transportation efficiency.

Utility Management: GIS plays a vital role in planning and managing utility networks such as water supply, sewerage, and electricity distribution. It assists in assessing infrastructure condition, prioritizing maintenance activities, and optimizing resource allocation based on spatial data analysis, ensuring the reliability and sustainability of utility services.

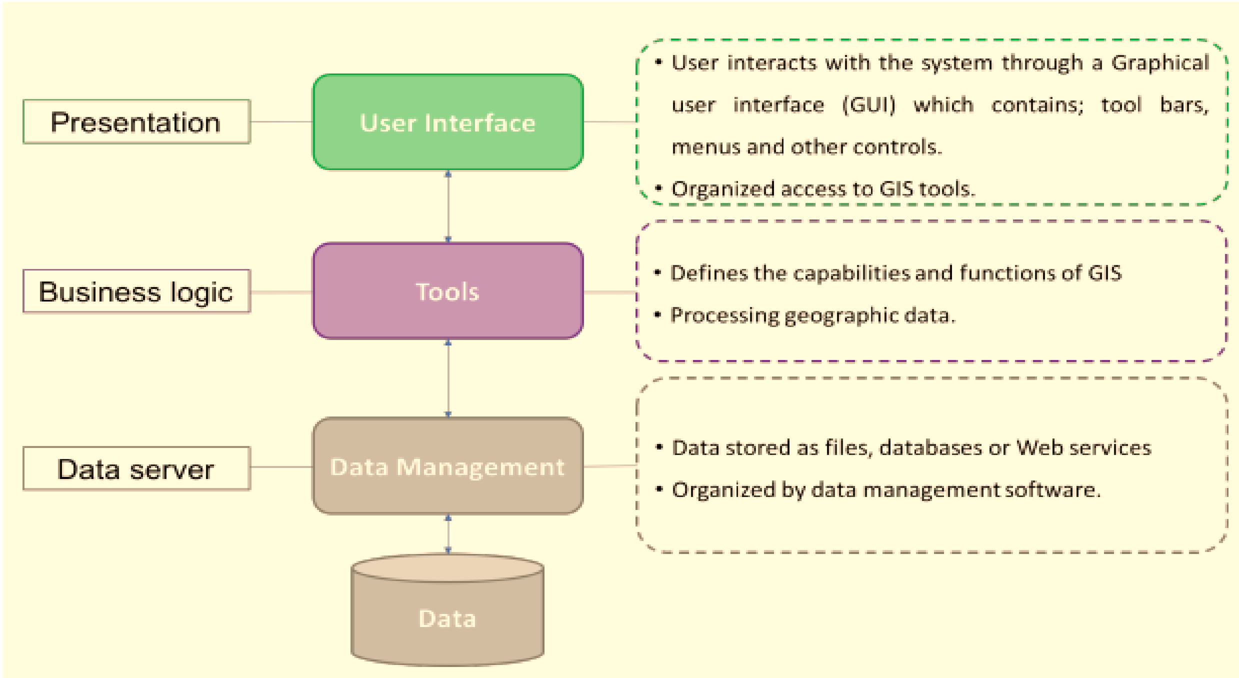

Figure 5 Architecture of GIS adopted from [47]

Geodata is represented in various forms within GIS, each serving different purposes. Traditional methods include vector and raster files, which respectively depict discrete objects (e.g., buildings, roads) and continuous fields (e.g., elevation, rainfall). However, advancements in technology have led to the emergence of hybrid data storage approaches, such as point clouds. Point clouds provide a detailed "3D color image" of the surroundings by combining RGB data with three-dimensional points. This hybrid approach enhances the realism and accuracy of GIS representations, especially in scenarios where precise spatial information is required.[48]

Thematic maps generated using GIS have evolved to become more visually descriptive and realistic over time. These maps provide insights into specific geographic phenomena, such as population distribution, land use patterns, or environmental characteristics. By incorporating advanced visualization techniques and data processing algorithms, GIS thematic maps offer a comprehensive understanding of spatial relationships and trends. Table 6 outlines the primary formats used for storing and representing geographic data, reflecting the diverse nature of geodata and its applications.[49]

Shapefile	Widely used vector data format developed by Esri	Administrative boundaries, roads, rivers
GeoJSON	Lightweight format for encoding geographic data in JSON	Point locations, line features, polygons
KML/KMZ	Keyhole Markup Language, used for geographic visualization	Google Earth placemarks, paths, polygons
GeoTIFF	Standard raster image format embedded with geographic metadata	Satellite imagery, digital elevation models
GML	Geography Markup Language, XML-based format for	Land parcels, transportation networks

	describing geographic data	
GeoDatabase	Database format developed by Esri for storing and managing spatial data	Multiple layers with complex relationships

Table 2 Types of Geo-Data and Its Applications

Spatial Analysis:

Spatial analysis in Geographic Information Systems (GIS) constitutes a fundamental component, playing a pivotal role in extracting valuable insights from spatial data. As elucidated by [43]spatial analysis encompasses a series of processes, including transformation, manipulation, and procedural techniques, aimed at deriving meaningful information from geographic data. This process is essential for elucidating implicit patterns and anomalies within spatial datasets, thereby facilitating informed decision-making processes.

According to[50], Examining the locations, characteristics, and connections between features in geographic data by overlay and other analytical methods is known as spatial analysis. This analytical approach enables the elucidation of spatial patterns, trends, and associations, thereby facilitating the extraction or generation of new information from the underlying spatial data. Through spatial analysis, disparate datasets can be integrated and analyzed to uncover meaningful insights, thereby aiding in the resolution of complex spatial problems and the formulation of informed decisions.

Spatial analysis is executed through a diverse set of tasks and procedures, encompassing techniques such as overlay, proximity analysis, interpolation, and spatial statistics. These analytical methods enable the exploration of spatial relationships, identification of spatial patterns, and quantification of spatial phenomena. By harnessing the power of spatial analysis, GIS enables users to gain deeper insights into spatial data, thereby empowering them to address spatially related questions and derive actionable intelligence from geographic information.

Data Exploration: Spatial analysis begins with the exploration of spatial data, which encompasses a wide range of geospatial information such as points, lines, polygons, and raster datasets. Researchers employ visualization techniques to understand the spatial distribution of features, identify trends, and detect anomalies within the data.

Spatial Relationships: One of the key aspects of spatial analysis is the examination of spatial relationships between geographic features. This involves determining proximity, adjacency, connectivity, and containment relationships, which can provide valuable insights into spatial patterns and interactions.

Overlay Analysis: Overlay analysis is a fundamental spatial analysis technique that involves the combination of multiple layers of spatial data to derive new information. By overlaying different datasets, researchers can identify areas of overlap, intersection, or spatial coincidence, enabling them to assess spatial patterns and assess the impacts of spatial phenomena.

Spatial Statistics: Spatial statistics play a crucial role in spatial analysis, allowing researchers to quantify and analyze spatial patterns, distributions, and relationships using statistical methods. Techniques such as clustering analysis, hot spot analysis, and spatial autocorrelation help researchers identify statistically significant patterns and trends within spatial data.

Geoprocessing: Geoprocessing refers to the suite of operations and algorithms used to manipulate and analyze spatial data. It includes operations such as buffering, interpolation, network analysis, and terrain analysis, which enable researchers to perform complex spatial analyses and derive meaningful insights from geospatial datasets.

Modeling and Simulation: Spatial analysis often involves the development and application of spatial models and simulations to predict spatial phenomena, assess scenarios, and evaluate the impacts of spatial interventions. Spatial modeling techniques such as spatial regression, agent-based modeling, and cellular automata enable researchers to simulate real-world processes and phenomena in a spatial context.

Decision Support: Ultimately, the goal of spatial analysis is to provide decision support by generating actionable insights and informing decision-making processes. By integrating spatial analysis results with domain knowledge and stakeholder input, researchers can make informed decisions, solve spatial problems, and address complex challenges in various domains, including urban planning, environmental management, public health, and disaster response.

Interoperability Between BIM and GIS:

Interoperability between Building Information Modeling (BIM) and Geographic Information Systems (GIS) involves enabling seamless communication and data exchange between these two distinct but complementary systems. In order to maximize the benefits of BIM and GIS working together, recent research has concentrated on improving interoperability for more effective facility management, infrastructure development, and urban planning. [51]

Building Information Modeling (BIM) and Geographical Information Systems (GIS) serve as extensively employed modeling tools for smart cities. BIM concentrates on specific structures, whereas GIS emphasizes the spatial placement of these structures and their connections to nearby objects. The utilization of BIM and GIS yields crucial insights for planning, maintenance, emergency response, and the facility Management .[52]

Building Information Modeling (BIM) uses the Industry Foundation Classes (IFC) as its primary data structure, and BIM/GIS integration projects heavily rely on it. IFC continues to evolve as a standard, furnishing a semantic data model that encapsulates various aspects of building information, the latest iteration of the IFC standard, IFC 4.1, encompasses a comprehensive definition of 21 building elements, including but not limited to beams, members, slabs, plates, columns, coverings, and building element proxies.[40]

The integration of Building Information Modeling (BIM) and Geographic Information System (GIS) represents a significant endeavor to bridge two distinct domains designed for different purposes. BIM primarily focuses on the detailed modeling and management of building-related data, including architectural, structural, and MEP (mechanical, electrical, plumbing) information. On the other hand, GIS specializes in the spatial analysis and visualization of geographic data, such as maps, terrain, and environmental features.[13]

The literature on integrating BIM and GIS categorizes approaches based on various criteria, including the semantic or geometric level of integration, the directionality of data flow (unidirectional or bidirectional), and the use of commercial or open-source platforms. Semantic integration involves aligning the meaning and semantics of data elements between BIM and GIS, ensuring compatibility and consistency in data interpretation. Geometric integration focuses on aligning the spatial representations of objects in both systems, enabling accurate spatial analysis and visualization.[18]

In the quest to streamline the conversion process of IFC (Industry Foundation Classes) clipping representations into shapefile format for seamless integration into Geographic Information Systems (GIS), an innovative approach was proposed focusing on automating the conversion process, ensuring a smooth transformation of IFC clipping data into shapefile format while accurately identifying the type of half space, despite enlarging the boundary size, the corresponding B-Reps (Boundary Representations) for half space do not experience a proportional increase in size. However, there is a marginal extension observed in the production time for half spaces and the processing duration for building components, underscoring the complexities inherent in such transformations.[36]

On the Geographic Information System (GIS) front, the predominant data formats or standards utilized revolve around City Geography Markup Language (CityGML) and shapefile formats. CityGML, an XML-based open data model, specializes in storing and exchanging virtual 3D city models. However, compared to shapefile, CityGML poses several challenges, such as class mapping, level of detail (LoD) alignment, and geometry transformation from solid models to surface models. Conversely, shapefile exhibits greater flexibility in accommodating BIM information and boasts advanced solid modeling capabilities, presenting advantages in scenarios like 3D printing and facilitating easier geometry transformations between BIM and GIS.[53]

While CityGML and shapefile are the primary formats discussed, other formats like Geography Markup Language (GML) and Geodatabase also find applications in BIM/GIS integration, albeit less frequently. These alternative formats offer distinct functionalities and characteristics, contributing to the diverse landscape of data exchange and interoperability within the BIM and GIS domains.[54].

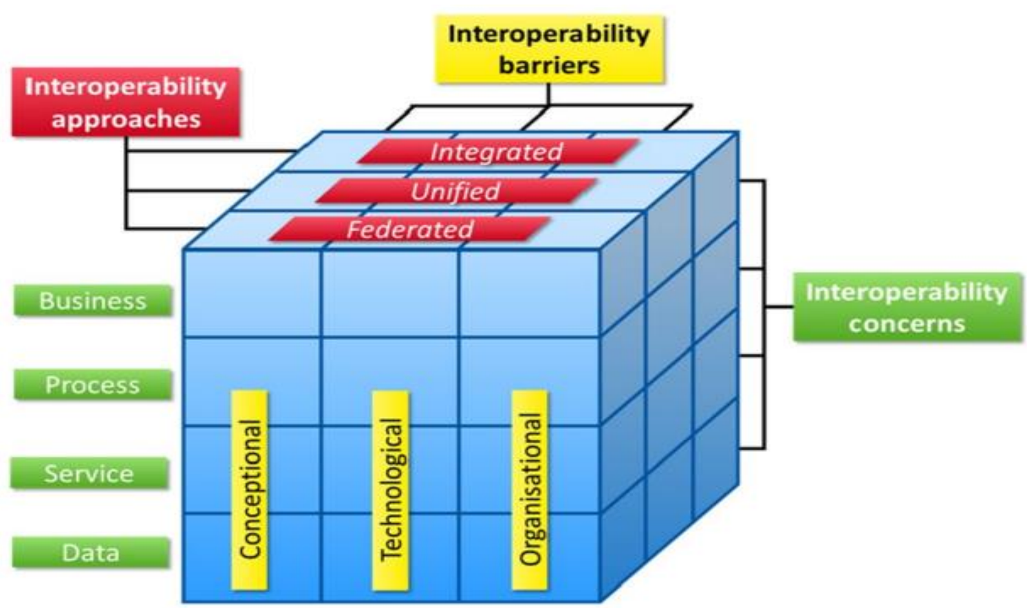

Figure 6 Framework for enterprise interoperability (FEI) (adapted from ISO/TC 184 2012)[54]

Differences and incompatibilities between BIM and GIS:

Both Building Information Modeling (BIM) and Geographic Information Systems (GIS) stand as pivotal pillars in the Architecture, Engineering, and Construction (AEC) industry, owing to their diverse array of features and capabilities, While both platforms share commonalities in facilitating data-driven decision-making, they diverge significantly in their intended purposes and functionalities.[55]

BIM is meticulously crafted to cater to the specialized needs of the AEC sector, focusing on the creation and management of digital representations of physical structures. It serves as a comprehensive repository of detailed parametric information about building components, facilitating the creation of intricate 3D models. Conversely, GIS is engineered to provide comprehensive mapping solutions, encompassing both geometric and functional data pertaining to geographic features such as land zones, parcels, rivers, and topography.[56]

A fundamental disparity lies in the nature of data each platform handles. GIS deals primarily with georeferenced data, enabling sophisticated 3D and spatial analyses, along with queries like distance calculation and optimal route determination. In contrast, while BIM offers exhaustive object-oriented parametric data, it lacks the inherent spatial analysis capabilities inherent in GIS [57].BIM excels in providing detailed building information and sophisticated 3D modeling, GIS shines in its capacity to analyze spatial data and provide invaluable insights for efficient decision-making in the realm of geographic mapping and analysis. Integrating the strengths of both platforms enables a holistic approach to AEC projects, optimizing efficiency and facilitating informed decision-making throughout the project lifecycle[58]

Property	**BIM**	**GIS**
Geometric complexity	Single building contains a few elements only	Single building contains 1000 s of elements
Features and attributes	Any spatial feature, any attributes	Focus on features of interest to construction
Data management	Focus on data flows within Spatial Data Infrastructure (data quality, validation, responsibilities), databases, data sharing	Data management for project sites/Focus on data functionalities in native software, files-based storage
Key players	Government dominated	industry dominated
Open data	Open data/sharing data is seen as public good	Sharing data complex; benefits for sharing are not always clear
Geometric representation	Geometry is measured (B-Rep)	Geometry is designed (parametrized)
Georeferencing	National, international	Local

Table 3 Incompatibilities between geographical information systems (GIS) and BIM [38]

[59] use the open-source, standardized indoorGML data structure as the basis for building an indoor ontology at the semantic level. This innovative approach serves as a bridge between Building Information Modeling (BIM)/IFC and Geographic Information Systems (GIS)/IndoorGML, fostering semantic interoperability between the two domains. By leveraging this method, the seamless exchange of data between BIM and GIS applications is greatly enhanced, consequently improving indoor routing during the project's operational phase. The information embedded within IFC elements, including ID, GUID, property names, and referenced IFC instance IDs, forms the basis of this interoperability. Furthermore, additional features like Overall Height and Overall Width are incorporated into the ontology for entities like IfcDoor and IfcWindow. While the translation process effectively captures geometric information, it should be noted that only limited detailed semantic information is transferred during the translation process.

With an emphasis on data management, data-level integration, 3D indoor GIS analysis, and 3D space management [60] conducted a thorough examination into the needs of 3D indoor GIS for space management.. Throughout their study, they specifically explored the process of exporting geometric information from Revit software, a common BIM tool, into a multipatch feature using the ESRI Data Interoperability Extension. Four essential IFC data components were converted: geometry, semantics, relationship classes, and building element characteristics. These were all transformed into a 3D indoor GIS environment.

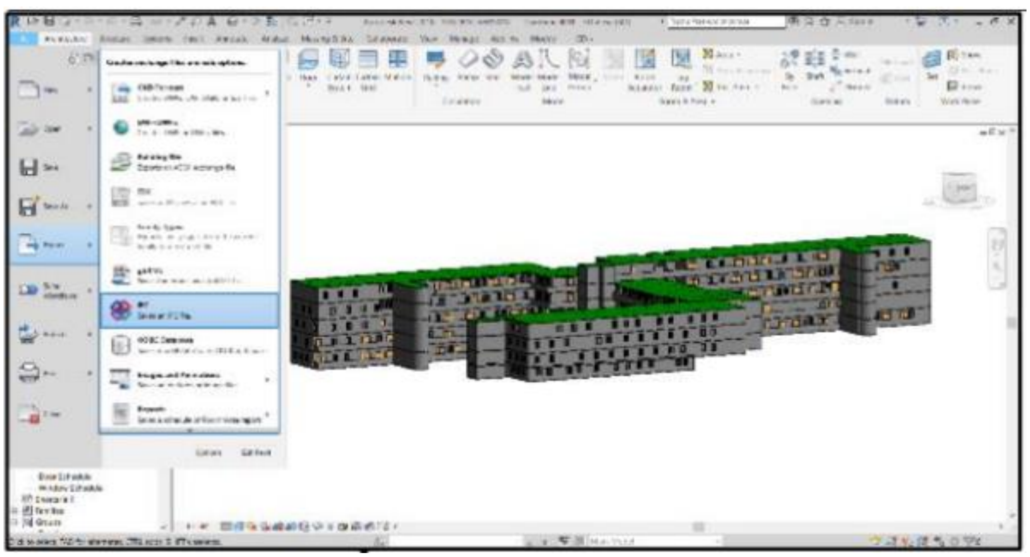

Figure 7 (Revit's BIM model exported in IFC format) [60]

Figure 8 (BIM Model Imported in GIS format) [60]

The viability of utilizing multi-model geospatial information to improve data management for procedures like location selection and fire response management by incorporating Building Information Modeling (BIM), in particular the Industry Foundation Classes (IFC) format, within a geospatial environment, the practicality of utilizing BIM, particularly the IFC format, within a geospatial context to streamline data management processes related to location selection and fire response management. By incorporating multi-model geospatial information, they explored the seamless transfer of comprehensive geometric and semantic data from BIM into GIS environments. This integration offers promising prospects for enhancing the efficiency and effectiveness of various spatial management tasks, underscoring the potential benefits of leveraging BIM within broader geospatial frameworks.[61]

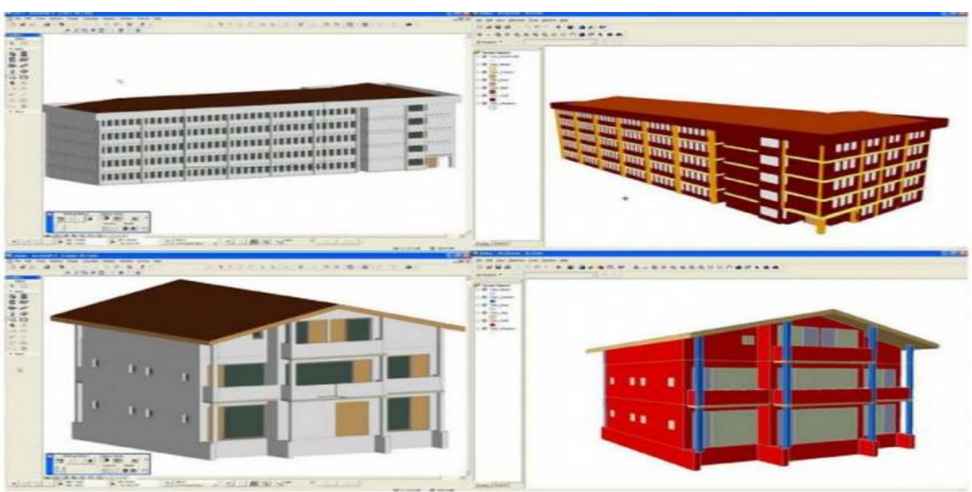

Figure 9 (Two different BIM representations displayed in a CAD and a GIS) [61]

Approaches for Integration of BIM and GIS:

Building Information Modeling (BIM) and Geographic Information System (GIS) have emerged as powerful platforms within the construction industry, each possessing unique features and capabilities. However, despite their strengths, each platform has inherent weaknesses. To address these limitations, the integration of BIM and GIS is deemed essential.[62]

The contrasts between Bim and GIS make integration between them difficult. Semantic inconsistencies between them as well as differences in spatial size, granularity, geometry representation techniques, storage and access techniques, and other aspects are examined. [63]

GIS is particularly valued for its provision of topological (georeferenced) data. This feature enables 3D analysis, spatial analysis, and queries, such as calculating distances between points, determining optimal routes, and defining optimal locations (Irizarry and Karan, 2012). On the other hand, BIM excels in offering a detailed database of object-oriented parametric information specific to buildings, presenting this information in a 3D model—a capability that GIS lacks.[57]

The integration of BIM and GIS, therefore, aims to harness the strengths of both platforms while mitigating their respective weaknesses. By combining GIS's geospatial analysis capabilities with BIM's detailed parametric information about building elements, the integrated platform becomes a comprehensive solution for the construction industry. This fusion allows for enhanced 3D and spatial analysis, providing valuable insights that support decision-making processes in construction projects.

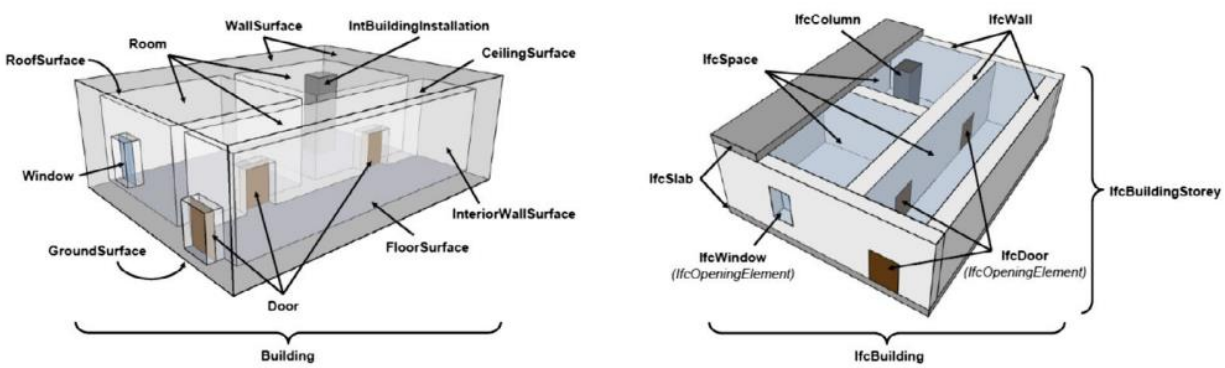

Figure 10. Comparing how the building components are represented in CityGML and IFC [28]

Integration of data between Building Information Modeling (BIM) and Geographic Information System (GIS) poses challenges that must be addressed. Data interoperability is a crucial requirement for this integration since BIM and GIS use separate primary standards—GIS uses the IFC standard, while BIM uses CityGML. In addition to interoperability problems, the fundamental distinctions between BIM and GIS present other significant obstacles.[64] Because of these incompatibilities, integration between Bim and GIS is not straightforward. These differences are examined in terms of the spatial scope, granularity, geometric representation techniques, storage and access techniques, and semantic inconsistencies between them.[65]

Various approaches have been employed to address these challenges. [63]categorize integration approaches into three groups: application level, process level, and data level.

1. **Application Level Integration:** This approach involves developing applications that can simultaneously utilize both BIM and GIS data. These applications serve as interfaces or tools that allow users to work seamlessly with information from both systems.
2. **Process Level Integration:** In this approach, the integration occurs at the process level, meaning that workflows and procedures are designed to facilitate the exchange and use of data between BIM and GIS. This ensures that the processes involved in construction or geospatial analysis consider information from both domains.
3. **Data Level Integration:** The most fundamental approach involves addressing interoperability challenges at the data level. This may include developing standardized data formats, mapping schemas between different standards (CityGML and IFC), and ensuring that data exchange occurs in a seamless and meaningful way.

Application-Level Method:

The application-level integration between Building Information Modeling (BIM) and Geographic Information Systems (GIS) involves combining data and functionalities from both systems to support various tasks in architecture, engineering, construction, and urban planning. At this level of integration, the focus is on leveraging the strengths of both BIM and GIS to enhance decision-making, analysis, and visualization processes.

Application Domain Extension

One way of integrating at the application level is using Application Domain Extensions. CityGML stands as the primary open data format for exchanging semantic 3D models of cities, valued for its flexibility and adaptability across various software platforms and geographic contexts. Its standout feature lies in its supple object modeling, allowing for the creation of virtual city models that can cater to different application requirements and levels of detail. However, despite its versatility, CityGML models may sometimes lack specific information required for certain applications. This arises from the standard's design, which prioritizes efficiency by storing only essential properties within a slim core data model. While this approach ensures lightweight models and efficient data exchange, it may result in the omission of specialized information. Nonetheless, CityGML's extensibility feature enables users to augment models with additional properties, thereby enhancing their suitability for diverse urban modeling tasks and ensuring adaptability to evolving application needs [66].

Application Domain Extensions (ADE) are integral tools for expanding the capabilities of the CityGML data model while preserving its semantic structure. As CityGML is not designed to cater to specific applications, ADE allows for the addition of new classes and attributes to accommodate diverse use cases. Two primary methods exist for extending the CityGML standard: Firstly, existing standard classes can be enriched by introducing new properties such as attributes and relationships. This enrichment enables users to tailor the data model to better suit their application needs without fundamentally altering its underlying structure. Secondly, to enable certain applications, entirely new object types, called ADE classes, can be introduced. Users will have the freedom to add particular features and functionalities that are not sufficiently represented in the standard schema by incorporating these additions, which can originate from pre-existing CityGML classes or be introduced independently. In essence, ADE provides a means to customize CityGML, ensuring its adaptability to various application domains while maintaining semantic coherence and interoperability.[67]

An Application Domain Extension (ADE) is generally organized in one of two ways: either via an XML schema definition file (XSD) or by adding application-specific information to the CityGML Unified Modeling Language (UML) model and then extracting the XSD from the UML model. However, when working with CityGML, the focus is primarily on the former approach. This involves crafting an XML-schema that encompasses a distinct namespace and interfaces with the foundational CityGML schema. In essence, this method establishes a specialized extension of CityGML's data model, allowing for the seamless integration of additional domain-specific elements while maintaining compatibility with the broader CityGML framework.[66]

When working with Application Domain Extensions (ADE), it's important to understand some key points. Firstly, each ADE needs its own unique namespace to avoid any conflicts with CityGML modules. This namespace helps keep things organized and prevents any mix-ups. Another thing to note is that ADEs can affect multiple parts of CityGML all at once, making them very versatile. Plus, you can use multiple ADEs together in the same dataset, giving you even more flexibility,It's also worth mentioning that anyone can create and use an ADE without needing permission from any official organization. However, CityGML 2.0 does offer some helpful advice on how to create ADEs using XML schema. These guidelines can make sure your ADE fits in smoothly with CityGML datasets and follows the right standards.[68]

The major objective of this Application Domain Extension (ADE) is to store and handle data that is essential for calculating building energy consumption. The ADE does not cover large-scale centralized energy systems, even though it focuses primarily on buildings and their integrated Geographic Information Systems (GIS) and Building Information Modeling (BIM) systems. ADEs are flexible, just as the CityGML standard, and the Energy ADE in particular strives to minimize redundancy while integrating with different degrees of detail and data quality. The Energy ADE consists mostly of building objects related to thermal utilization, which are connected to CityGML objects by means of abstract classes. These abstract classes go beyond features relevant to energy research, allowing for sophisticated transient heat simulations and the integration of demographic and socioeconomic data.Important Elements of the Energy. [66]

Despite CityGML traditionally focusing on exterior environments, numerous Application Domain Extensions (ADEs) have emerged to support indoor applications. This development is especially significant for us as BIM contains crucial indoor data, and integrating BIM with GIS necessitates bridging the gap between indoor and outdoor environments. One illustrative example is an ADE tailored for indoor routing and positioning. This ADE extends CityGML's capabilities by incorporating features specific to building storeys. For instance, they enhance the "FloorSurface" feature to encompass new datasets pertinent to indoor navigation and positioning, facilitating seamless integration between indoor and outdoor spatial data within the CityGML framework.[69]

Since CityGML normally does not naturally maintain such semantic data, this ADE covers a critical gap. It improves the information richness of CityGML models by allowing the storing of structural data and interactions between components. Furthermore, the Semantic City Model ADE guarantees that every element maintains its level of complexity even after conversion by supporting several levels of information.[28].

An analogous function of this ADE called The PANTURA ADE is to expand CityGML's capabilities to include necessary IFC data structures and their hierarchical structure. By handling a greater variety of data types and structures that are necessary for thorough urban modeling and analysis, both ADEs help to improve CityGML's capability. ,[70]

- IfcAnnotation
- IfcBeam
- IfcBuilding
- IfcBuildingElementComponent
- IfcBuildingElementPart
- IfcBuildingElementProxy
- IfcBuildingStorey
- IfcChamferEdgeFeature
- IfcColumn
- IfcCovering
- IfcCurtainWall
- IfcDiscreteAccessory
- IfcDistributionChamberElement
- IfcDistributionControlElement
- IfcDistributionElement
- IfcDistributionFlowElement
- IfcDistributionPort
- IfcElectricalElement
- IfcElectricDistributionPoint
- IfcElementAssembly
- IfcEnergyConversionDevice
- IfcEquipmentElement
- IfcFastener
- IfcFooting
- IfcGrid
- IfcMechanicalFastener
- IfcMember
- IfcOpeningElement
- IfcPile
- IfcPlate
- IfcProjectionElement
- IfcProxy
- IfcRailing
- IfcRamp
- IfcRampFlight
- IfcReinforcingBar
- IfcReinforcingMesh
- IfcRoof
- IfcRoundedEdgeFeature
- IfcSite
- IfcSlab
- IfcSpace
- IfcStair
- IfcStairFlight
- IfcStructuralCurveConnection
- IfcStructuralCurveMember
- IfcStructuralCurveMemberVarying
- IfcStructuralLinearAction
- IfcStructuralLinearActionVarying
- IfcStructuralPlanarAction
- IfcStructuralPlanarActionVarying
- IfcStructuralPointAction
- IfcStructuralPointConnection
- IfcStructuralPointReaction
- IfcStructuralSurfaceConnection
- IfcStructuralSurfaceMember
- IfcStructuralSurfaceMemberVarying
- IfcTransportElement
- IfcVirtualElement
- IfcFurnishingElement
- IfcWall
- IfcWallStandardCase
- IfcWindow

Figure 14:List of IFC classes that can be used in GIS

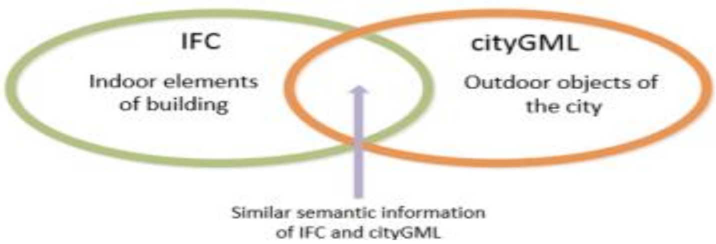

Figure 11 Relationship between IFC & GML [71]

The conversion process operates at an object level and comprises six distinct steps [71]

1. Retrieve an IFC object from BIMServer.
2. Utilize the IFC Engine DLL library to process the object.
3. Take the triangles out of the thing. The geometry from IFC to CityGML are translated by the IFC Engine DLL Library through an interface with the EMF interface.
4. Obtain the IFC properties connected to the item.
5. Acquire the subsequent item in the series.
6. Create a CityGML file by converting data from memory. Similar objects to those already in CityGML are transformed directly, and extra attributes from IFC are included effortlessly.

Geographic Information Systems (GIS) are now capable of much more thanks to the advent of Application Domain Extensions (ADEs), which has given the industry a wealth of options and new ways to use this standard. Still, if an ADE is included in a file too much, it may hinder information flow, which is why some claim that a saturation point has been reached. [40].

Process Level Method (Web Based Integration):

In the process level of integration between Building Information Modeling (BIM) and Geographic Information Systems (GIS), the original data structures and formats in both domains are retained. This means that the integrity and specificity of BIM data and GIS data are maintained throughout the integration process. However, despite preserving their distinct formats, both BIM and GIS systems actively interact and participate in operations that require functionalities from both domains. This ensures that users can seamlessly access and utilize data from both systems without compromising their individual characteristics or functionalities. This level of integration enables the simultaneous use of BIM and GIS data in tasks and operations where functionalities from both domains are necessary, facilitating more comprehensive analysis, decision-making, and collaboration in various applications within the built environment.[72].

In the context of process-level integration between Building Information Modeling (BIM) and Geographic Information System (GIS), a notable example is the OWS-4 project by the Open Geospatial Consortium (OGC) in 2007. This project employed a Service Oriented Architecture (SOA) to enable the collaborative participation of both BIM and GIS systems in tasks requiring the combined capabilities of both. Importantly, these systems retained their independence, operating live and distinct from each other. This process-level integration approach, facilitated by SOA, offers greater flexibility compared to application-level integration methods. The Service Oriented Architecture allows BIM and GIS systems to interact and contribute to tasks seamlessly without compromising their individual functionalities. This approach promotes flexibility by enabling both systems to operate concurrently, responding to specific tasks or requests, and collaborating in a dynamic manner.[73]

[44]expanded upon the ACTIVe3D platform, originally designed for facility management, to encompass a broader scope that incorporates the management of urban elements within building environments and across various buildings. To address the inherent heterogeneity between Building Information Modeling (BIM) and Geographic Information Systems (GIS), the researchers devised a semantic extension for BIM, termed Urban Information Modeling (UIM). This extension introduces spatial, temporal, and multi-representation concepts aimed at constructing an extensible ontology capable of modeling comprehensive city information, spanning urban proxy elements, networks, buildings, and more. The UIM extension serves as a means to bridge the semantic gap between BIM and GIS, enabling a unified representation of urban environments within the ACTIVe3D platform.

[74]employed CItyGML, Web Feature Service (WFS), and a 3D Viewer to create a web-based solution for city data management. They developed a WFS specifically tailored for Building Information Modeling (BIM) and conducted the translation of Industry Foundation Classes (IFC) into City Geography Markup Language (CityGML). Although this translation only provided a simplified "room" view of the IFC data, it demonstrated the viability of integrating architectural data, particularly for scenarios like disaster management, where such integration proves highly advantageous. By opting for the WFS architecture for BIM services, developers are also afforded the advantage of minimizing the efforts required in designing and specifying interfaces. This approach not only facilitates the merging of architectural data but also streamlines the implementation process for developers.

[64]utilized an instance-driven methodology to establish mapping guidelines between Industry Foundation Classes (IFC) and City Geography Markup Language (CityGML), centering on entities denoting identical components within a given model. They formulated a reference ontology comprising four core

concepts: building object, geometry, property sets, and inverse relationships, elucidating their intricate interdependencies by scrutinizing the IFC and CityGML schemas. Drawing upon this reference ontology, they introduced a CityGML scheme extension termed Semantic City Model AE, tailored to accommodate diverse data and inverse associations effectively. This extension augments the CityGML framework's capacity for storing comprehensive information, thereby facilitating more nuanced depictions of urban landscapes.[75]leveraged semantic web technology to facilitate data interpretation by both participants involved in construction projects and by the Building Information Modeling (BIM) and Geographic Information Systems (GIS) applications responsible for processing the transferred data. Their methodology demonstrated that semantic technology has the capability to enable semantic interoperability between heterogeneous building and geospatial data. Initially, all spatial and non-spatial data is encoded as RDF triples, enabling a standardized representation. Subsequently, a series of standardized ontologies specific to the construction and geospatial domains are employed to integrate and query the diverse spatial and temporal data within the semantic web data format. Finally, the SPARQL query language is utilized to access and retrieve the integrated data, facilitating seamless data exchange and interpretation within and between construction and geospatial domains.

[76] explored the technical challenges associated with developing a virtual globe-based 3D visualization framework tailored for disseminating urban planning information. Their approach embraced a Web Service Oriented Architecture (SOA) to facilitate the sharing and interoperability of visual planning models. This framework empowers end-users to seamlessly explore urban planning designs, spanning from broad macro-visions to intricate micro-details, using standard home computers. By leveraging the City Geography Markup Language (CityGML) as a standardized descriptive language for 3D city models, the architecture ensures seamless interoperability, enabling users to select from a variety of available urban planning designs for visualization. Additionally, the architecture's robust capacity to integrate distributed resources facilitates the seamless integration of diverse communication platforms, such as dynamic labeling, online bulletin boards (BBS), forums, and email, allowing users to conveniently provide feedback and remarks on the showcased urban planning solutions.

The work of [77]provided a step-by-step demonstration of how to implement the integration of BIM into a spatial information model using the ETL process. This demonstration likely offers practical insights into the application of ETL in the context of integrating BIM and GIS data.[75]conducted research focusing on leveraging semantic web technology to foster semantic interoperability between established Building Information Modeling (BIM) and Geographic Information Systems (GIS) tools. The study delineates a comprehensive approach consisting of three primary phases: ontology development, semantic integration utilizing interoperable data formats and standards, and querying heterogeneous information sources. By employing this methodology, the research aims to augment data exchange and integration between BIM and GIS platforms from a syntactic to a semantic level, thereby imbuing the data with meaningful semantics. Notably, the study introduces a novel ontology constructed based on the EXPRESS schema at the application level. This BIM ontology facilitates the seamless amalgamation of building and construction-related data, encompassing various Industry Foundation Classes (IFC) with diverse attributes, thereby enhancing the interoperability between BIM and GIS systems.

Semantic Web Technologies

Semantic web technologies and ontologies hold tremendous promise for the future of integrating Building Information Modeling (BIM) and Geographic Information Systems (GIS). These technologies offer the capability to structure data into graphs with well-defined meanings, allowing machines to comprehend and communicate with each other autonomously, without human intervention. This represents a significant advancement in interoperability and data exchange between BIM and GIS systems. By leveraging semantic web technologies and ontologies, data can be encoded with rich contextual information and semantics, facilitating a deeper understanding of the data by project stakeholders as well as by BIM and GIS software. This structured approach to data representation enhances communication, fosters collaboration, and enables more intelligent decision-making processes within the integrated BIM-GIS environment.[78]

Ontologies and semantic web technology play a crucial role in structuring and organizing domain knowledge related to concepts, their relationships, and attributes. By defining the semantics of data in a standardized and machine-readable format, ontologies enable software to automatically understand and integrate information within a model without requiring human intervention. This structured approach to representing knowledge allows for more efficient data processing, analysis, and interoperability between different systems.[75]

The challenges of integrating Building Information Modeling (BIM) and Geographic Information Systems (GIS) can be divided into two main aspects: syntactic and semantic. The syntactic aspect deals with obtaining shared data from the other domain and focuses on technical issues related to data exchange and interoperability. Meanwhile, the semantic aspect involves combining data from both systems into a new structured model while preserving its meaning and context. To facilitate this integration, an intermediate or new model is often introduced to synchronize the data exchange process.[37]

Data Level Method:

In the realm of integrating Building Information Modeling (BIM) with Geographic Information Systems (GIS) at the data level, several methods have been devised, each with its distinct approach and challenges. [64]presented four methods for data integration: direct data import, shared database access, formal semantics, and integrated data management with file translation. Their focus was on merging 3D data from both Geographic Information Systems (GIS) and Computer-Aided Design (CAD) software, utilizing the integrated data management and file translation approach. This strategy addressed two key concerns: the exchange of geometry and potential information loss during file translation. Through this method, the authors successfully implemented geometry translation, covering lines, surfaces, and solids, between 3D GIS and 3D CAD platforms, effectively resolving technical disparities in geometric representation. This highlights the practicality and efficiency of file translation in integrating these systems. However, achieving seamless integration requires a comprehensive solution at the data representation level. Presently, CAD-GIS integration projects tend to be tailored to specific projects and handled individually. Nonetheless, model conversions rarely rely solely on geometric translations, underscoring the importance of semantics. Thus, achieving interoperability between disparate systems remains a crucial aspect of efficient integration.

1. **Linking Methods**: One method involves linking BIM and GIS through facilities like ESRI ArcSDE, which facilitates data transfer between the two systems. This is achieved through an Application Programming Interface (API) at either the BIM or GIS software side.
2. **Translation/Conversion Methods:** Another set of methods focuses on translation or conversion between BIM and GIS formats. Notable tools like FME (Safe, 2013) .These methods often involve

direct conversion between GIS and BIM formats, such as translating data between Industry Foundation Classes (IFC) and City Geography Markup Language (CityGML). This method has some drawbacks, such as the potential loss of semantics, restrictions on the precision of geometric conversion, and a propensity to concentrate mostly on important building components while potentially ignoring other important details like utilities or connections.[79]

3. **Geometry Transformation Challenges:**. Geometry transformation refers to the process of aligning or transforming the geometric data between BIM and GIS models. While progress has been made in addressing this challenge, the research suggests that these efforts may not comprehensively cover the overall integration requirements.

4. **Semantics and Geometric Conversion Limitations:** A recurring theme in these methods is the trade-off between semantic richness and geometric accuracy. While translating or converting data between BIM and GIS formats, there may be limitations in retaining the full semantics of the information, and geometric transformations might not cover all intricacies of the models.The research suggests that some methods may focus more on major building elements, potentially neglecting utilities or other vital aspects of the integrated data.

Extension of Existing Standards, translation, and conversion (ETC):

In essence, the primary focus of researchers before has been on converting data from IFC to CityGML in a unidirectional manner. However, [61]and [80]have highlighted the necessity for a more comprehensive approach, emphasizing the importance of transforming both geometric and semantic datasets simultaneously due to the inherent conceptual misalignment between the two systems. Typically, the manual conversion process involves several steps such as semantic filtering, exterior shell computation, integrating building installations, refining geometry, and refining semantics. This established framework serves as a cornerstone for the conversion and translation processes between IFC and CityGML.

According to (Zlatanova & Beetz, 2012),a significant hurdle in converting data between Industry Foundation Classes (IFC) and City Geography Markup Language (CityGML) lies in the challenge of retaining semantic information. Even if the converted data contains semantic details, the original meaning of attributes often gets lost in translation [73]However, it's essential to note that converting geometry isn't always a straightforward task either. Converting from CityGML to IFC presents more complex challenges, encompassing both semantic nuances and geometric intricacies (Mignard & Nicolle, 2014).To mitigate these challenges, two potential solutions have been proposed: refining surface type definitions in CityGML and enhancing the representation of "IfcSpaces" within IFC These layers, particularly "IfcSpaces" and "IfcSlab," serve as crucial components in facilitating the conversion process between CityGML and IFC.

The Unified Building Model (UBM) methodology, introduced by [57], presents a novel approach to amalgamate the functionalities of Building Information Modeling (BIM) and Geographic Information Systems (GIS) within a unified framework. Acting as an intermediary model bridging BIM and GIS systems, UBM is constructed based on the IFC standard for BIM and City Geography Markup Language (CityGML) for GIS, with adaptability for different usage scenarios. A notable advantage of the UBM method is its capability for bidirectional data conversion between IFC and CityGML, unlike other approaches that typically support unidirectional data transfer. This bidirectional conversion potential holds promise for minimizing data loss during information exchange, marking a significant stride in facilitating seamless integration and collaboration between BIM and GIS platforms across various applications.

[81] sought to improve the compatibility of Industry Foundation Classes (IFC) and City Geography Markup Language (CityGML) within a unified system. Their approach involved simplifying the complexity of the IFC model, addressing both geometric and semantic aspects. This study utilized IFCExplorer, a software tool developed at the Karlsruhe Institute of Technology, designed for integrating, visualizing, and analyzing spatially referenced data. By implementing modifications within IFCExplorer, the researchers aimed to streamline the alignment between IFC and CityGML, facilitating smoother interoperability and enhancing the integration and analysis of spatial data across various domains and applications.

Comparative analysis of different approaches and their effectiveness

Integration Approach	Description	Differences	Limitations	Effectiveness	Other Considerations
Application Level Integration	Develops applications for simultaneous use of BIM and GIS data, offering user-friendly interfaces.	Utilizes specialized software/applications	May require significant development effort	Provides easy data interaction	Requires compatibility with various platforms
Process Level Integration	Integrates BIM and GIS data exchange into workflows, ensuring both domains are considered in construction or geospatial analysis processes	Integrates workflows and procedures	Requires standardized processes	Enhances coordination and collaboration	Relies on consistent adherence to processes
Data Level Integration	Addresses interoperability issues by standardizing data formats and mapping schemas for seamless data exchange between BIM and GIS.	Focuses on data formats and standards	May require extensive mapping efforts	Provides a foundation for data exchange	Requires ongoing maintenance

Table 4 Comparison of Integration Approaches between BIM and GIS Systems

File-based Interoperability: This method involves the direct exchange of files between BIM and GIS systems in compatible formats like Industry Foundation Classes (IFC) for BIM and Geography Markup Language (GML) for GIS. It allows manual import/export of data files, but it's limited in handling complex data structures. While it's easy to implement, it faces challenges such as potential data loss, format inconsistencies, and limitations with richer data structures.

Middleware-based Interoperability: Middleware tools or integration platforms act as intermediaries facilitating data translation between BIM and GIS systems. It enables smoother data exchange compared to file-based methods, but potential latency and compatibility issues with certain software may arise. However, it supports real-time communication between systems with different data structures, minimizing information loss.

Semantic Interoperability: Semantic interoperability focuses on establishing a shared understanding of data semantics between BIM and GIS systems. It utilizes ontologies, metadata, and semantic models to ensure accurate data semantics and reduce misinterpretation. However, developing ontologies can be resource-intensive, demanding careful curation and maintenance.[75]

Service-based Interoperability (Web Services): This approach relies on web services, APIs, or standardized protocols to enable systems' interaction. It facilitates real-time data sharing and dynamic interaction but can be reliant on stable network connections and might raise security concerns. Each approach addresses data exchange differently. File-based is straightforward but struggles with complexity, while middleware-based ensures smoother exchange yet may encounter compatibility issues. Semantic fosters accuracy but demands significant ontology development. Service-based allows real-time interaction but is reliant on network stability and security. These approaches vary in complexity, real-time capabilities, and suitability for different project scales and complexities.[82]

Interoperability Approach	**Data Handling**	**Accuracy & Reliability**	**Complexity & Resources**	**Real-time Capabilities**	**Applicability & Domains**
File-based	Limited	Potential data loss	Simple	No	Basic data transfer
Middleware-based	Improved	Reduced information loss	Moderate	Yes	Large-scale projects
Semantic	Accurate	Accurate data semantics	Resource-intensive	No	Complex projects
Service-based	Real-time	Real-time interaction	Moderate	Yes	Cloud collaborations

Table 5 Comparative analysis of different approaches

THE ROLE OF INTEROPERABLE BIM-GIS SYSTEMS IN CONSTRUCTION PLANNING AND MANAGEMENT:

In today's construction industry, the fusion of Building Information Modeling (BIM) and Geographic Information Systems (GIS) has emerged as a transformative strategy, offering considerable advantages in project planning, design coordination, and decision-making processes. Recent global research has emphasized the significance of integrated BIM-GIS systems in improving construction management practices. Studies have delved into the latest advancements, methodologies, and applications of integrated BIM-GIS, shedding light on its effectiveness, challenges, and implications. Scholars have proposed various methodologies, including federated approaches, interoperability standards such as IFC and CityGML, database integration, linked data approaches, and hybrid model integration, aiming to facilitate the smooth integration of BIM and GIS data. Nonetheless, challenges related to interoperability, data exchange, standardization, and data governance continue to pose significant hurdles to widespread adoption.[83]

The interoperable BIM-GIS systems enable seamless integration and exchange of data between BIM models and GIS platforms, enhancing decision-making, collaboration, and efficiency throughout the construction lifecycle. A noteworthy aspect highlighted by recent research is the capacity of interoperable BIM-GIS systems to offer a comprehensive understanding of project sites and their surroundings. By merging BIM's detailed building information with GIS's spatial data analysis capabilities, construction stakeholders gain valuable insights into site conditions, environmental factors, and infrastructure networks. This holistic perspective facilitates informed decision-making during site selection, design development, and construction planning phases, ultimately leading to optimized project outcomes.

The integration of Building Information Modeling (BIM) and Geographic Information Systems (GIS) in the context of building projects spans across various phases of construction and building lifecycle management. Depending on the stage of construction, this integration can be divided into four primary categories: planning and design, construction, operation and maintenance, and demolition. The application of integrated BIM-GIS systems includes tasks like building modeling, site analysis, architectural planning, program demonstration, visualization design, collaborative design, quantity statistics, building data collection, energy analysis, safety design, and sustainable design during the planning and design phase. Additionally, this integration extends to cover energy and climate adaptation design, facilitating energy simulations and buildings' energy management. Furthermore, it aids in building site selection, space conflicts resolution, preconstruction operations, structural and post-construction analysis, and construction safety planning, thereby optimizing the entire design process and enhancing building performance.[84]

BIM is used for digital construction, material tracking, site coordination, construction safety, construction visualization, construction progress and organization simulations, and green construction during the construction phase. Construction time control, supply chain management, the construction process, and activity monitoring can all be visualized with the use of BIM's integration with GIS, which enhances stakeholder coordination. Additionally, building refit projects are carried out using the integrated system to help decision-making regarding building renovation from an economic and environmental standpoint.[85]

Integerated Application of BIM and GIS in Construction Schedule Management:

The construction schedule is a fundamental component of any construction project, serving as a roadmap that dictates the sequence and timing of activities necessary for its completion. It plays a pivotal role in determining the speed, cost, and quality of construction endeavors. Several key factors influence the construction schedule, including time, space, technology, management, and resources. Time is a critical consideration in construction scheduling, encompassing the overall duration of the project and the specific start and end times allocated to individual activities. Space factors into scheduling by encompassing the physical environment where construction activities occur, including site layout, logistics, and spatial constraints. Technology also significantly impacts construction scheduling. The tools, machinery, and construction methods employed can either streamline or prolong project timelines. Effective management is essential for coordinating personnel, resources, and tasks to ensure that the project progresses smoothly according to the established schedule. Additionally, the availability and allocation of resources, including materials, labor, and equipment, play a crucial role in construction scheduling.[16]

Geographic Information Systems (GIS) and Building Information Modeling (BIM) technology have emerged as powerful tools for revolutionizing construction management practices. GIS integrates geographical data with other relevant information to provide spatial insights and analysis, while BIM creates digital representations of building or infrastructure projects, facilitating collaborative decision-making throughout the project lifecycle. By combining GIS and BIM technologies, construction teams can simulate multiple construction scenarios simultaneously, optimizing scheduling and resource allocation. Real-time monitoring of material inventory and procurement processes ensures alignment with construction progress, while identifying and resolving conflicts between construction activities, materials, and equipment usage.[86]

The integration of GIS and BIM technology enables construction managers to monitor and regulate construction progress in real-time, facilitating proactive decision-making and issue resolution. It allows for the coordination of various project stakeholders and tasks, minimizing delays and disruptions. Rational resource allocation based on dynamic project requirements and constraints becomes feasible, along with the evaluation and prediction of construction progress to facilitate timely adjustments and risk mitigation strategies.The application of GIS and BIM technology in construction management leads to enhanced project efficiency, quality, and cost-effectiveness. It reduces labor inefficiencies, repetitive tasks, and conflicts between departments while minimizing material waste and optimizing machinery and equipment utilization. Through comprehensive planning, real-time monitoring, and informed decision-making, construction schedules can be effectively managed to ensure projects are completed on time and within budget constraints.[51]

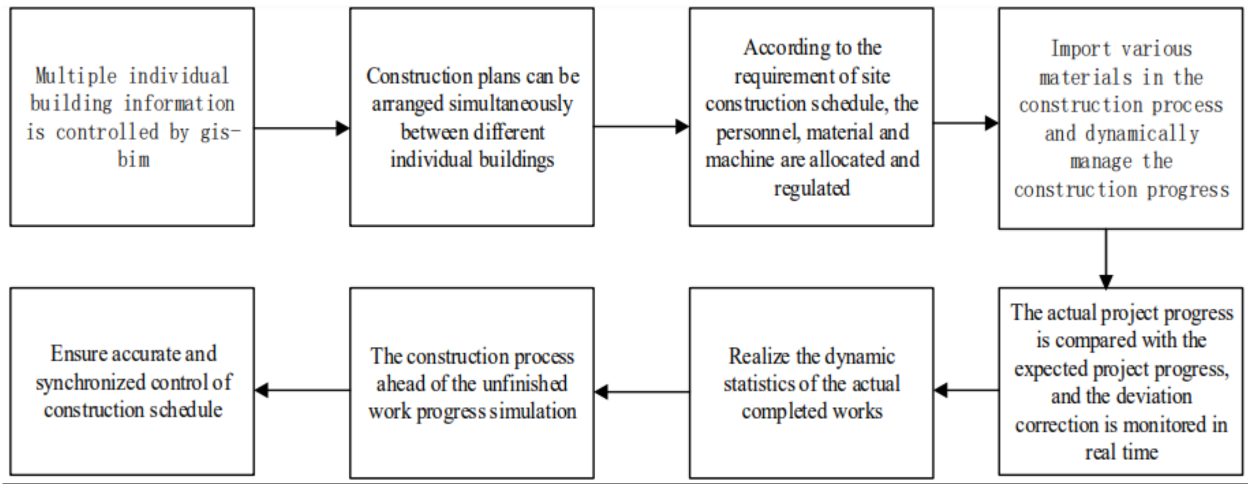

Figure 12 Utilizing 3G-BIM technologies for construction schedule management[51]

Integrated Application of BIM-GIS in Site Material Management

Site material management plays a critical role in construction projects, encompassing a wide array of activities ranging from storage and handling to disposal and waste removal. Its efficient execution is essential for achieving project objectives such as predictable outcomes, cost reduction, enhanced productivity, quality improvement, and ensuring a safe work environment. The integration of GIS and BIM technologies offers a holistic approach to site material management, leveraging the strengths of both systems to optimize processes and streamline operations. Through advanced data analysis capabilities, these integrated technologies enable the systematic optimization and arrangement of material stacking positions, quantities, and handling routes. By analyzing spatial data within the BIM model and overlaying it with geographic information from GIS, construction teams can make informed decisions regarding the allocation and utilization of materials across the construction site.[56]

One of the key benefits of GIS-BIM integration in material management is the ability to ensure uniform material allocation according to the specific requirements of different components within single buildings. This prevents construction delays and disruptions caused by material shortages or mismanagement, thereby contributing to project schedule adherence and overall efficiency. GIS and BIM integration facilitates the analysis of environmental and climatic factors at the construction site, enabling proactive measures to ensure the safe storage of materials. By assessing potential risks such as weather-related damage or environmental hazards, construction teams can implement appropriate strategies to mitigate these risks and safeguard both personnel and materials.[87]

Figure below illustrates how GIS and BIM technologies enable comprehensive planning and management of site materials, leading to cost savings across various aspects of construction operations. By optimizing material management processes, including management fees, hoisting costs, production costs, and equipment costs, construction projects can achieve greater financial efficiency and profitability. Construction projects can obtain more predictable results, save costs, increase productivity and quality, and create a safer work environment by implementing GIS-BIM technology in material management. By harnessing the power of spatial data analysis and digital modeling, construction teams can optimize material utilization, minimize waste, and enhance overall project success.[51]

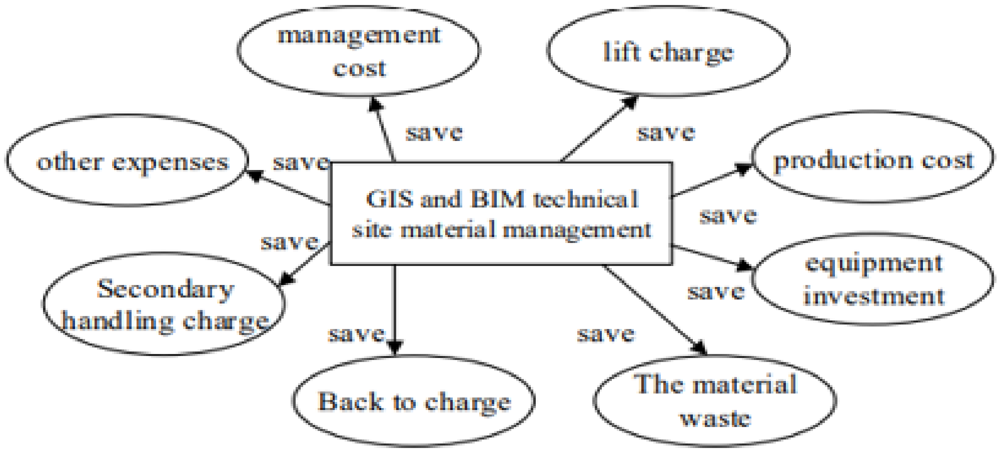

Figure 13 Technical site material management goals for GIS-BIM

Integrated Application of BIM-GIS in P&D

The integration of Building Information Modeling (BIM) and Geographic Information System (GIS) during the Planning and Design (P&D) phase of buildings represents a comprehensive approach that leverages both technologies to enhance various aspects of the construction process. In the realm of site selection.[58] employed a methodology where BIM models were seamlessly imported into the geospatial environment. This integration empowered planning department engineers to conduct a meticulous comparison between the profile and area of the architectural plans derived from BIM models and the site blocks delineated on GIS maps. The objective was to ascertain the suitability of a site block for the proposed construction. This innovative approach not only streamlined the decision-making process but also provided a visual and quantitative basis for determining the appropriateness of potential construction sites.

Similarly, by creating a middleware that can retrieve GIS and BIM data from public sources,. By combining BIM models with site maps, satellite photographs, land registration maps, and land planning data from GIS, this middleware proved crucial in creating and displaying a 3D picture of the project site. The builders were able to quickly and effectively perform a preliminary evaluation of the buildable volume because to the integration of these various datasets. The creation of this middleware was noteworthy since it solved the problem of integrating and retrieving data from various sources. Designers were able to save a significant amount of time and effort at the crucial early design stage by doing this. Making better decisions was made easier by having access to such a richness of integrated data. [56]

In the domain of energy design, significant advancements have been made by researchers who have pioneered the integration of Building Information Modeling (BIM) and Geographic Information System (GIS) to optimize energy efficiency at various spatial scales.[88]demonstrated a groundbreaking approach by establishing a connection between energy-related features and indicators at different spatial levels, ranging from single spaces to functional areas, buildings, and entire districts. The BIM and GIS compatibility was essential to this integration. Thus, throughout the design process, designers have a tool to assess and maximize the energy efficiency performance of various spatial levels. This approach guaranteed a thorough evaluation while also enabling focused increases in energy efficiency at different built environment scales.

The integration of Building Information Modeling (BIM) and Geographic Information Systems (GIS) has been a significant advancement in the realm of architectural and urban planning.[89] took this integration a step further by developing a BIM-GIS integrated web-based visualization system. This system facilitated designers in assessing the compliance of building designs with urban development schemas, thus establishing a direct link between individual building energy data and broader urban planning considerations. Moreover, it enabled urban planners to provide feedback to designers, fostering a collaborative approach aimed at refining and enhancing the energy performance of buildings. Consequently, this integrated feedback loop between BIM and GIS contributed to more sustainable and context-aware energy design decisions.

In the context of traffic design for high-rise buildings, [59]showcased the practicality of importing GIS data about the surrounding traffic conditions along with BIM models of buildings and nearby traffic facilities into simulation software. This enabled localized traffic simulations for optimizing the design. By leveraging real-world traffic data, designers could fine-tune their plans to ensure efficient traffic flow around high-rise structures. The integration of BIM and GIS in this scenario offered a dynamic and context-specific approach to traffic simulation, enhancing the overall design optimization process.The interoperability between these technologies not only empowers designers to make informed decisions but also fosters collaboration among various stakeholders, ultimately contributing to more sustainable and contextually aware design practices.[59]

In the area of structural design,[48]] conducted groundbreaking research that showcased the seamless integration of Geographic Information System (GIS) and Building Information Modeling (BIM) to enhance the structural analysis process. In their study, GIS data was initially acquired based on location, and this information was then seamlessly transferred into a cloud-based platform along with BIM data. This integration facilitated the outsourcing of data to different tools for structural analysis. The results of this analysis were subsequently communicated back to the designer in the form of revisions or layers added to the original design model. This iterative process not only enhanced the precision of structural analysis but also provided designers with valuable insights for potential post-construction assessments.

In the field of interior acoustic design, [28]demonstrated a sophisticated integration of BIM models and 3D GIS models within a unified platform. This integration aimed at evaluating and mapping noise levels in indoor environments, specifically in response to various outdoor traffic noise sources. By combining BIM and GIS data, designers were equipped with a comprehensive tool for assessing and mitigating the impact of external noise on interior spaces. This approach not only optimized the interior acoustic design process but also contributed to creating more conducive and comfortable indoor environments.

For climatic assessment,[90] pioneered the integration of BIM design models with climate data sourced from GIS databases. This integration allowed for a detailed climatic assessment of buildings, enabling designers to adapt their designs to mitigate potential climatic-related damages. By leveraging GIS-derived climate data, designers were empowered to make informed decisions about building design modifications that could enhance resilience against climatic challenges. This integrated approach bridged the gap between design and climatic considerations, contributing to more sustainable and resilient architectural outcomes.

In the field of design authorization, [84]have pioneered an innovative approach that significantly streamlines the architectural authorization procedure. In their research, BIM models of as-built buildings were transformed into Level of Detail 2 (LoD2) models. These LoD2 models were then seamlessly uploaded into an online Geographic Information System (GIS) platform. This integration allowed for a city-scale visualization of the buildings, offering robust support for the architectural authorization process.The key strength of this approach lies in its ability to facilitate a city-scale view, providing a comprehensive overview of the urban landscape. Architects, during the authorization procedure, could leverage this integrated system by uploading their BIM models of designed buildings, complete with crucial geometry and attribute data. The juxtaposition of proposed designs with existing structures in a city-scale GIS environment offered a powerful visual context for decision-makers during the authorization process.[84]

In the realm of post-occupancy evaluation (POE) for buildings already in use, [91]have introduced a novel methodology that enhances the assessment of building performance. In their research, they developed a new POE method that systematically evaluates various aspects of building performance, including indoor air temperature, humidity levels, lighting conditions, and user satisfaction levels. The results obtained from this evaluation were then input into databases, and through spatial mapping in Geographic Information System (GIS), they were superimposed onto floor plans derived from Building Information Modeling (BIM) models.

This integrated approach provides a comprehensive and visual representation of building performance on the floor plans, allowing for a nuanced understanding of how different parameters vary across spatial contexts within the building. The use of spatial mapping in GIS facilitates the overlay of performance data onto the corresponding locations within the BIM-derived floor plans. This not only streamlines the visualization of performance metrics but also allows for a more detailed analysis of how various factors interact within the building environment.

Aspect of P&D	**High Integration Approach Used**	**Software**	**Findings**	**Limitations**	**Other Details**
Site selection for construction projects	Seamless integration of BIM models into GIS environment [61]	ArcGIS, Autodesk Revit	Enabled detailed comparison of BIM-derived architectural plans with GIS maps for site suitability assessment	Dependency on accurate GIS and BIM data	Provided visual and quantitative basis for site suitability assessment
Energy design optimization	Interoperability between BIM and GIS for comprehensive energy	IES VE, ArcGIS	Facilitated targeted improvements in energy efficiency	Requires data interoperability and compatibility	Tool for evaluating and optimizing energy

	efficiency assessment [88]		across different spatial scales		efficiency
Traffic flow optimization around high-rise structures	Importing GIS traffic data into simulation software along with BIM models [59]	VISSIM, Autodesk Revit	Enabled dynamic and context-specific traffic simulations for optimized design	Reliance on accurate traffic data	Enhanced design optimization through real-world traffic simulations
Structural analysis and assessment	Seamless cloud-based integration of GIS and BIM data for structural analysis [48]	SAP2000, ArcGIS	Enhanced precision of structural analysis and provided valuable insights for post-construction assessments	Dependence on accurate GIS and BIM data	Streamlined structural analysis process
Interior acoustic design optimization	Unified platform integrating BIM and GIS data for noise level mapping [28]	Autodesk Revit, QGIS	Facilitated assessment and mitigation of external noise impact on interior spaces	Integration challenges between BIM and GIS data	Improved understanding of noise impact on interior spaces
Building design resilience against climatic challenges	Integration of BIM design models with GIS climate data for detailed climatic assessment [90]	EnergyPlus, ArcGIS	Enabled informed decisions about building design modifications for enhanced resilience against climatic challenges	Requires accurate GIS climate data	Bridged gap between design and climatic considerations
Architectural authorization process	Upload of BIM models into GIS platform for city-scale visualization during authorization process [84]	Autodesk Revit, ArcGIS	Streamlined authorization procedure and fostered informed decision-making through city-scale visualization	Dependence on accurate BIM and GIS data	Enhanced efficiency and informed decision-making in authorization
Building performance assessment	Correlation of actual performance	Autodesk Revit, ArcGIS	Facilitated nuanced understanding	Integration challenges between BIM	Tool for evidence-based

	data with spatial information from BIM models using GIS mapping [91]		of building performance and informed future design decisions	and GIS data	decision-making and design refinement

Table 6 Integrated Applications of BIM and GIS in P&D

Integrated Application of BIM-GIS in Construction

The integration of Building Information Modeling (BIM) and Geographic Information System (GIS) extends beyond new construction projects to encompass the retrofitting of existing buildings. This integration proves particularly valuable in various applications, such as supply chain management and schedule management for new construction endeavors. A notable example is the work of [75] where BIM and GIS were synergistically employed to optimize the early procurement phase and enhance the efficiency of construction supply chain management.

In the context of new construction projects, [75]harnessed the capabilities of BIM to achieve a detailed takeoff during the early procurement phase. This involved extracting precise quantities and measurements, contributing to a more accurate assessment of material requirements. Simultaneously, GIS was utilized for geospatial analysis within a visualized construction supply chain management system. This system was specifically designed to track the supply chain status of materials, providing real-time visibility into logistics delivery processes. The integration of BIM and GIS in this visualized system allowed for the seamless monitoring of material movements and facilitated timely decision-making.

A similar approach was adopted by [51]further validating the effectiveness of this integrated method for construction supply chain control. The visualized system implemented by both research groups significantly reduced the time and cost associated with logistics delivery. By leveraging the spatial analysis capabilities of GIS and the detailed information provided by BIM, construction professionals were able to optimize the flow of materials, anticipate potential issues, and implement preventative measures, ultimately enhancing the overall efficiency of the supply chain.

In the context of building retrofit projects, the integration of Building Information Modeling (BIM) and Geographic Information System (GIS) has emerged as a crucial tool for effective preparation and decision-making. [91]utilized this integrated approach by incorporating as-is geometric BIM data and other essential information into GIS. This fusion allowed them to create a pre-retrofit model, facilitating building data mapping to identify existing issues in the structure slated for renovation. This comprehensive analysis aided in the identification of problems and the formulation of corresponding solutions, streamlining the preparation phase of building renovation projects. This methodology ensures a more informed and targeted approach to retrofitting, optimizing the decision-making process and enhancing the overall efficiency of building renovation initiatives.

Similarly,[92] employed the integration of BIM and GIS in the context of retrofit projects by importing a BIM-based project time control model and scheduling data into GIS. This integration allowed for the visualization and management of the progress of repetitive construction projects across distributed sites. By amalgamating BIM with GIS, the researchers created a dynamic system that provided a real-time overview of project timelines and construction progress. This visual representation proved instrumental in coordinating and managing retrofit projects conducted in different locations, ultimately improving project management and coordination efficiency.

Aspect Of Application	**High Integration Approach Used**	**Software**	**Findings**	**Limitations**	**Other Details**
Supply Chain Management	Optimization of construction supply chain management through BIM-GIS integration[75]	Autodesk Revit, ArcGIS	Achieved detailed takeoff and material assessment with BIM; Utilized GIS for spatial analysis in visualized supply chain management system	Dependency on accurate BIM and GIS data	Enhanced efficiency in procurement and supply chain management
Supply Chain Management	Integration of BIM and GIS for construction supply chain control[51]	Autodesk Revit, ArcGIS	Reduced time and cost associated with logistics delivery; Optimized material flow and logistics processes	Integration challenges between BIM and GIS data	Improved efficiency in material logistics and supply chain management
Building Retrofit Preparation	Utilization of integrated BIM-GIS approach for building retrofit preparation[91]	Autodesk Revit, ArcGIS	Creation of pre-retrofit model for identifying structural issues; Streamlined preparation phase of building renovation projects	Dependency on accurate BIM and GIS data	Enhanced efficiency in preparation and decision-making for retrofit initiatives
Project Time Control and Scheduling	Integration of BIM and GIS for project time control and scheduling in retrofit projects[92]	Autodesk Revit, ArcGIS	Visualization and management of project timelines and construction progress; Real-time overview of project	Integration challenges between BIM and GIS data	Improved project management and coordination efficiency

			status across distributed sites		

Table 7 Integrated Application of BIM & GIS in Construction

Integrated Application of BIM-GIS in O&M:

The integration of Geographic Information System (GIS) and Building Information Modeling (BIM) has shown to be a transformative technique in the field of heritage protection, as demonstrated by the work of Their study showed how to combine historical semantic data from GIS databases with architectural information taken from BIM models of cultural heritage monuments. With a major focus on preservation and conservation, this integration of BIM and GIS data inside a single platform offered a comprehensive and unified environment for documenting and assessing cultural heritage buildings. This integrated approach enhanced the breadth of information accessible and enabled a more comprehensive comprehension of the heritage property, which in turn led to more successful preservation tactics.[93]

Similar advancements in heritage protection have been achieved by [94],One notable advantage is the conservation of storage space compared to relying solely on BIM tools. The integrated system optimizes data storage by utilizing the strengths of both BIM and GIS without unnecessary duplication. Additionally, the integration enhances geospatial analysis capabilities, allowing for a more robust examination of the heritage site within its broader geographic context. The support for visualization in different scales further underscores the versatility of the integrated BIM and GIS approach, enabling researchers and preservationists to analyze and appreciate cultural heritage sites from various perspectives.

Integrated building models, road network data, and fire brigade station locations into GIS to manage flood and fire concerns [95]. Faster reaction times are made possible by this integration, which enables firefighters to determine the shortest path from fire brigade stations to the fire scene before starting out. He also suggested a 3D geometric network model-based architecture, backed by BIM data, for simulating firefighting. By using this technique, firefighters may more effectively and efficiently respond to fires by locating the best points of entry and positioning their ladder trucks before they arrive at the scene.[95]

By combining data from GIS databases with information about the surrounding environment,[96] developed an indoor emergency spatial model based on Industry Foundation Classes (IFC). With the help of this cutting-edge model, emergency responders will be able to perceive indoor spaces better, reach indoor locations faster, and determine the best route. This method improves the overall efficacy of emergency response operations by combining geographical information from inside and outside sources.

In the field of energy management, current research has showcased innovative approaches by integrating Building Information Modeling (BIM) and Geographic Information System (GIS). [97]pioneered the development of a district information model by connecting BIM models and GIS models. This integrated model provides comprehensive information about buildings and their surrounding environment, offering a valuable tool for monitoring and controlling energy consumption at a district level. The integration of BIM and GIS facilitates a holistic understanding of energy dynamics, allowing for more informed decision-making in energy management.[75]took a multifaceted approach by utilizing BIM to calculate energy consumption in the building sector and GIS to calculate energy consumption in the transportation sector. The two sectors were then interconnected based on occupants' lifestyles, and the data was displayed on GIS maps. This integrated analysis not only identified energy use trends but also provided insights to reduce overall energy consumption. The combined use of BIM and GIS allowed for a nuanced understanding of energy usage patterns across different sectors, offering a holistic perspective for effective energy management strategies.

Researchers transferred BIM models of a hospital district, which included two other buildings and an old cancer center, into GIS as part of a European initiative called STREAMER.An extensive investigation of the building complex's overall energy efficiency was made possible by this integrated model. The analysis's findings were critical in guiding stakeholders' decisions over whether to move forward with demolition and reconstruction or choose a comprehensive overhaul of the former cancer center[98]. This decision-making support system, enabled by the integration of BIM and GIS, showcases the practical significance of this approach in evaluating and enhancing energy efficiency in complex building scenarios.In the area of space navigation, [19]have contributed to cutting-edge research by connecting indoor networks, generated using geometric and semantic information from Building Information Modeling (BIM) models, with outdoor networks from Geographic Information System (GIS) databases. This integration has a profound impact on supporting combined indoor and outdoor route planning.

The method employed by them involves leveraging the wealth of information embedded in BIM models to create detailed indoor networks. These networks include geometric details of the building's interior and semantic information that describes the various spaces and elements within. By seamlessly connecting these indoor networks with outdoor networks derived from GIS databases, a unified and comprehensive spatial navigation system is achieved. This integrated approach facilitates route planning that seamlessly transitions between indoor and outdoor spaces, offering users a cohesive navigation experience across diverse environments. This could be crucial in various scenarios, such as large campuses, shopping malls, or transportation hubs, where individuals need accurate and efficient route planning that spans both interior and exterior spaces.

In the domain of Facility Management (FM), [73]introduced an innovative approach by integrating BIM models into a GIS-based FM system. In this integration, the FM system selectively loaded and presented data based on the specific use case, user perspective, and chosen BIM objects in the GIS client. This dynamic loading of relevant information ensures that FM professionals access only the data pertinent to their specific needs. By integrating BIM into the GIS-based FM system, provided a flexible and user-centric approach to facility management, allowing for more targeted and efficient utilization of information.

Aspect of Application	**Integrated Approach**	**Software**	**Findings**	**Limitations**	**Other Details**
Heritage Protection	BIM and GIS data fusion for cultural heritage site documentation and analysis.[93]	Revit, ArcGIS	Enhanced understanding of heritage sites, improved preservation strategies	Data integration challenges	Enhanced conservation and protection of cultural heritage sites.
Fire and Flood Hazard Mitigation	GIS integration for emergency response	Revit, ArcGIS	Quicker response times,	Data accuracy dependency	Enhanced emergency response

	planning and simulation.[95]		improved effectiveness in emergency situations		capabilities, reduced property damage
Energy Management	BIM-GIS integration for district-level energy modeling and sector-specific assessments.[97]	BIM 360, QGIS	Comprehensive energy analysis, insights for consumption reduction strategies	Data compatibility issues	Enhanced energy efficiency, informed decision-making in urban planning.
Space Navigation	BIM indoor networks integrated with GIS outdoor networks for seamless route planning.[19]	ArcGIS, Revit	Unified navigation system, cohesive route planning for indoor and outdoor spaces	Data synchronization challenges	Improved spatial navigation experience, enhanced user convenience
Facility Management (FM)	BIM models integrated into GIS-based FM system for dynamic data loading.[73]	ArcGIS, Revit	Flexibility in facility management, targeted resource access based on specific needs	Data integration complexity	Enhanced facility management efficiency, optimized resource utilization.

Table 8 Integrated Application of BIM & GIS in O&M

Integrated Application of BIM-GIS in Demolition:

In the context of demolishing large-scale projects, [99]have contributed to cutting-edge research by integrating the transportation network in Geographic Information System (GIS) with material information from Building Information Modeling (BIM) models. Traditionally, BIM tools are utilized for managing and analyzing the material aspects of a construction project. However, this integrated approach goes beyond this by incorporating GIS to bring geospatial analysis capabilities into the process. By combining the transportation network data with material information from BIM models, the researchers provide a more comprehensive and spatially aware solution for estimating, sorting, and managing demolition waste. This integrated method is particularly advantageous in megaprojects where the scale of demolition activities is substantial. The use of GIS enhances the analysis capabilities, allowing for a more nuanced understanding of the spatial aspects of waste generation and disposal. The integration ensures a more efficient and optimized demolition process by considering both the material characteristics and the geospatial factors involved in waste transportation.

Integrated Application of BIM-GIS in Infrastructure:

In the domain of highway and transportation infrastructure, recent research has showcased innovative approaches by integrating Building Information Modeling (BIM) with Geographic Information System

(GIS) for various applications, spanning construction, schedule management, risk analysis, maintenance, and utility management.

In order to link road construction data from a BIM-based system with topography data from GIS databases,[100] developed an integrated system. With the goal of optimizing earthwork and lowering the overall volume of excavation and embankment in highway building projects, this integrated technique makes cut and fill operation balance analysis easier. This system's integration of BIM and GIS results in a more thorough understanding of the topography, which promotes wise decision-making and increased construction efficiency.

[101]established a platform for highway construction management by integrating BIM models of the highway, Digital Elevation Models (DEM) of the surrounding area, in-site photos, and schedule information. This comprehensive platform supports highway construction schedule management, allowing for the querying of schedules and the analysis of project progress. The integration of BIM and GIS enhances the visualization and analysis of construction activities, facilitating effective decision-making in construction project management.

A risk early warning and management system was suggested by, [49]in the context of metro building. For the purpose of conflict analysis, this system uses a building-related information model and GPS receivers to track the location of major construction equipment. Encouraging metro construction projects to be both safe and efficient is made possible by the integration of location data and BIM, which improves the capacity to recognize and handle equipment conflicts in the constrained underground environment.

For road maintenance, [100]developed an ontology based on BIM to audit and describe a school district's walkability. The results were visualized in GIS, providing an assessment of walkability conditions and suggesting safe routes for students and parents. This integrated approach leverages the information stored in BIM models and utilizes GIS for visualization, supporting decision-making in road maintenance and ensuring safer environments for pedestrians.

[42] linked the underground pipeline network around the building's MEP (Mechanical, Electrical, and Plumbing) systems using BIM models that were sourced from GIS sources. This 3D comprehensive utility model improves the operation and maintenance (O&M) of subterranean utility networks by acting as a visible system for utility management.

Aspect of Application	**Integrated Approach**	**Software**	**Findings**	**Limitations**	**Other Details**
Highway and Transportation Infrastructure	Earthwork optimization using BIM and GIS	Autodesk Revit, Esri ArcGIS	Optimized earthwork, reduced excavation volume in highway construction	Data compatibility issues	Improved construction efficiency, informed decision-making.
Highway Construction Management	Schedule management platform integrating BIM and GIS	BIM (e.g., Bentley OpenRoads), GIS (e.g., QGIS)	Enhanced visualization and analysis of construction activities,	Integration complexity	Facilitated highway construction schedule management,

			improved project progress monitoring		effective decision-making.
Metro Construction	Risk early warning and management system for metro construction	BIM (e.g., Tekla Structures), GPS	Improved conflict identification and management in underground construction projects	Dependency on accurate location data	Enhanced safety and efficiency in metro construction.
Road Maintenance	Walkability assessment using BIM and GIS ontology	Autodesk Revit, ArcGIS	Assessment of walkability conditions, suggestion of safe routes for pedestrians	Data ontology development challenges	Safer environments for pedestrians, informed road maintenance decisions.
Utility Management	Holistic utility management system for subsurface pipeline networks	Autodesk Revit, ArcGIS	Holistic utility management system for subsurface pipeline networks	Integration of legacy data	Enhanced operation and maintenance of underground utility networks.

Table 9 Integrated Application of BIM & GIS in Infrastructures

Integrated Application of BIM-GIS on Urban Districts:

Applications in bigger areas, such an urban district, where buildings, the road system, and subterranean utilities are all connected and used for analysis, are supported by BIM combined with GIS. The main applications of BIM and GIS integration in urban districts are in program administration, energy management, facility management, and emergency response.[102]

In research did by[61]] has introduced an innovative information fusion framework that leverages multiple data sources, including Building Information Modeling (BIM) models and Internet of Things (IoT) nodes. This framework is integrated into a Geographic Information System (GIS)-based system, creating a robust and interconnected platform. This system has proven beneficial across various fields in city management, especially through web services. The integration of diverse data sources allows for a comprehensive and real-time understanding of urban environments, enhancing decision-making and management processes.

In the realm of program management for large-scale urban renewal mega projects, [103]have contributed to research by developing a Program Information Management System. This system is based on the integration of BIM and GIS, providing a unified and comprehensive platform for managing program information. The integration allows different stakeholders, involved in the planning phase of urban renewal projects, to better comprehend the outcomes of their decisions. By combining BIM's detailed information about buildings and structures with GIS's geospatial capabilities, the system facilitates a holistic understanding of the urban environment, supporting stakeholders in making informed decisions that contribute to the success of the urban renewal initiative.

In another research by, [104]have put forth a cutting-edge software architecture designed to enhance energy consumption simulation and management at the urban district level. This software architecture integrates detailed building data from Building Information Modeling (BIM), geo-referenced information from Geographic Information System (GIS) databases, and real-time data from sensors. The aim is to create a comprehensive platform that facilitates accurate energy consumption analysis and efficient management within urban districts.

The software architecture proposed by [104]leverages BIM to provide intricate details about individual buildings within the urban district. This includes information on the building's geometry, materials, and systems that influence energy consumption. GIS contributes geo-referenced data, allowing for the spatial context of buildings within the urban fabric. The real-time data from sensors introduce a dynamic element, capturing current conditions and usage patterns.One of the key applications demonstrated using this architecture is energy demand calculation at the urban district level. By integrating data from BIM, GIS, and sensors, the software enables a comprehensive analysis of energy needs, considering both the building-specific characteristics and the broader urban context. Additionally, the architecture facilitates the calculation of solar radiation maps, providing insights into areas with optimal sunlight exposure for potential energy generation or conservation measures.

The integration of real-time sensor data is particularly significant, as it allows for the consideration of dynamic factors such as occupancy patterns, equipment usage, and external environmental conditions. This real-time input enhances the accuracy of energy simulations and provides a more responsive framework for energy management within urban districts. In their indepth research,[44]have introduced a groundbreaking approach by developing a semantic extension to Building Information Modeling (BIM), termed Urban Information Modeling (UIM), in conjunction with Geographic Information System (GIS). This extension is designed to broaden the scope of a facility management platform, allowing it to manage not only buildings but also various urban elements such as urban proxy elements and networks. This integration empowers facility managers to support activities throughout the entire lifecycle of an urban environment within a collaborative context. The development of UIM serves as a semantic extension to traditional BIM, incorporating elements relevant to urban environments. By combining this extended BIM framework with GIS, the researchers have expanded the capability of the facility management platform. This enriched platform is now capable of handling diverse urban elements, including but not limited to buildings, networks, and urban proxy elements (representations of real-world objects in the urban environment).

The significance of this integration lies in the ability of facility managers to operate within a collaborative context while overseeing the entire lifecycle of an urban environment. The collaborative nature of the platform enables stakeholders to share and exchange information seamlessly, fostering a holistic understanding of urban elements. Facility managers can now navigate beyond individual buildings to manage a broader array of components within the urban landscape.

Aspect of Application	Integrated Approach	Software	Findings	Limitations	Other Details
Urban Districts	Developed an information fusion framework integrating BIM, IoT, and GIS into a city management system.[61]	AutoCAD, ArcGIS, CityGML	Enhanced decision-making and management processes in city management through real-time understanding of urban environments	Limited availability and reliability of IoT data sources may impact the accuracy and effectiveness of the integrated system.	The fusion of BIM, IoT, and GIS allows for a comprehensive platform in city management, particularly beneficial for web services.
Urban Renewal	Created a Program Information Management System by integrating BIM and GIS for better decision-making in urban renewal projects.[103]	Revit, ArcGIS	Facilitates a holistic understanding of the urban environment, aiding stakeholders in making informed decisions for urban renewal.	Lack of standardized protocols for data exchange between BIM and GIS systems may pose challenges in seamless integration and interoperability.	The system offers stakeholders a unified platform for managing program information in urban renewal projects.
Energy Management	Proposed a software architecture integrating BIM, GIS, and real-time sensor data for accurate energy consumption analysis[104]	IESVE, ArcGIS	Enables comprehensive energy consumption analysis at the urban district level, considering building-specific characteristics	Dependency on real-time sensor data introduces potential issues related to data accuracy, calibration, and maintenance.	Real-time sensor data enhances the accuracy of energy simulations and provides a responsive framework for energy management

Table 10 Integrated Applications of BIM & GIS in Urban Districts

CASE STUDIES HIGHLIGHTING SUCCESSFUL IMPLEMENTATION:

In recent studies, various methodologies have been adopted to integrate Building Information Modeling (BIM) and Geographic Information Systems (GIS) datasets, aiming to enhance spatial and construction-related analyses. Here's an evaluation and comparison of these methodologies, highlighting their strengths and limitations:

Integration of BIM & GIS for Optimizing Tower Cranes Location on Construction site (Case 1):

Tower cranes are necessary for lifting and moving a variety of loads, making them an indispensable part of contemporary construction projects. On the other hand, they frequently face difficulties in their operations, including overlapped work zones and labor, cost, and time limits. The choice of the right crane can have a major impact on the cost, schedule, and safety of construction activities on ordinary projects. Thus, it is essential to maximize the quantity and placement of tower cranes in order to reduce disputes and improve productivity. Tower crane placement optimization can be achieved through the use of Geographic Information Systems (GIS), a potent tool for spatial data analysis. Managers may make well-informed decisions and obtain comprehensive insights into potential conflicts by integrating GIS analysis with BIM models.

The project under consideration is a large commercial complex located in Tehran, Iran. It includes a 6-story shopping mall, an entertainment complex, underground parking, and recreational amenities, among other things. With a total gross floor space of 128,200 square meters, the project is quite large, occupying an area of 8 acres, or over 32,000 square meters. Tower cranes must be deployed strategically for effective construction operations because of the urban context, restricted workspace, and close proximity to busy thoroughfares.

Figure 14 General View of the case study [105]

[105] developed an integrated BIM-GIS model that maximizes tower crane positions by utilizing both GIS and BIM. Using factors like geometric proximity and coverage of supply and demand points, the procedure starts with determining practicable tower crane placements. The model then calculates the best configuration of tower cranes to reduce conflicts and increase productivity once the building site geometry has been created using BIM. The BIM tool is used to show the output of the GIS model in three dimensions, together with one or more viable zones that encompass all supply and demand points. As a result, project planning and execution can be improved as managers are able to recognize possible conflicts from various angles and determine the best place for tower cranes.

The urban setting and limited workspace, coupled with the proximity to congested thoroughfares, necessitate the strategic deployment of tower cranes for efficient construction operations. To showcase the capabilities of the model, three distinct types of tower cranes, were factored into the analysis when identifying optimal locations. The model's functionality extends to considering various combinations of tower cranes to minimize overall costs. The process commences with task grouping based on the different types of cranes, followed by the assignment of a tower crane to each task group. Subsequently, additional task groups are generated for the remaining types of cranes. This iterative process continues until the optimal combination of cranes, resulting in minimal costs, is determined. In practical scenarios where the type and quantity of tower cranes are predetermined, the contractor's objective is to pinpoint the most suitable or nearly optimal locations for each supply point across the construction site. The methodology outlined can also be applied to scenarios where supply points serve as dependent variables, allowing for the calculation of total costs associated with different layout configurations.

Integrated BIM-GIS MODEL:

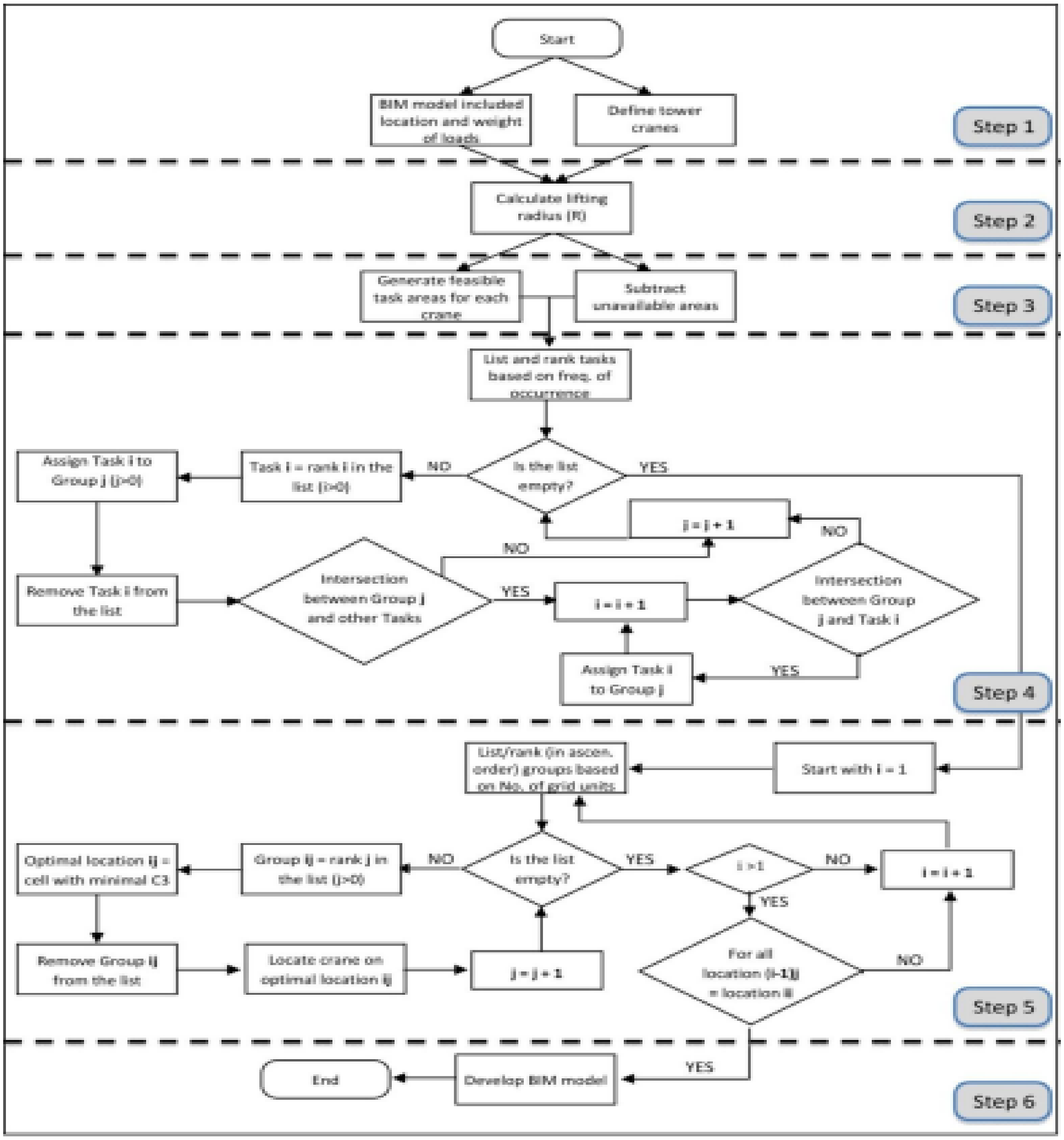

Figure 15 Flowchart of GIS-BIM optimization location model

In order to determine the bare minimum of tower cranes, the proposed method strives to leverage the assumption of coverage of all demand and supply points. In order to identify the practical area where there would be the least amount of conflict between the tower crane and its surroundings, conflict detection was carried out.

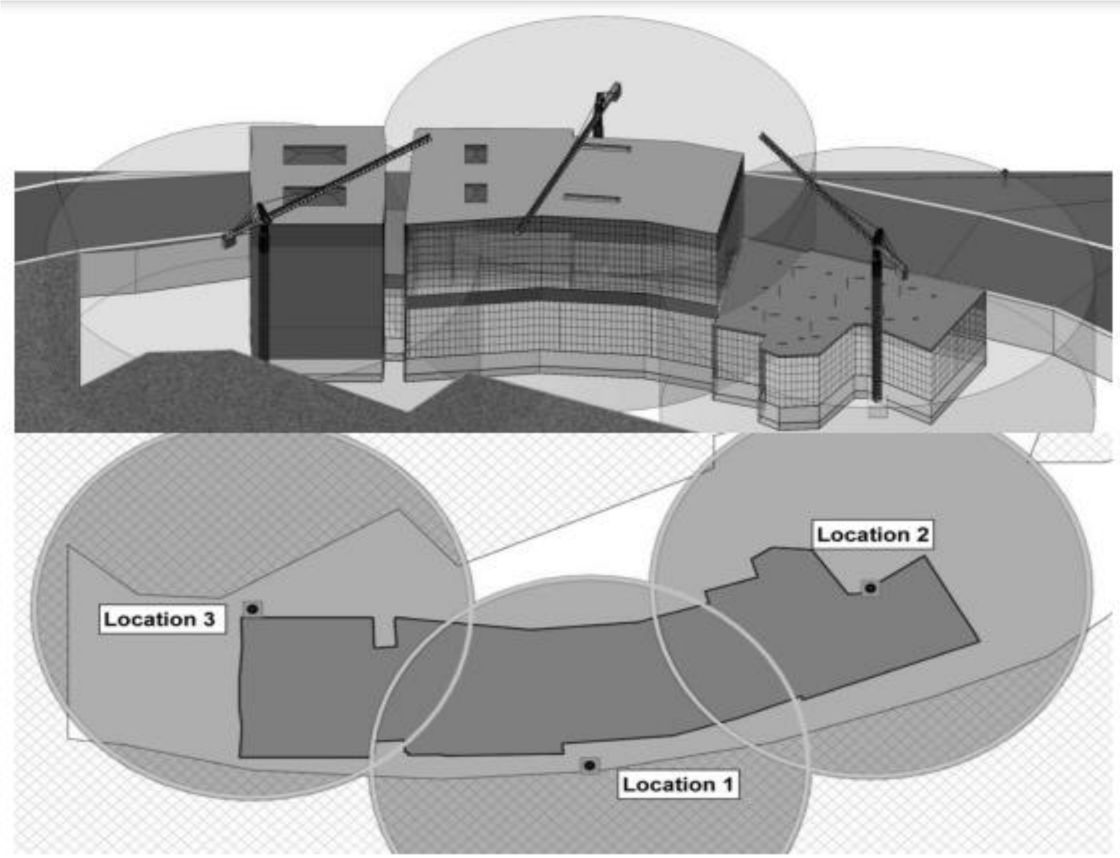

Figure 16 3D BIM (top) and plan (bottom) views for crane [11]

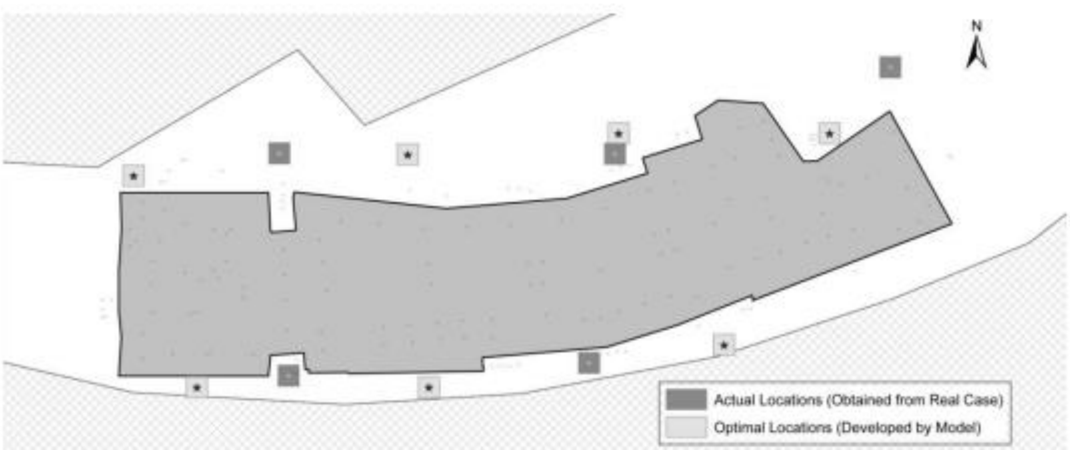

Figure 17 Comparison of actual and optimal locations for tower cranes [11]

The implementation of this model demonstrates its feasibility and practicality, particularly for construction managers who have access to a comprehensive Building Information Modeling (BIM) model containing detailed material information. By integrating GIS functionality with BIM data, the model enhances decision-making processes during site layout planning.

One key aspect of the proposed method is its flexibility to handle different types of tower cranes, ensuring that the model can adapt to the specific requirements of each construction project. The model is capable of accommodating variations in the arrangement of supply and demand points, providing versatility in site planning. Moreover, it can effectively address the complexities of construction site topography, allowing for accurate and efficient crane positioning regardless of the terrain.

Integration of BIM and GIS for Construction Waste and Debris Management (Case 2):

In contemporary construction practices worldwide, the demolition of existing buildings generates a significant volume of waste and debris, posing challenges for construction managers and site engineers in accurately estimating and managing these materials. This issue directly impacts project duration and costs. To address this challenge, [99]proposed a novel solution leveraging the integration of Building Information Modeling (BIM) and Geographic Information System (GIS) technologies. This integrated model was designed to enhance demolition waste management and control for megaprojects.

By utilizing BIM and GIS functions, this model seeks to simplify the procedures involved in calculating trash quantities. It specifically determines the travel time and distance between the landfills, storage facilities, and building sites. The program also calculates the quantity of vehicles required to load and transport waste products to and from various locations. The model offers construction managers a full tool for waste management and control by merging BIM and GIS data, which is advantageous compared to depending only on BIM.[99]

The primary goal of this integrated approach was to provide construction managers with enhanced capabilities for estimating and managing demolition waste. By combining BIM's detailed building information with GIS's spatial analysis capabilities, the model facilitates more accurate estimations of waste quantities and optimized logistics planning for waste transportation. Ultimately, this integrated model offers construction managers a holistic solution for improving efficiency and cost-effectiveness in demolition waste management, highlighting the potential benefits of integrating BIM and GIS technologies in construction projects worldwide.

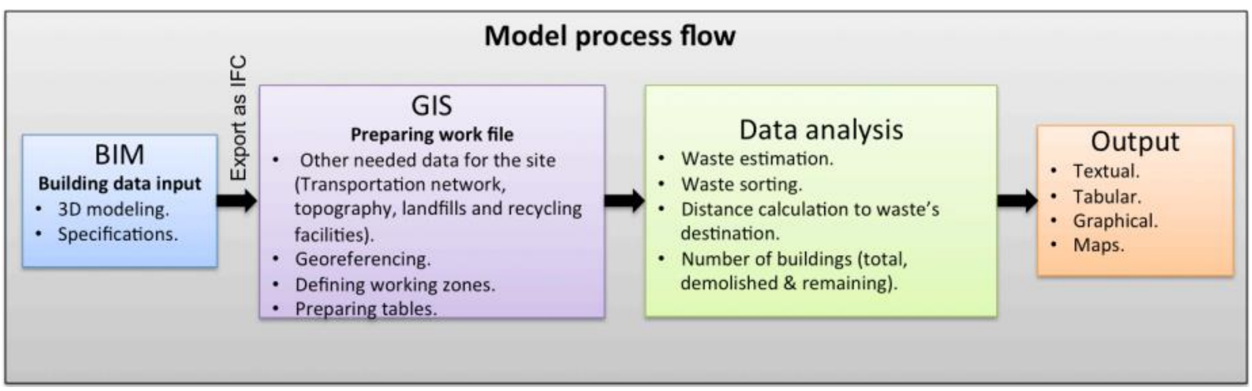

Figure 18 Process flow diagram for the BIM-GIS model

Steps	Description
Export Revit file as IFC2x3 format	Export the Revit file of the urban development project as an IFC2x3 file to ensure alignment of BIM coordinates with real-world coordinates, facilitating accurate placement of buildings in GIS.
Organize BIM file in GIS	Import the BIM file into GIS and categorize families (objects) into feature classes based on type, such as doors, windows, walls, floors, and ceilings.
Georeferenced the imported BIM file	Assign appropriate projection system to the imported BIM file, especially important for overlaying on existing transportation networks and topography layers. Consider using a multiuser Geodatabase (.gdb) file for versioning and data sharing.
Define work zones in GIS	Import work zones from the BIM file, assigning each a unique name to prevent conflicts and ease analysis.
Create essential fields in attribute table	Create fields such as "condition" (with attributes reusable, recyclable, total loss) and "classification" (Inert or Non-inert) within the attribute table of each component or feature class to facilitate waste estimation, sorting, categorizing, and quantification processes.

Figure 19 Steps in Integrating Building Information Modeling (BIM) and Geographic Information System (GIS) for Urban Development Projects

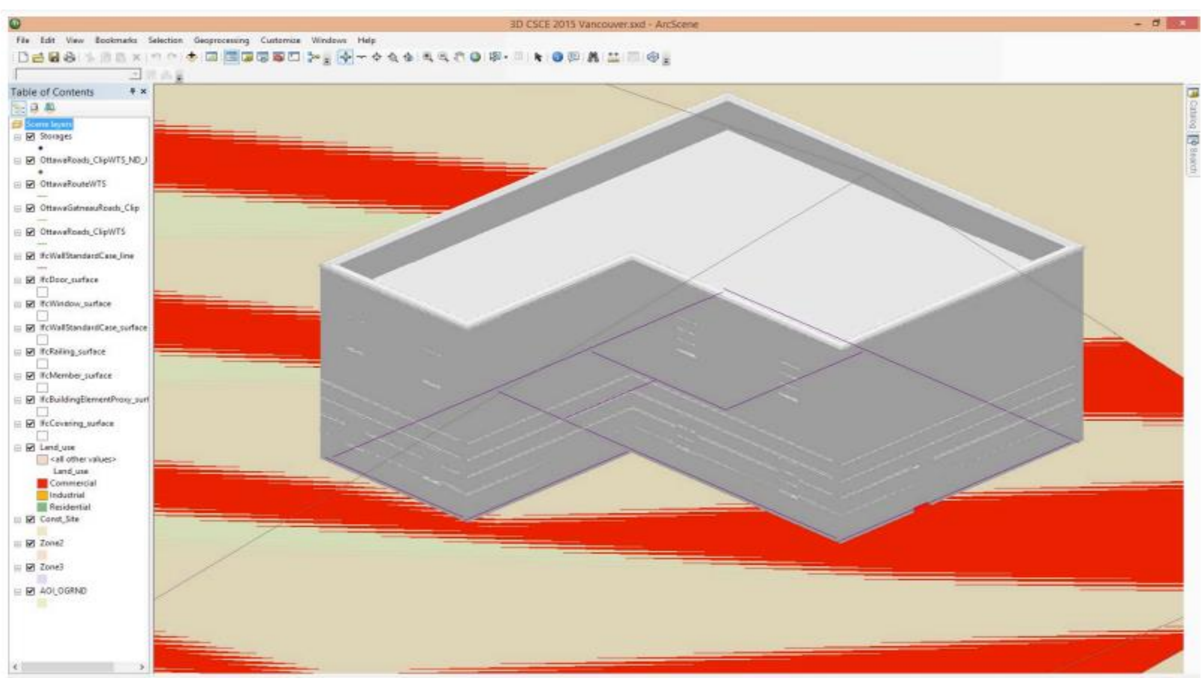

Figure 20 Imported BIM (IFC) urban development into Arc scene.

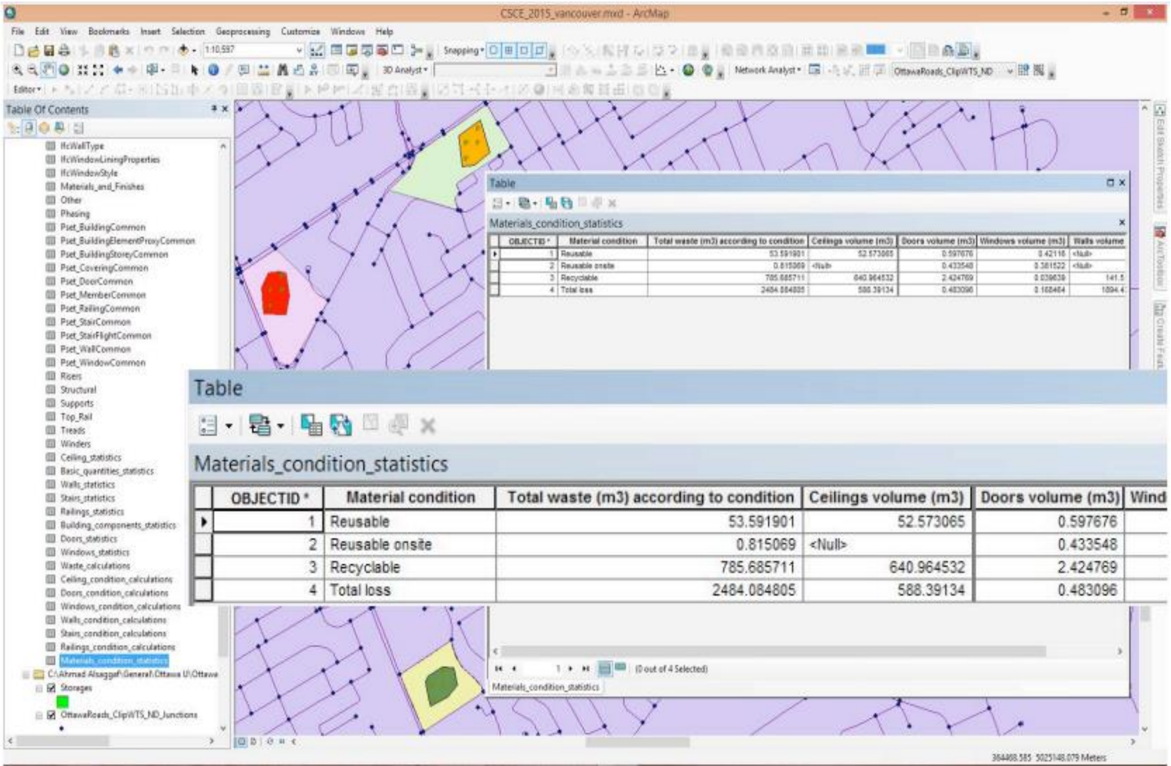

Figure 21 Calculations of waste volume produced by the BIM-GIS model [106].

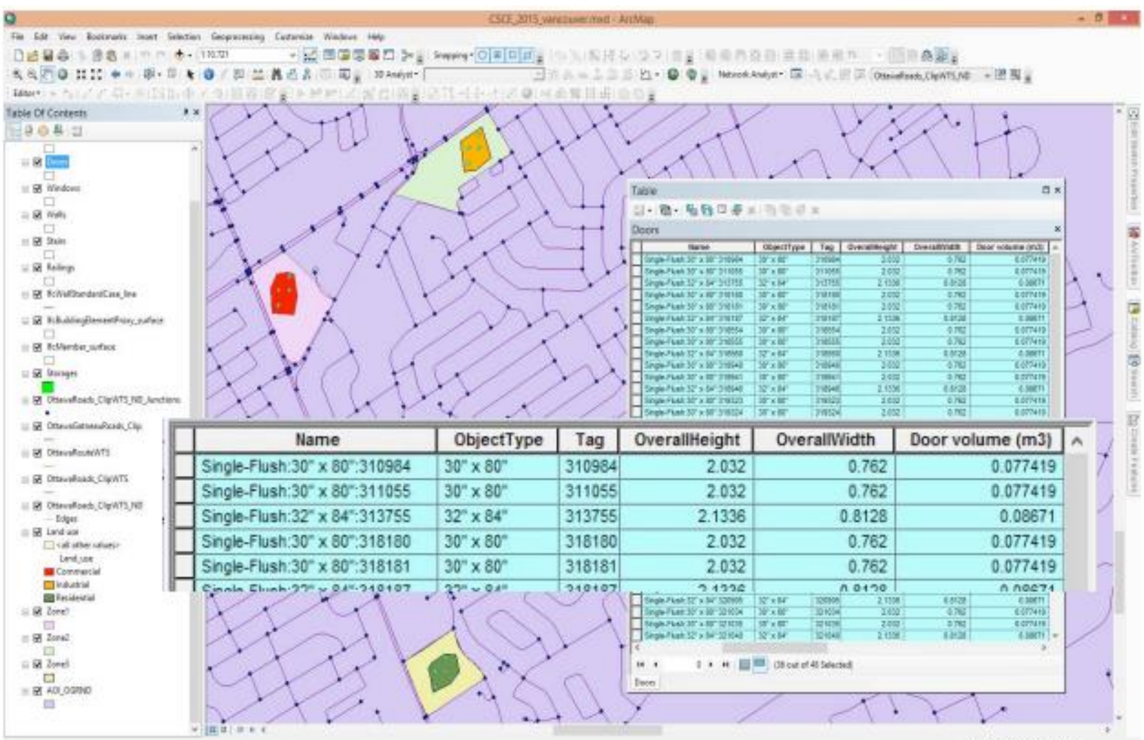

Figure 22 Waste volume calculation for a single component in three distinct zones.[107]

The number of vehicles needed to collect the garbage produced, the sorting of the materials, and the estimation of the demolition waste were all done using the Integrated Model. The BIM-GIS model is a powerful tool for controlling demolition debris because of its broad capabilities for data manipulation, inquiry, and analysis. It allows waste to be sorted into three basic categories that can be customized: condition, material type, and component. Each category is further divided into features like recyclable, total loss, and reusable (on-site or at another location). If needed, the latter group can also be further divided into inert and non-inert materials. By exporting sorted attributes into distinct layers for additional analysis and statistics, this sorting procedure makes it easier to efficiently organize and manage demolition waste.

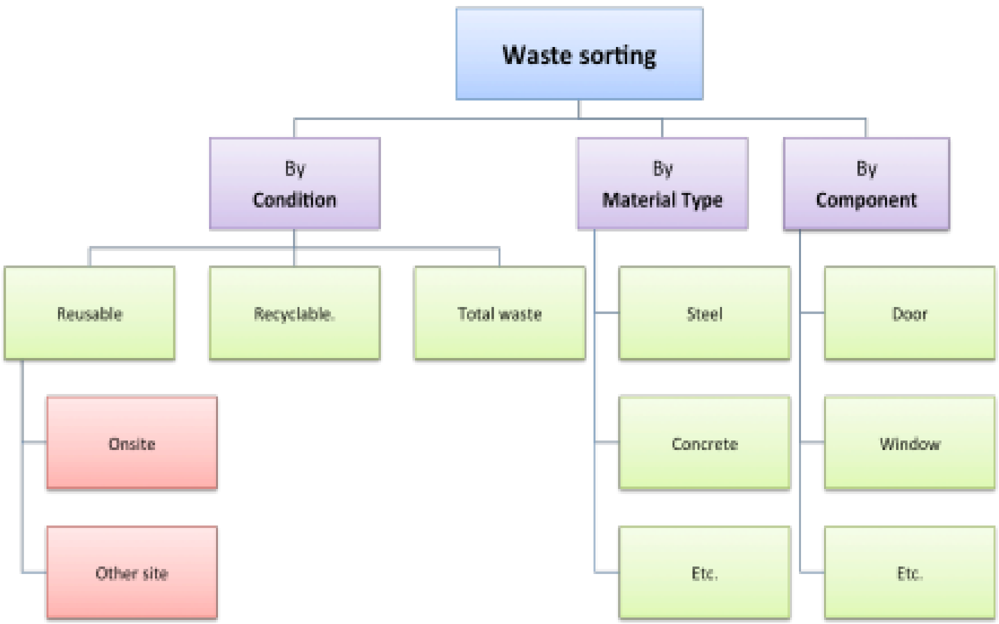

Figure 23 waste-sorting module.

The model highlights the importance of locating facilities closer to the waste source to minimize trip times and optimize waste removal efficiency, demonstrating the spatial problem-solving capability of the integrated BIM-GIS model. The total round-trip time method offers a more accurate and practical approach to estimating the number of trucks required for waste removal, enhancing the efficiency of waste management processes in construction projects.

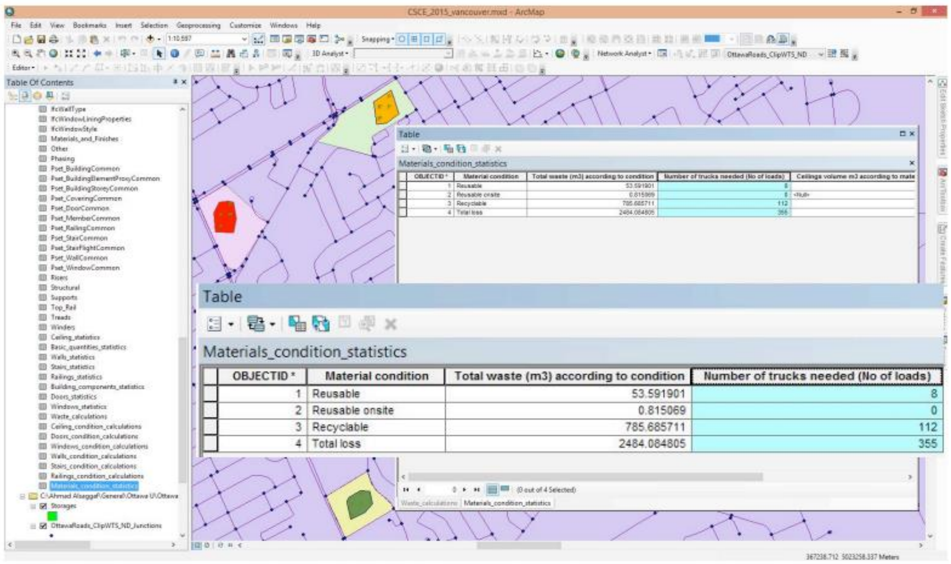

Figure 24 The route distance and time calculations generated by the BIM-GIS model.

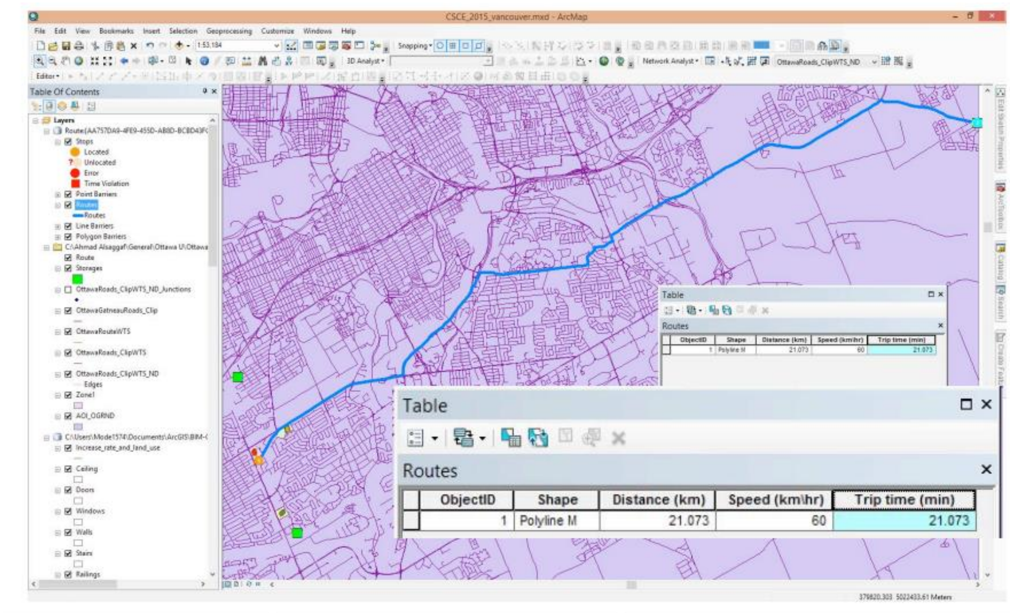

Figure 25 Number of trucks estimated based on number of loads that need to be transported.

The developed BIM-GIS model offers a robust framework for monitoring subcontractors' progress and efficiency in implementing best practices for demolition and sustainable waste management. By accurately estimating the total waste generated and incorporating a margin for potential error, the model enables easy identification of discrepancies between estimated and actual waste quantities. This discrepancy analysis can be performed at various scales, from individual buildings to entire project sites, allowing for comprehensive monitoring and evaluation of subcontractors' performance.

SMART INTEGRATED BIM GIS MODEL FOR CONSTRUCTION MANAGEMENT

The advantages of each environment are leveraged by the BIM-GIS model. While ArcGIS Desktop is superior at data visualization, spatial analysis, and geospatial data management, Autodesk Revit is well known for its ability to create and manage intricate 3D architectural models. Through the integration of these pre-existing technologies into the BIM-GIS model, users may take advantage of their pre-existing functionality for tasks like data visualization, architectural modeling, and spatial analysis. By using tried-and-true tools and workflows, this minimizes the need to create the wheel and maximizes efficiency.

The suggested integrated model's adaptability will enable its application during the construction phase of projects in situations when design modifications or construction delays arise. The methodology that has been described will be put into practice by creating an integrated smart model that is formatted to make the process of designing a building site safer, more effective, and nearly conflict-free easier. To do this, the idea of a virtual review of the construction sequence is implemented, along with site layout and route planning, to facilitate the creation of 4D models and help users in the process of choosing TFs, laying out the site, and verifying their plan for potential conflicts in 2D and 3D throughout the project lifecycle

In order to help site planners make effective judgments, this smart model highlights some of the fundamental features and specifications. These include: a) having 4D capabilities (visualization and the ability to create a 4D model in an intuitive way), as this can help planners make more informed decisions; allocating time to the various components of a 3D model is a demanding process; having the ability to perform spatial-temporal analysis is crucial because users need to know what, when, and where resources (such as site objects) are onsite and the kinds of relationships they have during the construction period; and having a comprehensive parametric library that contains both functional and physical information about temporary facilities.

For an effective Construction Site, it is imperative to identify any potential conflicts in 2D and 3D for the duration of the construction project. This is because users may overlook some of these conflicts during the planning phase, particularly when working on larger and more complex projects. Professionals should apply their knowledge throughout the planning phase to arrive at an optimal site layout plan . This model is also helpful in creating documentation and generation of reports, as well as the acquisition of a variety of outputs (such as graphical, textual, and tabular formats for checking and referencing purposes) and an actual path for construction resources to be planned.

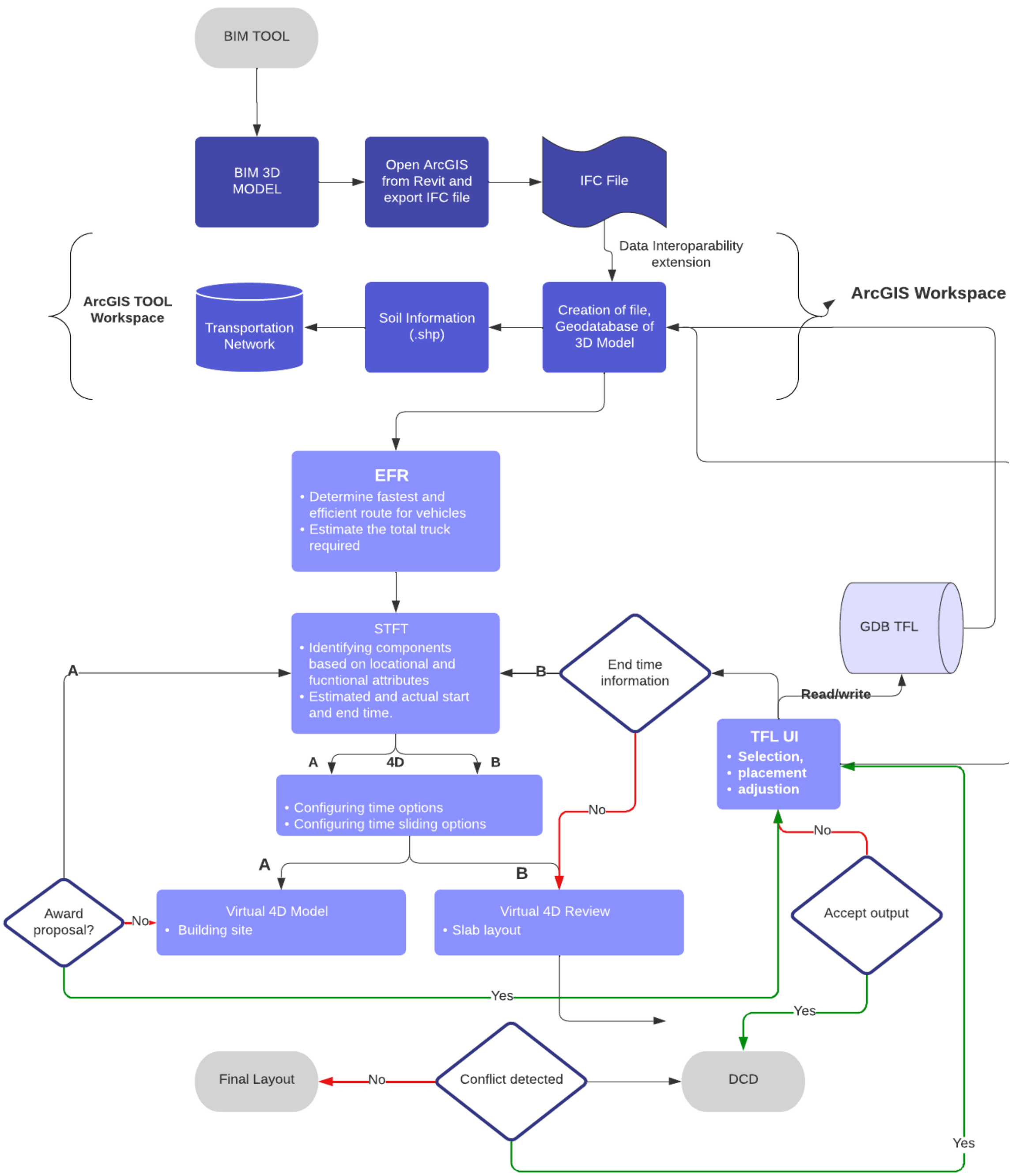

Figure 26 Data Process Flow of the Integrated BIM-GIS Model for smart construction management.

STEPS OF PROPOSED INTEGERATED MODEL:

1. **Design Detailed 3D BIM Model:**
    - Using a BIM software tool such as Autodesk Revit, design a detailed 3D model of the facility under construction and its surrounding environment.
    - Ensure that the BIM model captures all relevant architectural, structural, and MEP components with high accuracy and detail.
    - The 3D model should be developed with sufficient detail to align accurately with the aerial photograph or satellite image of the project area. This typically corresponds to LOD 200 or higher, ensuring that key features are represented with appropriate geometry and attributes.
2. **Prepare BIM Model for Export:**
    - Check the BIM model to ensure that it contains all the necessary information required for analysis and visualization in the GIS environment.
    - Verify that the model is correctly structured and organized, with appropriate object properties and metadata assigned.
3. **Export BIM Model in Compatible Format:**
    - Within the BIM software (e.g., Autodesk Revit), initiate the export process to generate a file format compatible with the GIS tool.
    - Common export formats for interoperability between BIM and GIS environments include Industry Foundation Classes (IFC) and Revit's native format (RVT).
4. **Prepare GIS Tool for Import:**
    - Launch the GIS software tool, such as ESRI ArcMap Desktop, and open a new or existing project where the BIM model will be imported.
    - Ensure that the GIS project is configured to support the import of 3D spatial data and that necessary extensions or plugins are enabled.
5. **Import BIM Model into GIS Tool:**
    - Locate the option or tool within the GIS software for importing external spatial data or models.
    - Select the exported BIM model file (e.g., IFC or RVT) from the designated directory and initiate the import process.
6. **Verify Data Alignment and Projection:**
    - Upon import, verify that the BIM model aligns correctly with the existing GIS data layers and that they share a consistent coordinate system and projection.

- Adjust the position, scale, and orientation of the BIM model as necessary to ensure proper alignment within the GIS environment.

7. **Convert BIM Model to GIS-Compatible Format:**
    - Depending on the GIS software's requirements and preferences, convert the imported BIM model into a format suitable for GIS analysis and visualization.
    - Common formats for GIS data include shapefiles, feature classes, or geodatabases, depending on the complexity and structure of the BIM model.
8. **Perform Quality Checks and Validation:**
    - Review the imported BIM model within the GIS software to ensure that all components and attributes are accurately represented.
    - Conduct visual inspections and attribute queries to validate the integrity and completeness of the BIM data within the GIS environment.
9. **Save and Finalize GIS Project:**
    - Once satisfied with the import and validation process, save the GIS project to preserve the imported BIM model and any associated data layers or analyses.
    - Ensure that the GIS project is properly documented and organized for future reference and analysis.

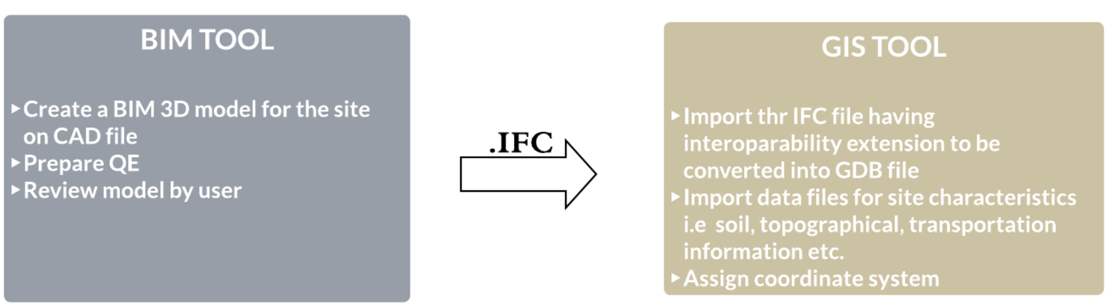

Figure 27 Process Flow of Model

Steps	Description
Review BIM 3D Model	Ensure that the BIM 3D model in Revit contains all necessary information for the facility.
Export BIM Model as IFC File	Configure export options in Revit and export the model as an IFC file for compatibility with GIS.
Develop Plug-in for Seamless Transition	Create a plug-in within the BIM tool to enable seamless integration with ArcMap.
Transform IFC File to File Geodatabase Format	Use ArcMap's Data Interoperability extension to

	convert the exported IFC file into a Geodatabase.
Import Data into ArcMap	Import the Geodatabase containing the BIM model and associated layers into ArcMap.
Examine Imported 3D Model	Explore the imported 3D model within ArcMap to verify component details and functionality.
Enrich Feature Classes with Additional Information	Enhance feature classes within ArcMap by associating additional information or data as needed.

Table 11 Procedure for Ensuring Accurate Placement of 3D Model in ArcMap

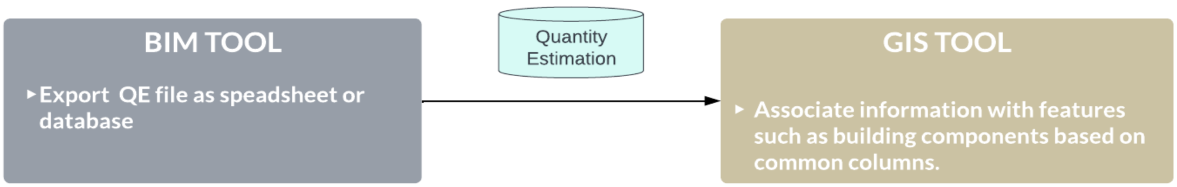

Figure 28 Process Flow of Exporting Quantity Estimation from BIM to GIS

Efficient Route Planning:

- To Enhance construction site management by identifying the safest and most efficient route between designated points.
- Streamline transportation logistics within the construction site to optimize efficiency and resource utilization.
- Utilize GIS network analysis capabilities to determine the most efficient route between two points within the construction site.
- Identify the supply point (e.g. for materials or waste) and the demand point (e.g., storage or disposal facilities) for transportation tasks.
- Use the Network Analyst tool in ArcMap to calculate the shortest route available, considering safety and efficiency.
- Apply restrictions, such as road closures or sensitive areas (e.g., schools, hospitals), to simulate real-world scenarios and identify alternative routes.
- Merge the selected routes into a "Roads" layer.
- Locate, estimate, and categorize building components and demolition waste into three categories: building materials, building components, and material/component condition (recyclable, reusable, total loss).
- Assist in identifying suitable locations for supply and demand points based on sorting categories and functional attributes.
- Filter sorting categories based on locational and functional attributes, such as specific building components existing on certain floors or areas within buildings.

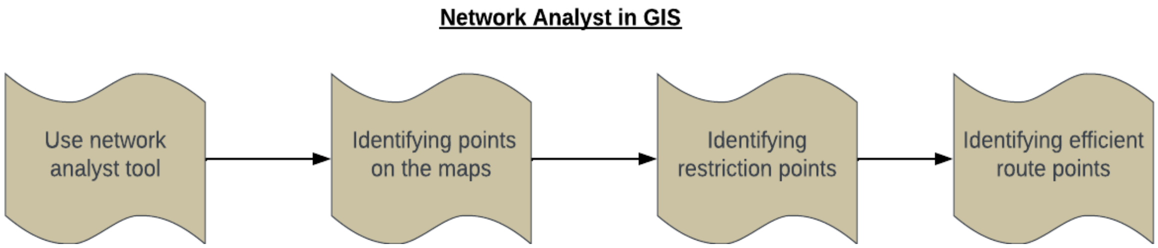

Figure 29 Process Flow of Route Planning

Construction Site Operation Management.

Using the proposed mode the total number of trips needed to transport the material from one point to another is determined. This could be based on factors such as the volume or weight of the material, distance between points, and capacity of each truck.

- **Determining Maximum Trips per Day:** The maximum number of trips that a single truck can make within one business day is established. This factor may vary depending on various considerations such as distance, loading and unloading times, traffic conditions, and legal restrictions.
- **Estimating the Number of Trucks Required:** Using the calculated maximum trips per day and the total number of trips needed, users can estimate the number of trucks required for the hauling and moving operations. This calculation considers the duration over which the trucks will be operating.
- **Example Scenario:** For instance, if the task requires 90 trips to transport Material X, and one truck can perform a maximum of 10 trips per day, then it would take 9 days to complete the transportation of Material X.
- **Adjusting the Number of Trucks:** Users have the flexibility to adjust the number of trucks based on their preferences and project requirements. Increasing the number of trucks can decrease the number of days required to complete the transportation task for a certain material.

Streamlining Resource Management Processes:

Optimized Resource Allocation: By accurately allocating start and finish times to construction activities, Phase C ensures efficient resource utilization. This enables project managers to schedule equipment, materials, and manpower effectively, reducing downtime and minimizing costs.

Improved Schedule Management: With the ability to add and edit Actual Start Time, Actual Finish Time, Estimated Start Time, and Estimated Finish Time in an easy and fast manner, Phase C enhances schedule management. Project managers can track progress in real-time, identify delays or bottlenecks, and make informed decisions to keep the project on track.

Enhanced Risk Mitigation: The ability to query objects based on locational and attribute criteria allows for targeted analysis of construction activities. Project managers can identify high-risk tasks or areas prone to delays and implement proactive measures to mitigate risks, ensuring project success and safety.

Effective Communication and Collaboration: Streamlining 4D modeling processes improves communication and collaboration among project stakeholders. Clear visualization of the construction schedule and progress enables better coordination between teams, subcontractors, and clients, fostering a collaborative environment and minimizing conflicts.

Accurate Progress Tracking: By utilizing the Modeling tool and Model Builder for 4D modeling, this model provides a systematic approach to tracking project progress. Project managers can monitor the completion status of various activities, compare actual vs. planned timelines, and adjust schedules as needed to meet project milestones.

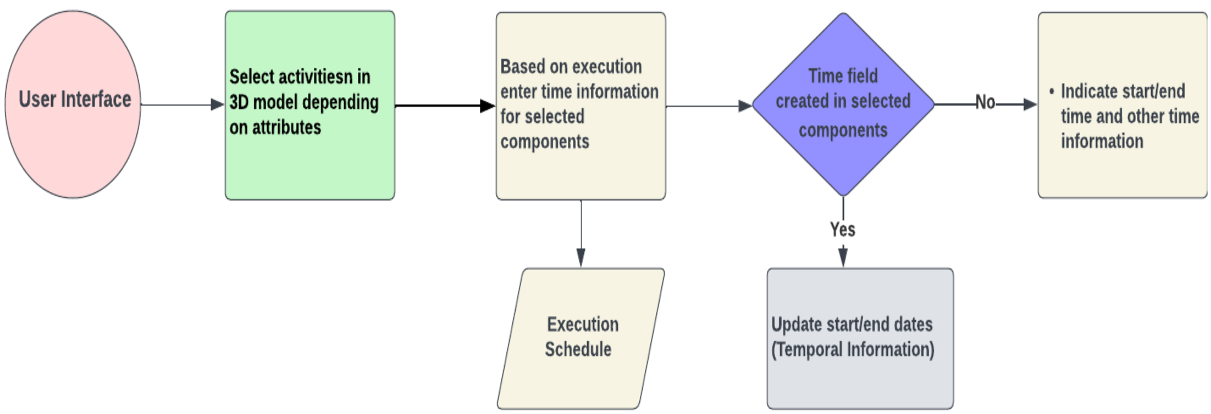

Figure 30 Process Flow for simulating Detailed Execution Plan

4D Modeling Facilitating Construction Schedule Management Processes:

- Facilitates allocation of start and/or finish times based on locational and attribute queries for individual objects or multiple features/activities within a feature class (layer) in the 3D model.
- Allows object selection based on many parameters, including component number, position (e.g., first and second floors), width and length, or global unique identifier (GUID).
- Supports querying objects within specific ranges, such as a range of TAG numbers (e.g., TAG number 1234 to 1345).
- Utilizes the Modeling tool, depicted in Figure above, to streamline the process flow.
- Implements ModelBuilder, a visual programming language within the ArcGIS desktop package, to develop the toolbar extension and user interface for the ESTE module.

Spatial-Temporal Analysis with 4D Simulation in ArcMap: Time-based Visualization: The Timeslider allows for the visualization of different layers within the simulation over time. Users can set separate display outputs for each layer, showing the progression of site objects either incrementally over time or for the duration they exist onsite.

Dynamic Attribute Table: During the simulation, only the layers displayed within a specific time period will have their attributes visible in the attribute table. For example, if only four floors of a ten-story building are completed during the first five months, only the attributes for those floors will appear in the attribute table for the floor layer. This functionality enables users to focus on and manipulate the features relevant to the current stage of construction along with their associated data.

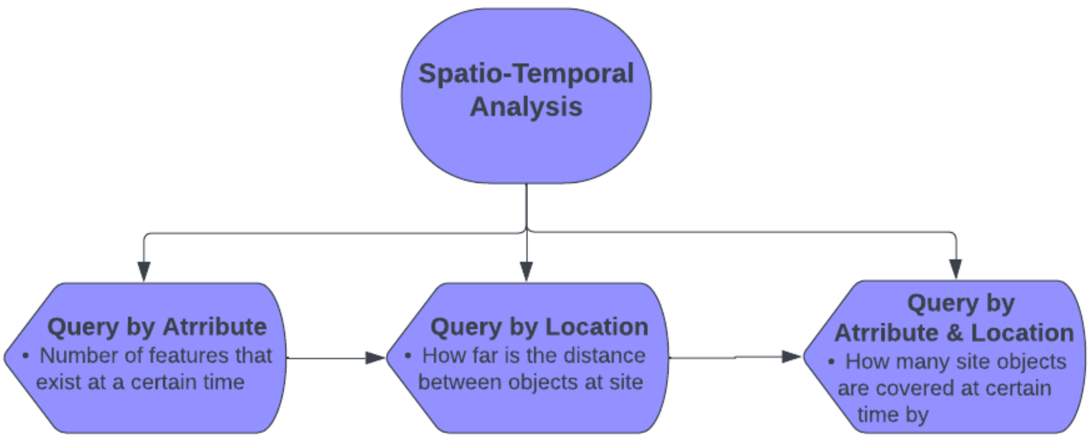

Figure 31 Spatial-Temporal Analysis that can be conducted in the model

Spatial-Temporal Analysis: The module facilitates spatial-temporal analysis, allowing users to ask specific questions related to the construction progress. For instance:

- How many objects (e.g., floors, windows, slabs, walls) will be completed after the first five months?
- How many site objects will be within the jib radius of the tower crane at a specific date and time?
- What is the distance between a certain temporary facility (e.g., batch plant or parking lot) and the site office?
- What is the total area of the finished floors after the first 8 weeks?

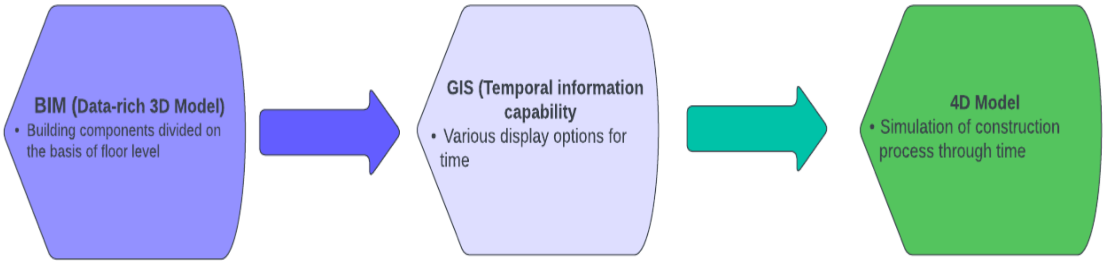

Figure 32 Data Flow of 4D Model

Strategic Temporary Facilities Placement for Construction Site Optimization:

1. **Site Layout Planning:** One of the primary objectives of this method is to aid users in planning the layout of the construction site. This involves strategically selecting and placing various temporary facilities essential for the construction process.

2. **Temporary Facilities:** Temporary facilities refer to infrastructure or amenities required during the construction phase but are not permanent features of the final structure. These may include facilities such as construction offices, storage areas, temporary power supply units, restrooms, parking lots, and material staging areas.

3. **Strategic Placement:** This approach enables users to strategically select suitable locations for placing different temporary facilities based on several factors such as accessibility, proximity to work areas, logistical considerations, safety requirements, and zoning regulations.

4. **Optimizing Construction Workflow:** By facilitating the planning and placement of temporary facilities, Construction managers can optimize the construction workflow. Properly located facilities can enhance efficiency, minimize downtime, improve resource utilization, and streamline the overall construction process.

5. **Space Utilization:** Effective site layout planning ensures efficient utilization of available space within the construction site. By carefully positioning temporary facilities, This approach can helps maximize the use of available land while ensuring sufficient space for construction activities, material storage, equipment maneuvering, and worker safety.

6. **Workflow Integration:** The model integrates seamlessly with other aspects of construction site management, such as scheduling, resource allocation, and logistics planning. This holistic approach enables project managers to coordinate various activities effectively, mitigate potential conflicts, and ensure smooth operations throughout the construction project lifecycle.

7. **Enhanced Decision-Making:** By providing tools for site layout planning, This Model can empowers project stakeholders to make informed decisions regarding the organization and management of the construction site. This includes considering factors such as workflow efficiency, safety compliance, resource allocation, and project timelines.

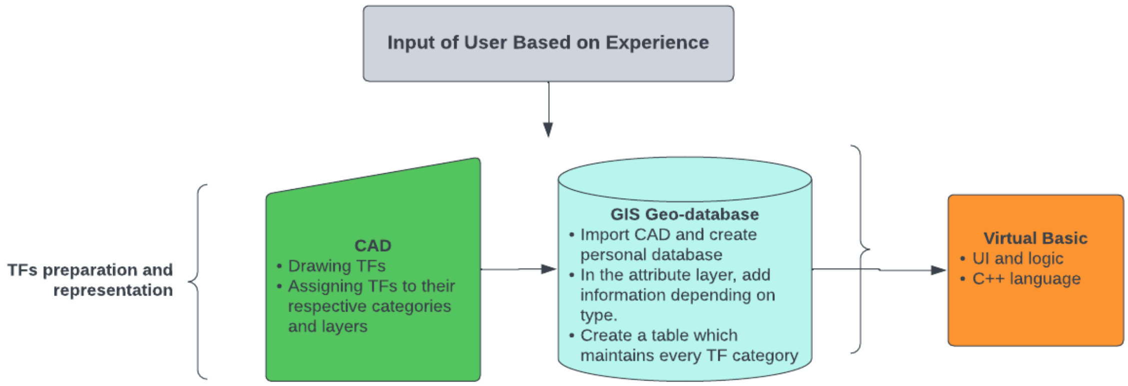

Figure 33 Temporary Facilities Management Module

<u>Temporary facilities Placement on the construction site:</u>

1. Objective: The primary goal of the this model is to streamline the process of identifying viable locations for TF placement on the construction site. By analyzing various factors such as site accessibility, terrain characteristics, and environmental considerations, this approach aims to identify areas that meet predefined suitability criteria.
2. Development and Integration: The tool is developed as part of the BIM-GIS model using ModelBuilder, a feature-rich tool within the ArcGIS desktop package. This integration allows for seamless interaction between the SAI tool and other components of the model, enhancing overall functionality.
3. Analysis Process: The model conducts a comprehensive analysis of the construction site map, considering both spatial and attribute data. By applying predefined criteria and algorithms, the tool identifies areas that are both available and suitable for TF placement.
4. Visualization and Output: Upon completion of the analysis, the SAI tool generates a visual output in the form of a separate layer on the construction site map. This layer highlights the identified suitable areas, providing users with clear guidance on where TFs can be placed effectively.

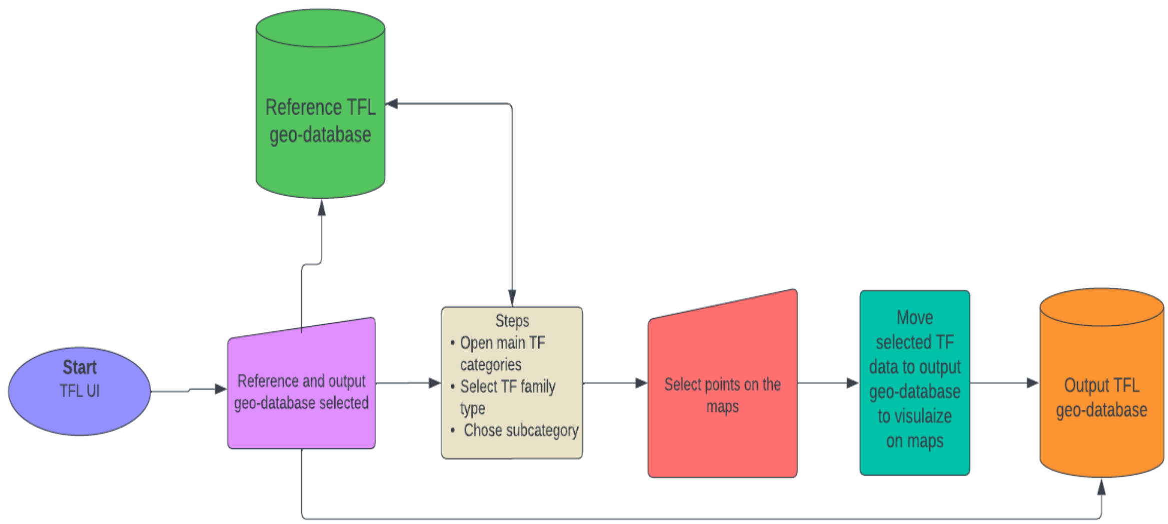

Figure 34 Process Flow of Facilities details

All TFs in the presented in the model can be categorized under 3 main categories as per the categorization mentioned.

1) Operation and Processing facilities (OPTF)

2) Storage facilities (STF)

3) Residence facilities (RTF)

There may be various families (such as Cranes) under each primary category; there may be various types (such as Tower Cranes) under each type; and within each type, there may be various sub-types (such as varying sizes).

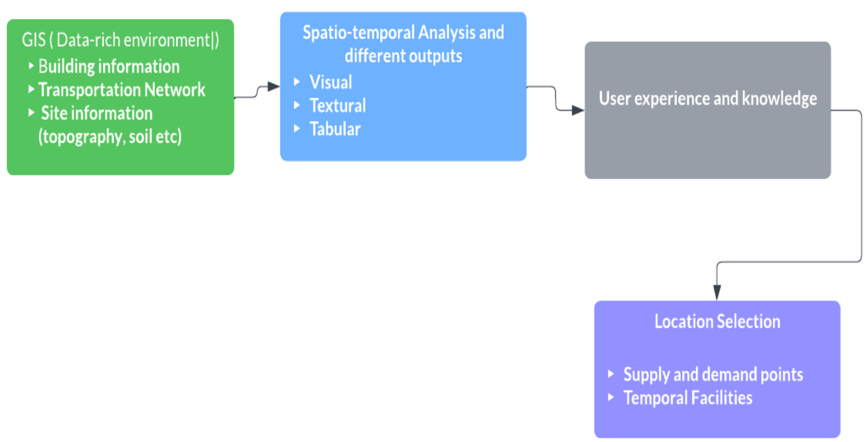

Figure 35 Work Flow of Suitable location selection

Benefits of the proposed Integrated BIM- GIS Model in Smart Construction Management:

The goal of creating a flexible and adaptable model is predicated on the integration of BIM and GIS to support the efficient decision-making process involved in the planning and administration of construction projects. Because of the integrated model's flexibility and ease of use, users may handle a variety of construction management jobs quickly and effectively. This is made possible by the development and design methodology used. Certain functions in the BIM tool (Revit) and GIS tool (ArcGIS desktop) can be customized to meet the needs of the model's development, or they can be used as-is to achieve the development of the integrated BIM-GIS model. Additionally, new plugins that can be linked to the associated tool (BIM or GIS) can be used. It has the ability to carry out numerous connected jobs.

Feature	**Description**
Information Intensive	Provides extensive data about the construction site, including topography, soil conditions, buildings, infrastructure, and transportation network. Also includes details about temporary facilities. Aims to support decision-making throughout construction planning and management.
Versatile	Offers various analyses and tools for efficient construction management, such as route planning, selecting and placing temporary facilities, 4D visualization, construction sequence review, risk assessment, and diverse output formats. Designed to address multiple challenges in construction management and provide timely support for decision-making.
Flexible	Adaptable format allows for the integration of new modules and functions, incorporating past studies or future research. Users can easily add or modify data, including details about temporary facilities and safety distances. Ensures the model can evolve to meet changing project needs and industry advancements.
Efficient	Facilitates decision-making for users without technical backgrounds by streamlining tasks related to Site Layout Planning (SLP). Accessible to individuals with varying levels of industry knowledge, ensuring efficient and effective decision-making processes.
Automatic	Simplifies the addition of temporal information to 3D building models and temporary facilities through visual selection and automatic feedback. Helps users select and place temporary facilities, and provides automatic risk assessment throughout the project. Enhances efficiency and decision-making capabilities by automating key processes.

Table 12 Key Characteristics of the Integrated BIM-GIS Model

.

Conclusion:

In conclusion, this study has provided valuable insights into the transformative potential of integrating Building Information Modeling (BIM) and Geographic Information System (GIS) technologies, emphasizing their profound impact on construction management across various project scales. Through a comprehensive examination of case studies and research findings, several key observations and implications have emerged, shedding light on the multifaceted benefits of this integration.

Firstly, the case studies analyzed in this research have unequivocally demonstrated the immediate advantages of integrating BIM and GIS in construction management. By leveraging the combined capabilities of these technologies, stakeholders can streamline project workflows, optimize resource allocation, and enhance coordination among project teams. This synergy not only leads to cost reductions and time savings but also significantly improves project outcomes in terms of quality and efficiency.

Furthermore, the suggested integrated model of BIM and GIS has revealed its instrumental role in fostering long-term resilience and adaptability in construction projects. By harnessing the wealth of data and spatial analysis tools offered by GIS, construction managers can make informed decisions that anticipate and mitigate potential challenges throughout the project lifecycle. This proactive approach to risk management and contingency planning contributes to the overall resilience of construction projects, ensuring their ability to withstand unforeseen disruptions and changes.

Moreover, the Proposed Model have underscored the pivotal role of integrated BIM and GIS in enhancing decision-making processes both before and during construction phases. By providing stakeholders with comprehensive, real-time insights into project data and spatial relationships, this integration empowers them to make strategic decisions that optimize project performance and mitigate risks. Whether it's identifying optimal site locations, optimizing construction schedules, or managing resources effectively, integrated BIM and GIS tools offer invaluable support in driving informed decision-making.

In summary, the findings of this study highlight the potential of integrating BIM and GIS technologies in construction management. From improving operational efficiency and project outcomes to fostering long-term resilience and enabling informed decision-making, this integration represents a paradigm shift in the way construction projects are planned, executed, and managed. Moving forward, further research and implementation of integrated BIM and GIS approaches are essential to realizing the full spectrum of benefits and driving continuous innovation in the construction industry.

References

[1] M. J. Mawdesley, S. H. Al-jibouri, and H. Yang, "Genetic Algorithms for Construction Site Layout in Project Planning," *J Constr Eng Manag*, vol. 128, no. 5, 2002, doi: 10.1061/(asce)0733-9364(2002)128:5(418).

[2] Y. Sugimoto, H. Seki, T. Samo, and N. Nakamitsu, "4D CAD-based evaluation system for crane deployment plans in construction of nuclear power plants," *Autom Constr*, vol. 71, 2016, doi: 10.1016/j.autcon.2016.04.004.

[3] M. Andayesh and F. Sadeghpour, "A comparative study of different approaches for finding the shortest path on construction sites," in *Procedia Engineering*, 2014. doi: 10.1016/j.proeng.2014.10.526.

[4] E. P. Karan and A. Ardeshir, "Safety assessment of construction site layout using geographic information system," in *Proceedings of the AEI 2008 Conference - AEI 2008: Building Integration Solutions*, 2008. doi: 10.1061/41002(328)63.

[5] X. Su, A. R. Andoh, H. Cai, J. Pan, A. Kandil, and H. M. Said, "GIS-based dynamic construction site material layout evaluation for building renovation projects," *Autom Constr*, vol. 27, 2012, doi: 10.1016/j.autcon.2012.04.007.

[6] A. W. A. Hammad, D. Rey, and A. Akbarnezhad, "A cutting plane algorithm for the site layout planning problem with travel barriers," *Comput Oper Res*, vol. 82, 2017, doi: 10.1016/j.cor.2017.01.005.

[7] V. K. Bansal, "Integrated Framework of BIM and GIS Applications to Support Building Lifecycle: A Move toward nD Modeling," *Journal of Architectural Engineering*, vol. 27, no. 4, 2021, doi: 10.1061/(asce)ae.1943-5568.0000490.

[8] M. Marzouk and A. Abubakr, "Decision support for tower crane selection with building information models and genetic algorithms," *Autom Constr*, vol. 61, 2016, doi: 10.1016/j.autcon.2015.09.008.

[9] R. Volk, J. Stengel, and F. Schultmann, "Building Information Modeling (BIM) for existing buildings - Literature review and future needs," *Automation in Construction*, vol. 38. pp. 109–127, Mar. 2014. doi: 10.1016/j.autcon.2013.10.023.

[10] J. K. Berry, "Beyond mapping: concepts, algorithms and issues in GIS," *Beyond mapping: concepts, algorithms and issues in GIS*, 1993, doi: 10.1016/s0167-5877(96)01071-9.

[11] J. Irizarry, E. P. Karan, and F. Jalaei, "Integrating BIM and GIS to improve the visual monitoring of construction supply chain management," *Autom Constr*, vol. 31, 2013, doi: 10.1016/j.autcon.2012.12.005.

[12] V. K. Bansal, "Integrated CAD and GIS–Based Framework to Support Construction Planning: Case Study," *Journal of Architectural Engineering*, vol. 23, no. 3, 2017, doi: 10.1061/(asce)ae.1943-5568.0000262.

[13] M. El-Mekawy, A. Östman, and I. Hijazi, "An Evaluation of IFC-CityGML Unidirectional Conversion," *International Journal of Advanced Computer Science and Applications*, vol. 3, no. 5, 2012, doi: 10.14569/ijacsa.2012.030525.

[14] M. El-Mekawy, A. Östman, and I. Hijazi, "A unified building model for 3D urban GIS," *ISPRS Int J Geoinf*, vol. 1, no. 2, 2012, doi: 10.3390/ijgi1020120.

[15] M. J. Sani and A. A. Rahman, "GIS and BIM integration at data level: A review," in *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences - ISPRS Archives*, International Society for Photogrammetry and Remote Sensing, Oct. 2018, pp. 299–306. doi: 10.5194/isprs-archives-XLII-4-W9-299-2018.

[16] M. F. Hergunsel, "Benefits of building information modeling for construction managers and BIM based scheduling," *Design*, no. May, 2011.

[17] C. Eastman, P. Teicholz, R. Sacks, and K. Liston, *BIM handbook: A Guide to building Information Modeling for owners, managers, designers, Engineers and contractors (2nd edition ed.): Wiley Publishing*. 2011.

[18] A. Borrmann, M. König, C. Koch, and J. Beetz, "Building information modeling: Why? What? How?," in *Building Information Modeling: Technology Foundations and Industry Practice*, Springer International Publishing, 2018, pp. 1–24. doi: 10.1007/978-3-319-92862-3_1.

[19] T. A. Teo and K. H. Cho, "BIM-oriented indoor network model for indoor and outdoor combined route planning," *Advanced Engineering Informatics*, vol. 30, no. 3, 2016, doi: 10.1016/j.aei.2016.04.007.

[20] D. Bryde, M. Broquetas, and J. M. Volm, "The project benefits of building information modelling (BIM)," *International Journal of Project Management*, vol. 31, no. 7, 2013, doi: 10.1016/j.ijproman.2012.12.001.

[21] B. Succar, "Building information modelling framework: A research and delivery foundation for industry stakeholders," *Autom Constr*, vol. 18, no. 3, 2009, doi: 10.1016/j.autcon.2008.10.003.

[22] A. Jrade and F. Jalaei, "Integrating building information modelling with sustainability to design building projects at the conceptual stage," *Build Simul*, vol. 6, no. 4, 2013, doi: 10.1007/s12273-013-0120-0.

[23] S. Azhar, "Building information modeling (BIM): Trends, benefits, risks, and challenges for the AEC industry," *Leadership and Management in Engineering*, vol. 11, no. 3, 2011, doi: 10.1061/(ASCE)LM.1943-5630.0000127.

[24] buildingSMART alliance and buildingSMART alliance, "NBIMS-US-3: 1 - Scope," *National BIM Standard - United States - Version 3*, 2015.

[25] J. E. Taylor and P. G. Bernstein, "Paradigm Trajectories of Building Information Modeling Practice in Project Networks," *Journal of Management in Engineering*, vol. 25, no. 2, 2009, doi: 10.1061/(asce)0742-597x(2009)25:2(69).

[26] W. E. Kraus, S. Watt, and P. D. Larson, "Challenges in estimating costs using building information modeling," in *AACE International Transactions*, 2007.

[27] M. Alshawi and I. Faraj, "Integrated construction environments: Technology and implementation," *Construction Innovation*, vol. 2, no. 1, 2002, doi: 10.1108/14714170210814676.

[28] Y. Deng, J. C. P. Cheng, and C. Anumba, "A framework for 3D traffic noise mapping using data from BIM and GIS integration," *Structure and Infrastructure Engineering*, vol. 12, no. 10, 2016, doi: 10.1080/15732479.2015.1110603.

[29] NIBS, "Frequently Asked Questions About the National BIM Standard-United States™ | National BIM Standard - United States," National Institute of Building Sciences.

[30] S. Azhar, D. Ph, and A. Behringer, "A BIM-based Approach for Communicating and Implementing a Construction Site Safety Plan Salman," *Z Papyrologie Epigraphik*, vol. 140, 2013.

[31] S. Azhar, M. Khalfan, and T. Maqsood, "Building information modeling (BIM): Now and beyond," *Australasian Journal of Construction Economics and Building*, vol. 12, no. 4, 2012, doi: 10.5130/ajceb.v12i4.3032.

[32] Richard McPartland. (2017)., "BIM dimensions - 3D, 4D, 5D, 6D BIM explained | NBS. Retrieved April 28, 2020".

[33] G. Acampa, C. M. Parisi, and M. Grasso, "Prove tecniche di interoperabilità: dalla teoria alla pratica," 2018. [Online]. Available: https://www.researchgate.net/publication/325544848

[34] P. Tobiáš, "An Investigation into the Possibilities of BIM and GIS Cooperation and Utilization of GIS in the BIM Process," *Geoinformatics FCE CTU*, vol. 14, no. 1, 2015, doi: 10.14311/gi.14.1.5.

[35] J. Zhu and P. Wu, "BIM/GIS data integration from the perspective of information flow," *Automation in Construction*, vol. 136. 2022. doi: 10.1016/j.autcon.2022.104166.

[36] J. Zhu, X. Wang, M. Chen, P. Wu, and M. J. Kim, "Integration of BIM and GIS: IFC geometry transformation to shapefile using enhanced open-source approach," *Autom Constr*, vol. 106, 2019, doi: 10.1016/j.autcon.2019.102859.

[37] A.-H. Hor, A. Jadidi, and G. Sohn, "BIM-GIS INTEGRATED GEOSPATIAL INFORMATION MODEL USING SEMANTIC WEB AND RDF GRAPHS," *ISPRS Annals of Photogrammetry, Remote Sensing and Spatial Information Sciences*, vol. III–4, 2016, doi: 10.5194/isprsannals-iii-4-73-2016.

[38] C. Ellul, F. Noardo, L. Harrie, and J. Stoter, "THE EUROSDR GEOBIM PROJECT - DEVELOPING CASE STUDIES for the USE of GEOBIM in PRACTICE," in *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences - ISPRS Archives*, 2020. doi: 10.5194/isprs-archives-XLIV-4-W1-2020-33-2020.

[39] X. Xu, L. Ding, H. Luo, and L. Ma, "From Building Information Modeling to city Information Modeling," *Journal of Information Technology in Construction (ITcon)*, vol. 19, no. December 2013, 2014.

[40] J. Zhu, Y. Tan, X. Wang, and P. Wu, "BIM/GIS integration for web GIS-based bridge management," *Ann GIS*, vol. 27, no. 1, 2021, doi: 10.1080/19475683.2020.1743355.

[41] B. Wu, R. Zhou, Y. Long, X. Cai, and B. Li, "Research on Application of BIM+GIS Technology in Building Life Cycle," in *Journal of Physics: Conference Series*, 2021. doi: 10.1088/1742-6596/1885/2/022039.

[42] R. Liu and R. R. A. Issa, "3D visualization of sub-surface pipelines in connection with the building utilities: Integrating GIS and BIM for facility management," in *Congress on Computing in Civil Engineering, Proceedings*, 2012. doi: 10.1061/9780784412343.0043.

[43] A. Longley, M. F. Goodchild, D. J. Maguire, D. W. Rhind, and W. M. Moon, "Geographic Information Systems and Science (3rd Edition) by P." [Online]. Available: https://www.researchgate.net/publication/279524026

[44] C. Mignard and C. Nicolle, "Merging BIM and GIS using ontologies application to Urban facility management in ACTIVe3D," *Comput Ind*, vol. 65, no. 9, 2014, doi: 10.1016/j.compind.2014.07.008.

[45] G. Boyes, C. Thomson, and C. Ellul, "Integrating BIM and GIS : Exploring the use of IFC space objects and boundaries," in *GISRUK 2015*, 2015.

[46] M. H. S. et Al., "Potential Application of GIS to Layout of Construction Temporary Facilities," *International Journal of Civil Engineering*, vol. 6, no. N0.4, 2008.

[47] Paul. Longley, *Geographical information systems*. Wiley, 1999.

[48] D. M. Sergi and J. Li, "Applications of GIS-enhanced networks of engineering information," in *Applied Mechanics and Materials*, 2014. doi: 10.4028/www.scientific.net/AMM.444-445.1672.

[49] H. Du, J. Du, and S. Huang, "GIS, GPS, and BIM-Based Risk Control of Subway Station Construction," in *ICTE 2015 - Proceedings of the 5th International Conference on Transportation Engineering*, 2015. doi: 10.1061/9780784479384.186.

[50] ESRI 2019, "What is GIS? Retrieved June 15, 2019, from https://www.esri.com/en-us/what-isgis/overview."

[51] Z. H. Han, Z. K. Wang, C. Gao, M. X. Wang, and S. T. Li, "Application of GIS and BIM Integration Technology in Construction Management," in *IOP Conference Series: Earth and Environmental Science*, Institute of Physics Publishing, Jul. 2020. doi: 10.1088/1755-1315/526/1/012161.

[52] A. Borrmann, T. H. Kolbe, A. Donaubauer, H. Steuer, J. R. Jubierre, and M. Flurl, "Multi-Scale Geometric-Semantic Modeling of Shield Tunnels for GIS and BIM Applications," *Computer-Aided Civil and Infrastructure Engineering*, vol. 30, no. 4, 2015, doi: 10.1111/mice.12090.

[53] J. C. P. Cheng, Y. Deng, and C. Anumba, "Mapping BIM schema and 3D GIS schema semi-automatically utilizing linguistic and text mining techniques," *Journal of Information Technology in Construction*, vol. 20, 2015.

[54] P. Pauwels, S. Zhang, and Y. C. Lee, "Semantic web technologies in AEC industry: A literature overview," *Automation in Construction*, vol. 73. 2017. doi: 10.1016/j.autcon.2016.10.003.

[55] A. Alsaggaf and A. Jrade, "A framework for an integrated bim-gis decision support model for site layout planning," in *6th CSCE-CRC International Construction Specialty Conference 2017 - Held as*

Part of the Canadian Society for Civil Engineering Annual Conference and General Meeting 2017, 2017.

[56] M. S. Khan, J. Park, and J. Seo, "Geotechnical property modeling and construction safety zoning based on gis and bim integration," *Applied Sciences (Switzerland)*, vol. 11, no. 9, 2021, doi: 10.3390/app11094004.

[57] M. El-Mekawy, A. Östman, and K. Shahzad, "Towards Interoperating CityGML and IFC Building Models: A Unified Model Based Approach," in *Lecture Notes in Geoinformation and Cartography*, 2011. doi: 10.1007/978-3-642-12670-3_5.

[58] U. Isikdag, J. Underwood, and G. Aouad, "An investigation into the applicability of building information models in geospatial environment in support of site selection and fire response management processes," *Advanced Engineering Informatics*, vol. 22, no. 4, 2008, doi: 10.1016/j.aei.2008.06.001.

[59] N. Wang and R. R. A. Issa, "Ontology-Based Integration of BIM and GIS for Indoor Routing," in *Construction Research Congress 2020: Computer Applications - Selected Papers from the Construction Research Congress 2020*, 2020. doi: 10.1061/9780784482865.107.

[60] S. N. A. Syed Mustorpha and W. M. N. Wan Mohd, "A BIM ORIENTED MODEL to A 3D INDOOR GIS for SPACE MANAGEMENT-A REQUIREMENT ANALYSIS," in *IOP Conference Series: Earth and Environmental Science*, 2019. doi: 10.1088/1755-1315/385/1/012046.

[61] U. Isikdag, "BIM and IoT: A synopsis from GIS perspective," in *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences - ISPRS Archives*, International Society for Photogrammetry and Remote Sensing, Oct. 2015, pp. 33–38. doi: 10.5194/isprsarchives-XL-2-W4-33-2015.

[62] X. Zhang, Y. Arayici, S. Wu, C. Abbott, and G. Aouad, "Integrating BIM and GIS for large scale (building) asset management : a critical review," in *The Twelfth International Conference on Civil, Structural and Environmental Engineering Computing*, 2009.

[63] S. Amirebrahimi, A. Rajabifard, P. Mendis, T. D. Ngo, and T. Ngo, "A data model for integrating GIS and BIM for assessment and 3D visualisation of flood damage to building." [Online]. Available: https://www.researchgate.net/publication/281976889

[64] Y. Deng, J. C. P. Cheng, and C. Anumba, "Mapping between BIM and 3D GIS in different levels of detail using schema mediation and instance comparison," *Autom Constr*, vol. 67, 2016, doi: 10.1016/j.autcon.2016.03.006.

[65] D. M. Azevedo *et al.*, "Development of BIM (building information modeling) concept applied to projects of Substations integrated with the geographic intelligence system," *WSEAS Transactions on Power Systems*, vol. 16, pp. 1–7, 2021, doi: 10.37394/232016.2021.16.1.

[66] R. Nouvel *et al.*, "Development of the citygml application domain extension energy for urban energy simulation," in *14th International Conference of IBPSA - Building Simulation 2015, BS 2015, Conference Proceedings*, 2015. doi: 10.26868/25222708.2015.2863.

[67] F. Biljecki, K. Kumar, and C. Nagel, “Open Geospatial Data, Software and Standards CityGML Application Domain Extension (ADE): overview of developments,” *Open Geospatial Data, Software and Standards*, 2018.

[68] F. Noardo *et al.*, “GeoBIM Benchmark 2019: Intermediate results,” in *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences - ISPRS Archives*, 2019. doi: 10.5194/isprs-archives-XLII-4-W15-47-2019.

[69] A. Dutta, S. Saran, and A. Senthil Kumar, “Development of CityGML Application Domain Extension for Indoor Routing and Positioning,” *Journal of the Indian Society of Remote Sensing*, vol. 45, no. 6, 2017, doi: 10.1007/s12524-017-0665-y.

[70] R. Sebastian, M. Böhms, and P. Van Den Helm, “BIM AND GIS FOR LOW-DISTURBANCE CONSTRUCTION 1.”

[71] R. de Laat and L. van Berlo, “Integration of BIM and GIS: The Development of the CityGML GeoBIM Extension,” in *Lecture Notes in Geoinformation and Cartography*, Springer Science and Business Media Deutschland GmbH, 2011, pp. 211–225. doi: 10.1007/978-3-642-12670-3_13.

[72] S. Amirebrahimi, A. Rajabifard, P. Mendis, and T. Ngo, “A BIM-GIS integration method in support of the assessment and 3D visualisation of flood damage to a building,” *J Spat Sci*, vol. 61, no. 2, pp. 317–350, Jul. 2016, doi: 10.1080/14498596.2016.1189365.

[73] T. W. Kang and C. H. Hong, “A study on software architecture for effective BIM/GIS-based facility management data integration,” *Autom Constr*, vol. 54, 2015, doi: 10.1016/j.autcon.2015.03.019.

[74] A. Lapierre and P. Cote, “Using open web services for urban data management: A testbed resulting from an OGC initiative for offering standard CAD/GIS/BIM services,” in *Proceedings of the Urban and Regional Data Management - UDMS Annual 2007*, 2008. doi: 10.4324/9780203931042-34.

[75] E. P. Karan, J. Irizarry, and J. Haymaker, “BIM and GIS Integration and Interoperability Based on Semantic Web Technology,” *Journal of Computing in Civil Engineering*, vol. 30, no. 3, May 2016, doi: 10.1061/(asce)cp.1943-5487.0000519.

[76] W. Wu, X. Yang, and Q. Fan, “GIS-BIM based virtual facility energy assessment (VFEA) - Framework development and use case of California State University, Fresno,” in *Computing in Civil and Building Engineering - Proceedings of the 2014 International Conference on Computing in Civil and Building Engineering*, 2014. doi: 10.1061/9780784413616.043.

[77] A. Rafiee, E. Dias, S. Fruijtier, and H. Scholten, “From BIM to Geo-analysis: View Coverage and Shadow Analysis by BIM/GIS Integration,” *Procedia Environ Sci*, vol. 22, 2014, doi: 10.1016/j.proenv.2014.11.037.

[78] P. Pauwels, S. Zhang, and Y. C. Lee, “Semantic web technologies in AEC industry: A literature overview,” *Automation in Construction*, vol. 73. 2017. doi: 10.1016/j.autcon.2016.10.003.

[79] C. Nagel, A. Stadler, and T. H. Kolbe, “Conceptual Requirements for the Automatic Reconstruction of Building Information Models from Uninterpreted 3D Models,” in *Proceedings of the Academic*

Track of the Geoweb 2009 - 3D Cityscapes Conference in Vancouver,Canada, 27-31 July 2009, 2009.

[80] S. Zlatanova and J. Beetz, “3D spatial information infrastructure: The case of Port Rotterdam,” 2012. doi: 10.1051/3u3d/201203010.

[81] J. Benner, A. Geiger, K.-H. Haefele, and J. Isele, “Interoperability of Geothermal Data Models,” 2010.

[82] S. Niu, W. Pan, and Y. Zhao, “A BIM-GIS Integrated Web-based Visualization System for Low Energy Building Design,” in *Procedia Engineering*, Elsevier Ltd, 2015, pp. 2184–2192. doi: 10.1016/j.proeng.2015.09.091.

[83] A. El Haite and C. Boton, “An Integrated BIM-GIS Dashboard to Improve BIM Coordination,” in *Lecture Notes in Civil Engineering*, Springer Science and Business Media Deutschland GmbH, 2023, pp. 623–636. doi: 10.1007/978-3-031-34593-7_38.

[84] Z. Ma and Y. Ren, “Integrated Application of BIM and GIS: An Overview,” in *Procedia Engineering*, Elsevier Ltd, 2017, pp. 1072–1079. doi: 10.1016/j.proeng.2017.08.064.

[85] M. Blanche Manjia, U. J. Merveilles Nana Pettang, P. Ouambo, C. Cabral Fandjio, F. H. Abanda, and C. Pettang, “Integration and impact of BIM in the rehabilitation of buildings in developing countries,” *J Decis Syst*, vol. 31, no. S1, pp. 319–330, 2022, doi: 10.1080/12460125.2022.2074345.

[86] A. M. Abd, A. H. Hameed, and B. M. Nsaif, “Documentation of construction project using integration of BIM and GIS technique,” *Asian Journal of Civil Engineering*, vol. 21, no. 7, 2020, doi: 10.1007/s42107-020-00273-9.

[87] W. N. F. W. A. Basir, Z. Majid, U. Ujang, and A. Chong, “Integration of GIS and BIM techniques in construction project management - A review,” in *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences - ISPRS Archives*, International Society for Photogrammetry and Remote Sensing, Oct. 2018, pp. 307–316. doi: 10.5194/isprs-archives-XLII-4-W9-307-2018.

[88] S. De Hoogh, R. Di Giulio, C. Quentin, B. Turillazzi, and R. Sebastian, “Hospital campus design related with EeB challenges,” in *eWork and eBusiness in Architecture, Engineering and Construction - Proceedings of the 10th European Conference on Product and Process Modelling, ECPPM 2014*, 2015. doi: 10.1201/b17396-144.

[89] S. Niu, Y. Yang, and W. Pan, “Logistics Planning and Visualization of Modular Integrated Construction Projects Based on BIM-GIS Integration and Vehicle Routing Algorithm,” *Modular and Offsite Construction (MOC) Summit Proceedings*, 2019, doi: 10.29173/mocs141.

[90] T. Thiis and E. Hjelseth, “Use of BIM and GIS to enable climatic adaptations of buildings,” in *eWork and eBusiness in Architecture, Engineering and Construction*, Taylor & Francis, 2008, pp. 409–417. doi: 10.1201/9780203883327.ch46.

[91] Ö. Göçer, Y. Hua, and K. Göçer, “A BIM-GIS integrated pre-retrofit model for building data mapping,” *Build Simul*, vol. 9, no. 5, 2016, doi: 10.1007/s12273-016-0293-4.

[92] E. Elbeltagi and M. Dawood, "Integrated visualized time control system for repetitive construction projects," *Autom Constr*, vol. 20, no. 7, 2011, doi: 10.1016/j.autcon.2011.03.012.

[93] I. Bianco, M. Del Giudice, and M. Zerbinatti, "A DATABASE FOR THE ARCHITECTURAL HERITAGE RECOVERY BETWEEN ITALY AND SWITZERLAND," *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, vol. XL-5/W2, pp. 103–108, Jul. 2013, doi: 10.5194/isprsarchives-xl-5-w2-103-2013.

[94] A. Baik, R. Yaagoubi, and J. Boehm, "Integration of jeddah historical bim and 3D GIS for documentation and restoration of historical monument," in *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences - ISPRS Archives*, International Society for Photogrammetry and Remote Sensing, 2015, pp. 29–34. doi: 10.5194/isprsarchives-XL-5-W7-29-2015.

[95] L. C. Chen, C. H. Wu, T. S. Shen, and C. C. Chou, "The application of geometric network models and building information models in geospatial environments for fire-fighting simulations," *Comput Environ Urban Syst*, vol. 45, 2014, doi: 10.1016/j.compenvurbsys.2014.01.003.

[96] H. Tashakkori, A. Rajabifard, and M. Kalantari, "A new 3D indoor/outdoor spatial model for indoor emergency response facilitation," *Build Environ*, vol. 89, 2015, doi: 10.1016/j.buildenv.2015.02.036.

[97] M. Del Giudice, A. Osello, and E. Patti, "BIM and GIS for district modeling," in *eWork and eBusiness in Architecture, Engineering and Construction - Proceedings of the 10th European Conference on Product and Process Modelling, ECPPM 2014*, CRC Press/Balkema, 2015, pp. 851–854. doi: 10.1201/b17396-136.

[98] E. Iadanza, B. Turillazzi, F. Terzaghi, L. Marzi, A. Giuntini, and R. Sebastian, "The Streamer European Project. Case Study: Careggi Hospital in Florence," in *IFMBE Proceedings*, 2015. doi: 10.1007/978-3-319-11128-5_162.

[99] A. Al-Saggaf and A. Jrade, "BENEFITS OF INTEGRATING BIM AND GIS IN CONSTRUCTION MANAGEMENT AND CONTROL."

[100] S. H. Park and E. Kim, "Middleware for translating urban GIS information for building a design society via general BIM tools," *Journal of Asian Architecture and Building Engineering*, vol. 15, no. 3, pp. 447–454, 2016, doi: 10.3130/jaabe.15.447.

[101] H. Kim, Z. Chen, C. S. Cho, H. Moon, K. Ju, and W. Choi, "Integration of BIM and GIS: Highway cut and fill earthwork balancing," in *Congress on Computing in Civil Engineering, Proceedings*, 2015. doi: 10.1061/9780784479247.058.

[102] D. Castro-Lacouture, S. J. Quan, and P. P. J. Yang, "GIS-BIM framework for integrating urban systems, waste stream and algal cultivation in residential construction," in *31st International Symposium on Automation and Robotics in Construction and Mining, ISARC 2014 - Proceedings*, 2014. doi: 10.22260/isarc2014/0077.

[103] H.-J. Choi and J.-H. Kim, "A Program Management Information System for Managing Urban Renewals," in *Advances in Spatial Planning*, InTech, 2012. doi: 10.5772/34645.

[104] A. Ronzino *et al.*, “The energy efficiency management at urban scale by means of integrated modelling.,” in *Energy Procedia*, 2015. doi: 10.1016/j.egypro.2015.12.180.

[105] J. Irizarry and E. P. Karan, “Optimizing location of tower cranes on construction sites through GIS and BIM integration,” *Electronic Journal of Information Technology in Construction*, vol. 17, 2012.

[106] A. Al-Saggaf and A. Jrade, “BENEFITS OF INTEGRATING BIM AND GIS IN CONSTRUCTION MANAGEMENT AND CONTROL.”

[107] A. Al-Saggaf and A. Jrade, “BENEFITS OF INTEGRATING BIM AND GIS IN CONSTRUCTION MANAGEMENT AND CONTROL.”