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Building Information Modeling for Construction

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ABSTRACT
Building information modelling (BIM) is a holistic process most commonly used in the construction industry. It is one of the most promising developments in the architecture, engineering, and construction (AEC) industries. BIM is one of the disrupting technologies in the construction industry that allows the project stakeholders, primarily, architects, designers, engineers, and contractors to visualize how their contributions fit in the big picture. It is a digital representation of the physical and functional characteristics of a building or facility. This digital transformation is providing value across the construction industry. The main objective of BIM is to enhance project performance and produce better outcomes. BIM is transforming the way construction and infrastructure projects are planned, designed, constructed, and managed. It is a powerful driver leading the construction sector towards sustainability. The aim of this paper is to examine how BIM is used in the construction industry.

KEYWORDS: *building information modeling, BIM, construction industry, architecture, engineering*

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INTRODUCTION

The construction industry is undergoing fundamental changes. An innovative and time-saving tool called building information modeling (BIM) is responsible for that revolution. BIM is the foundation of digital transformation in the architecture, engineering, and construction (AEC) industry. It is a cutting-edge building design technology that starts with creating an intelligent 3D model. It is a digital representation of physical and functional characteristics of a building or other physical asset and facility. It rapidly enhances complex building processes, shortcutting any project completion date, cutting the expenses, and improving the overall quality of the construction. It allows construction managers and architectural professionals to communicate easily and build more efficiently, while giving clients a higher quality finished product. In short, it allows us to build a 3D model before the physical project is built. The fundamental use of BIM is to link people and technology with processes and workflows to enhance decision making and outcomes in architecture, engineering and construction (AEC).

The construction industry is considered by some to be behind other industries when it comes to adopting new technologies. AEC companies use a variety of software packages to design, commission, and operate assets. The construction industry is ever evolving with new and exciting technologies that arise everyday. Figure 1 shows a typical construction site [1], while Figure 2 shows some construction workers [2].

BACKGROUND ON BUILDING INFORMATION MODELING

Building information modeling (BIM) is a digital representation of physical and functional characteristics of a facility. It is the holistic process of creating and managing information for a built asset. BIM is a digital representation of the physical and functional characteristics of a building or facility. The representation can be used to simulate the construction and operation of the facility, and to provide information for decision-making throughout the project lifecycle.

Building information models (BIMs) are computer files (often but not always in proprietary formats and containing proprietary data) which can be extracted, exchanged or networked to support decision-making regarding a built asset. The main objective of creating the models is to provide builders with all relevant information about the project in a digital format. BIM software (such as Revit, Microstation, Vectorworks, Infraworks, ArchiCAD, BIM 360, Formit, Civil 3D, GBS Tekla, etc.) allows the design team on a project to construct a 3D model that represents the one we intend to build. Two typical examples of 3D models used in BIM are presented in Figure 3 [5] and Figure 4 [6]. The BIMsoftware is used by individuals, businesses and government agencies who plan, design, construct, operate and maintain buildings and diverse physical infrastructures, such as water, refuse, electricity, gas, communication utilities, roads, railways, bridges, ports and tunnels. The BIM concept envisages virtual construction of a facility prior to its actual physical construction, in order to reduce uncertainty, improve safety, work out problems, and simulate and analyze potential impacts. However, the use of BIM goes beyond the planning and design phase of a project, extending throughout the life cycle of the asset. Figure 5 shows various components of BIM [7]. Figure 6 displays BIM project stakeholders, including architects, surveyors, engineers, contractors and the owner of the building itself [8].

Though the 'B' in BIM stands for building, it covers all constructions in the AEC industry, from residential and industrial buildings to bridges and roads. The 'I' in BIM stands for information, referring to the integrated information within BIM models. This is its core concept - information, parameters, attributes, whatever we call it. The 'M' in BIM stands for modelling. BIM models are known to be condensed with data. Thus, BIM is not a type of software, but a holistic process for managing the building information. We use software and tools that aid the BIM process. BIM covers the entire cycle of the building, from design development to post-construction maintenance. It includes planning, designing, construction, and even operations.

AEC professionals relied on manual drawings for decades until CAD came into existence. Traditional building design was largely reliant upon two-dimensional technical drawings (plans, elevations, sections, etc.). Building information modeling extends the three primary spatial dimensions (width, height and depth). The model can contain all the physical and functional characteristics of a project, including structure, geometry, aesthetics, materials, systems, and dynamic performance. A 3D model becomes 4D if a time component is added, and 5D when cost-related information is included. BIM enables a virtual information model to be shared by the design team (architects, landscape architects, surveyors, civil, structural and building services engineers, etc.), the main contractor and subcontractors, and the owner/operator. It enables all the stakeholders to use the same shared 3D model, from architects to surveyors, engineers, contractors, to building owners. This allows everyone to have access to the relevant information at the right moment during the design and construction of a project.

The concept of BIM has existed since the 1970s, when architects and engineers began to explore the use of computer-aided design (CAD) software to create 3D models of buildings. The terms "Building Information Model" or "Building Information Management," and "Building Information Modeling" did not become popularly used until some 10 years later. BIM only became an agreed term in the early 2000s. BIM has evolved over the past few decades from simple 2D drafting to sophisticated 3D modeling with rich data integration. Figure 7 shows early developments of BIM [9]. Today, BIM is an essential tool for the AEC industry. It is used throughout the entire project lifecycle, from design and construction to operation and maintenance.

A comprehensive BIM modeling solution combines the major elements of building information modeling software, data repository, collaboration, analysis, visualization, and project management tools [6]. Different levels of BIM can be achieved for various types of projects**.** Below are brief descriptions of the levels [10]:

Level 0 BIM: Paper-based drawings + zero collaboration

Level 1 BIM: 2D construction drawings + some 3D modeling

Level 2 BIM: Teams work in their own 3D models

Level 3 BIM: Teams work with a shared 3D model

Level 4 BIM: Incorporating time-related data into the BIM model

Level 5 BIM: Integrating cost estimation and management within the BIM model

Level 6 BIM: Including sustainability data

Level 7 BIM: Used to manage and maintain facilities

BIM IN CONSTRUCTION

Beyond AEC, BIM is applied in other industries, including infrastructure, manufacturing, and facilities management, Other applications include running scenarios, such as the function of an emergency ventilation system, and energy analysis and modeling. Different applications of BIM are illustrated in Figure 8 [11]. Common areas of application of BIM include [7,11]:

- *Architecture:* It is in the field of architecture that we might perhaps see the best uses of BIM. BIM application has allowed architects to participate in all phases of the project. Energy and building performance analyses can also be done which in turn produce more user and environment responsive designs.
- *Civil Engineering:* BIM technology in civil engineering enables structural analysis and design. BIM helps civil engineers digitally explore alternative design decisions, capture more detail, and enhance coordination. Using BIM increases accuracy, predictability, and understanding throughout project life cycles. BIM allows collating real capture data, CAD, and GIS data to create an optimized model fit for engineering works. The BIM models are rich in data and with the capacity to perform simulations and analysis. Advanced tools and plug-ins are available for road and bridge construction, reducing risk during and after construction while also lessening the negative environmental impact.
- *Architectural Design:* The architectural design process used to be a tedious and time-consuming process before the advent of BIM architecture. Figuring out various design iterations and diagrams for a building project was usually carried out using paper, pen, and CAD, which are not efficient tools. BIM helps in the architectural design of a building. This makes the architectural design process faster and more efficient.
- *Construction Management:* BIM implementation in construction management is an inevitable topic when discussing its uses in the AEC industry. Effective construction management is equivalent to effective handling of schedules, cost, safety, and quality through all stages of the project.
- *Facility Management:* BIM technology makes facility management smooth and streamlined. Facility Managers can use BIM throughout the facility's lifecycle to make smarter choices about things like space utilization, layout, equipment and asset upkeep, energy efficiency, and cost savings. From designing to 4D scheduling, 5D cost estimation, and facility management, BIM is an important ingredient across the project lifecycle.
- *Project Visualization:* BIM helps to visualize the project during the pre-construction stage, which enables the architects, engineers, and clients to find out the problems with the building, and fix them before construction. This helps to save materials, and costs considerably. BIM visualization also enables virtual reality and augmented reality.
- *Fabrication Drawings:* It is not difficult to produce shop drawings for the many different kinds of building systems with the help of BIM. The use of BIM for manufacturing allows the manufacturer to get precise details for fabrication. Fabrication drawings are automatically created while modeling the BIM model. HVAC, electrical, plumbing, firefighting, façade, and structural shop drawings are some examples of shop drawings.
- *Cost Estimation:* 5D BIM helps in cost estimation. This feature of BIM technology is a boon in saving a considerable amount of money and enables the contractors to keep the building construction within the budget.

The application of BIM is not limited to these areas but is also used in other AEC fields such as urban planning, landscape, and structural engineering.

BENEFITS

As a result of comprehensive capabilities, BIM is becoming increasingly popular in the construction industry. Some benefits of BIM are displayed in Figure 9 [9]. BIM software allows all stakeholders in a construction project to collaborate in real-time. Using BIM gives you greater visibility, better decision-making, more sustainable options, and cost-savings on architecture, engineering, and construction (AEC) projects. Other benefits include [12]:

- *Collaboration:* At the heart of a BIM process is collaboration. Working as a collaborative team requires the development of better and more efficient ways of working to achieve shared goals. It brings about many advantages for the construction industry, such as improved communication and understanding, leading to greater productivity, quality, and cost certainty. Ultimately collaboration results in better outcomes. BIM enables collaboration across the project team –helping to optimize designs, improve accuracy, and connect design to fabrication to deliver projects faster and more efficiently.
- *Communication:* Communicating with stakeholders is simpler and can help speed up decision-making about the project. The BIM

process helps all parties involved in a construction project to communicate easily. Everything is available in one place, and using cloud-based software means it is accessible from anywhere.

- *Centralization:* All aspects of the project are centralized. This reduces the chance of information loss that typically occurs when a new team takes ownership of a project. BIM serves as a centralized repository for all project-related information, including geometric data, specifications, materials, and performance characteristics. This information is accessible to all stakeholders involved in the project, ensuring transparency and consistency.
- *Global Usage:* BIM software is used by individuals, businesses, and government agencies worldwide. Across the world, BIM is a crucial and even mandated process to ensure the planning, design, and construction of buildings is highly efficient and collaborative. Most of the world's leading AEC firms are using BIM for nearly all of their projects. Many countries have adopted BIM standards and regulations to standardize processes and ensure interoperability. For example, the government of Hong Kong mandates the use of BIM for all government projects over HK$30M since 1 January 2018. Since 2010, the Korean government has been gradually increasing the scope of BIM-mandated projects. Figure 10 shows BIM mandate by country [13]. Mandates are simply government policies dictated for a requirement.
- *Green BIM:* BIM in green building, or green BIM, is a process that can help architecture, engineering, and construction firms to improve sustainability in the built environment. It can allow architects and engineers to integrate and analyze environmental issues in their design over the life cycle of the asset. Using BIM increases accuracy, predictability, and understanding throughout project life cycles. Through the time-efficiencies achieved with BIM, we can reduce energy use and cost. BIM helps reduce material waste during construction and building management, and it can eventually assist in sustainable demolition. Energy modeling using BIM can also minimize energy consumption over a building's life.
- *Error Elimination:* Because the virtual 3D building model is the source for all 2D and 3D drawings, design errors caused by inconsistent 2D drawings are eliminated. Conflicts and constructability problems are identified before they are detected in the field. Coordination among participating designers and contractors is enhanced and errors of omission are significantly reduced.
- *Construction Planning:* Construction planning using 4D CAD requires linking a construction plan to the 3D objects in a design, so that it is possible to simulate the construction process and show what the building and site would look like at any point in time. This graphic simulation provides considerable insight into how the building will be constructed day-by-day and reveals sources of potential problems and opportunities for possible improvements (site, crew and equipment, space conflicts, safety problems, and so forth).
- *Cost:* BIM helps in cost estimation and monitoring, leading to cost savings and budget adherence. BIM allows thorough cost analysis across a project. Reliable estimates for materials, shipping, and labor are made well before the construction stage begins. This helps project managers and teams reduce costs, by sourcing materials at their best possible price, selecting a more cost-effective material, or reducing any unnecessary labor.
- *Opportunity:* As BIM is helpful for predicting project outcomes, it can open a variety of opportunities. It is possible to view a 3D model using virtual reality which allows stakeholders, and other professionals to see the built environment before it exists. This provides more scope for innovation before investing in construction.
- *Efficiency:* BIM streamlines project scheduling and reduces construction time. It enables constant information exchange among architects, engineers, specialists, developers, contractors, and other parties. It helps teams to make well-informed decisions faster, thereby achieving more effective and efficient design than if BIM were not used.
- *Visualization:* BIM offers tools that help in proper planning and clear visualization before the initiation of the construction work. 3D visualization and the simulation of the surface area help the client to get the post-construction visualization of the infrastructure thus facilitating easy modifications prior to the construction stage.
- *Interoperability:* BIM software supports interoperability, allowing data exchange between different platforms and disciplines. This facilitates collaboration among architects, engineers,

contractors, and other stakeholders, enabling seamless integration of design and construction processes.

- *Reduced Waste:* In today's construction environment, labor is in short supply, timelines are compressed, and budgets are tighter. Eliminating waste becomes a critical goal. By using building information modeling, HVAC materials estimates can be exact and fabrication waste is reduced. By optimizing on-site labor through efficient design, BIM helps reduce waste from fabrication.
- *Clash Detection:* BIM software detects clashes and discrepancies in the design phase, preventing expensive revisions during the construction process. This guarantees a smooth workflow and mitigates potential project setbacks.

CHALLENGES

Despite the demonstrated benefits from numerous case studies, there still remains a few BIM challenges that continue to hinder the wider adoption and implementation of BIM. There is no clear consensus on how to implement or use BIM. There is no single BIM document providing instruction on its application and use. There is also a need to outline who should develop and operate the building information models and how the developmental and operational costs should be distributed. Other challenges include [9,13]:

- *Increased Adoption*: BIM adoption is likely to continue growing worldwide. Governments and industry bodies in various countries have already mandated or encouraged the use of BIM in construction projects, and this trend is expected to continue.
- *Interoperability:* Improving interoperability between different BIM software and data formats is a significant challenge that the industry will continue to address. Open standards and collaborative efforts will be crucial in achieving better data exchange and integration.
- *Integration with Emerging Technologies:* BIM will integrate with other emerging technologies like artificial intelligence (AI), machine learning (ML), augmented reality (AR), virtual reality (VR), and mixed reality (MR). These technologies can help in visualizing and interacting with BIM models in more immersive and interactive ways. Artificial intelligence and machine learning will be used to analyze and extract insights from BIM data, optimizing designs, identifying potential issues, and aiding in decision-making throughout the construction process.
- *Generative Design:* BIM software is expected to incorporate generative design tools that can automatically create and evaluate design options based on specific project parameters, leading to more innovative and efficient designs.
- *Regulation and Standards:* Regulations and standards related to BIM will continue to evolve as the technology matures and becomes more prevalent. Staying up-to-date with these changes will be essential for industry professionals.
- *No Standardized Mandates:* Mandates are simply government policies dictated for a requirement. BIM mandates require its implementation in projects. To this day, only a few countries have BIM mandates, and even then they are not strict or required for all project types. Furthermore, most, if not all, are developed nations where training for BIM is more readily available.
- *Education:* BIM has not been extensively taught as part of the curriculum, especially during undergraduate studies. Only the basics are covered. Undergraduate students may be familiar with software like Revit and may have used it for their coursework. As BIM becomes increasingly important in the AEC industry, there will be a greater emphasis on educating and training professionals in BIM skills and best practices.
- *Lack of Trained Professionals:* Many construction companies have complained there is a lack of skilled professionals. The aftermath is an inefficient workflow with errors and profit loss. Such BIM challenges can make the firms even more hesitant to train existing staff or hire those with skills due to the misconception that BIM technology is difficult and inefficient to adopt.
- *Cost:* BIM software can be expensive. As the need to train the existing employees or hire BIM educated professionals overwhelms, BIM implementation becomes seen as an expense rather than an investment. Most of these firms would not even realize it would have a high ROI (return on investment).
- *Change*: There is hesitation and unwillingness of stakeholders to adopt BIM. Another reason for the hesitation is that along with the implementation comes the necessary change in operation. Therefore, rather than investing in training or hiring, the firms stick to the more traditional methods. The gap between the skilled and the

unskilled becomes noticeable, adding to the reluctance.

CONCLUSION

BIM technology is a revolutionary approach to the design, construction, and management of buildings and infrastructure. It is one of the most promising developments in the architecture, engineering, and construction (AEC) industries. The construction industry is yet to realize the full capabilities of BIM. Implementing BIM requires a shift in the way stakeholders in the construction industry work together. It requires collaboration, communication, and a willingness to share information.

BIM is a game-changer for the AEC industry. It has become the standard for modern construction projects. In the coming years, BIM adoption rates are likely to increase. Pressure on the industry is intensifying as the population grows, and BIM processes help meet these demands. The global growth of BIM is indisputable and we can only expect it to soar as more and more companies and countries are adopting BIM. More information on BIM for construction is available from the books in [14-21] and in the following related journals:

- *Construction Magazine*
- *Buildings*
- *Journal of Building Engineering*
- *Journal of Construction Engineering and Management*
- *WIT Transactions on The Built Environment*

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Figure 1 A typical construction site [1].

Figure 2 Some construction workers [2].

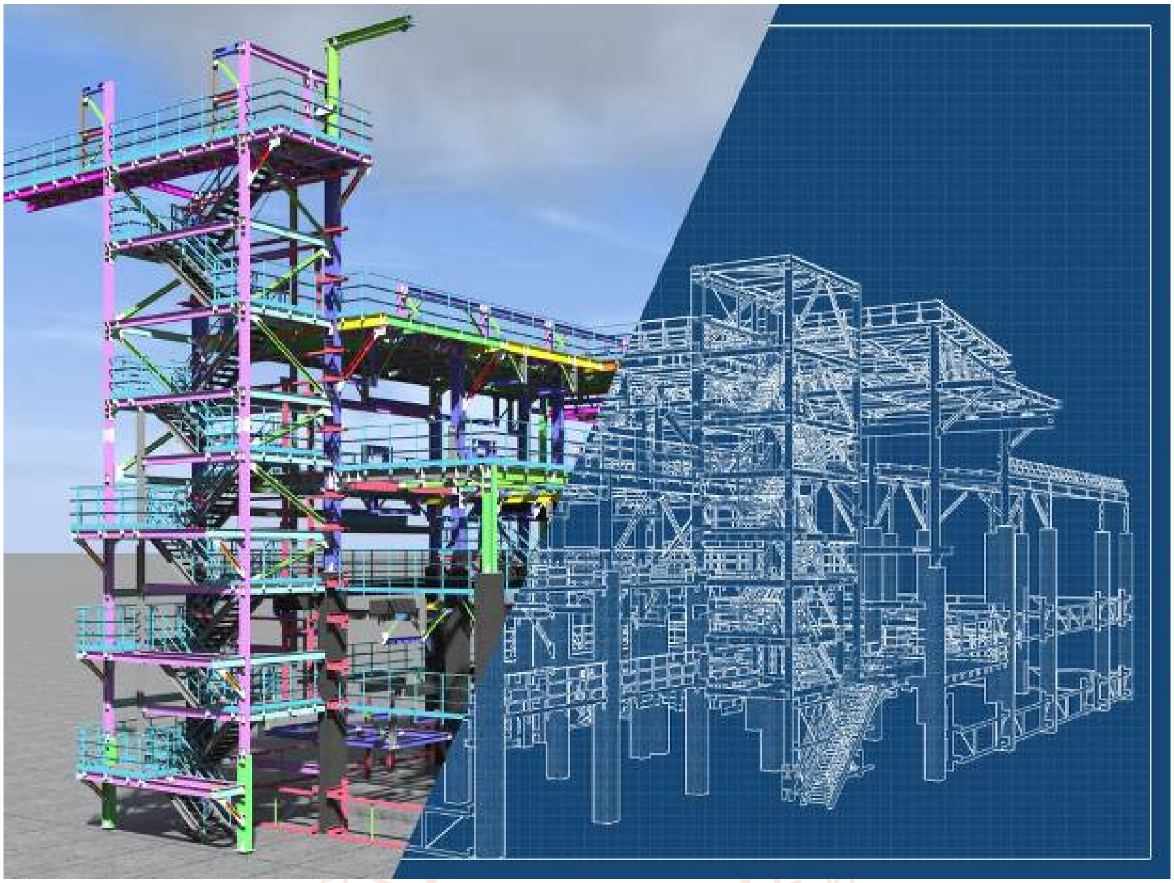

Figure 3 A typical 3D model used in BIM [3].

Figure 4 Another example of 3D model used in BIM [4].

Figure 5 Various components of BIM [7].

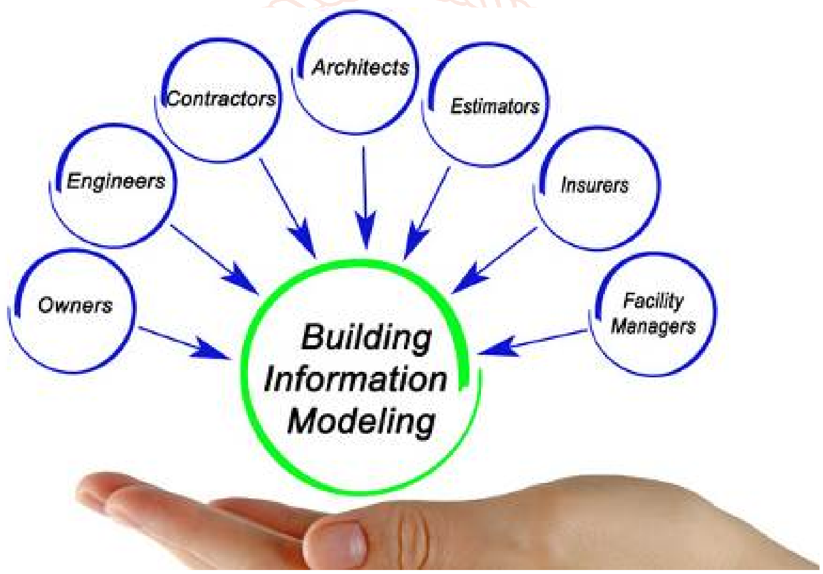

Figure 6 BIM project stakeholders [8].

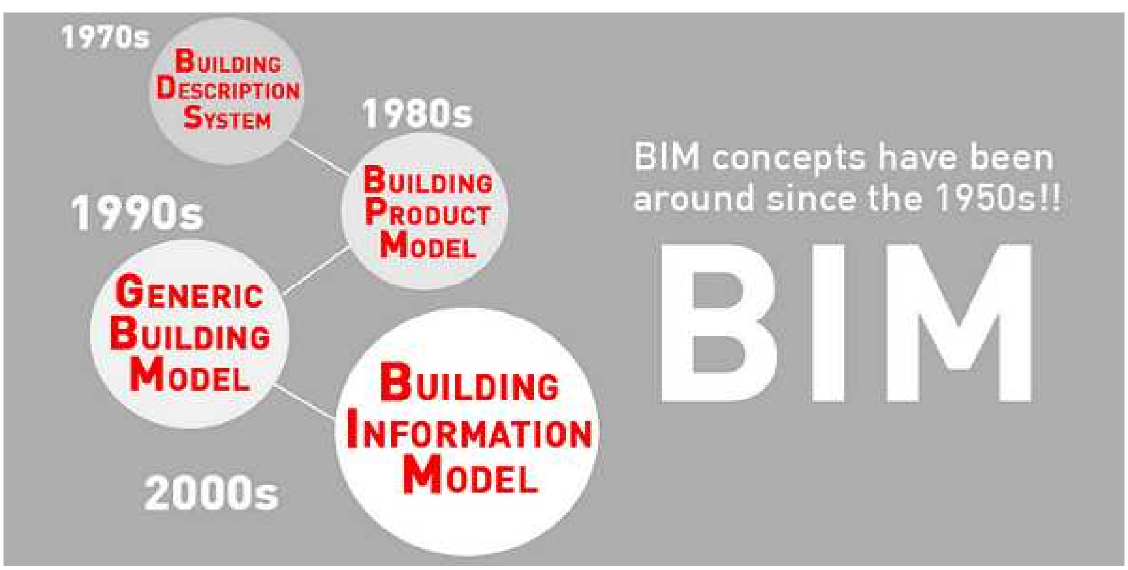

Figure 7 Early developments of BIM [9].

Figure 8 Different applications of BIM [11].

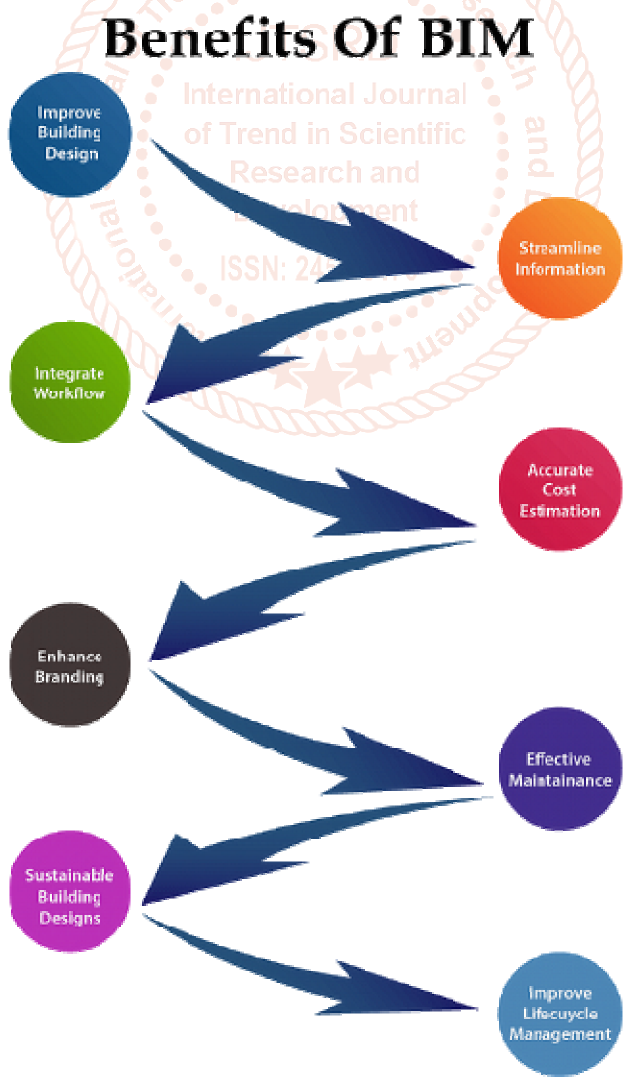

Figure 9 Some benefits of BIM [9].

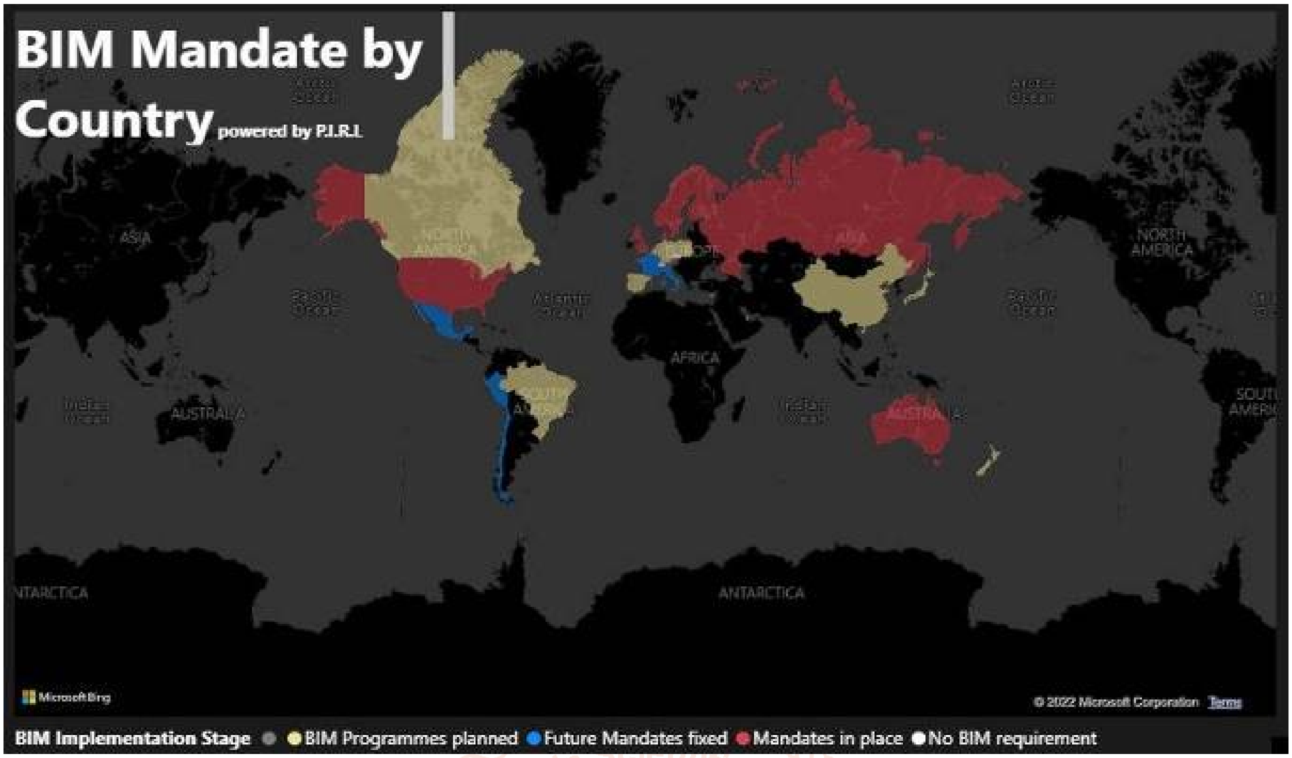

Figure 10 BIM mandate by country [13].