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Application of Building Information Modeling (BIM) in Bridge Design and Construction Management

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ABSTRACT

BIM software has now become a reliable tool for both large and small-scale construction projects. Especially in areas relating to bridge construction and design. Bridge modelling is slightly different from a traditional building modelling as bridges requires acute condition monitoring from start to finish for avoiding collapses. The BIM software is capable to analyze every corner of the structure without directly testing the physical structure itself. This allows for predictive analysis of a structure and its overall integrity. This helps to save cost, allows for virtual editing for better design and supports the structure from start to finish. There is various BIM software that engineers and designers use to produce 3D models of buildings and bridges. Examples of such BIM software are: Autodesk Revit, ArchiCAD, BIM 360 etc. Bangladesh has also used BIM software to support mega projects like Padma Bridge and Metro Rail in Dhaka (Barma *et al.*, 2024). BIM software implementations in such cases made the industrial implementation of these structures much more manageable by promoting optimization, energy efficiency, effective collaboration and resource management (Haque *et al.*, 2025). This research paper aims to highlight the effectiveness of BIM software, along with its implementation in terms of bridge design and construction management. The paper primarily focuses on BIM implementation of China's Cocodala bridge as it perfectly encompasses the applications of a BIM induced bridge design and construction management.

INTRODUCTION

Technological advancements have greatly catapulted the steps of construction management and structural modelling (Roy *et al.*, 2024a). Thanks to advanced software, it is now possible to produce accurate 3D representations of complex structures of buildings and bridges (Arayici, 2008). Such acute visualization allows engineers and construction maintenance staff to accurately assess a project from start to finish. Such software that allows 3D rendering of bridge and building models are called BIM or Building Information Modelling software. There are various BIM software platforms which are equipped with special features and tools that are conveniently programmed for aiding bridge design and enhanced construction management (Zhou *et al.*, 2024). Bangladesh also uses BIMs in complex structures like Metro Rail and Padma Bridge which allowed for enhanced foresight for designing, planning and maintaining the projects. In the world of industrial engineering, BIM software plays a crucial role in producing a high-quality and safe structure (Annenkov, 2022). Bridges and buildings are highly reliant in structural integrity and the quality of those structures are directly dependent on construction and project step management. Bridges are often more difficult to work with, as bridges have a higher tendency to lose its structural integrity overtime (Gonzalez *et al.*, 2020). Many heavy vehicles weighing several tons passes through

bridges every day. Factors like these combined with other natural factors can greatly contribute to weakening bridges as time passes by (Deng *et al.*, 2016). If the defects within the bridge structures are left untreated, it can cause structural failures or even a full collapse and can end up causing mass destruction and panic within surrounding inhabitants (Roy *et al.*, 2024b). This is why BIMs are crucial tools as it can help designers and engineers utilize advanced features that can improve design accuracy, help with cost reduction and efficiently accelerate construction processes (Adeyemi *et al.*, 2024).

Background and Context

The usage of BIM software has steadily increased over the years. Bangladesh has also used BIM software for enhanced 3D structural rendering and acute designing. Including BIM application in various types of structures like; high-rise buildings, residential complexes, gated communities and other commercial spaces. BIM applications are also used in other structures include complex bridge designing for maximized structural integrity and longevity (Ahmad *et al.*, 2024). The usage of BIM software has allowed Bangladesh to produce enhanced bridge and building design with improved structural accuracy, improved collaboration amongst engineers and stakeholders and greatly improved the rate of the project with efficiency (Datta *et al.*, 2023). Clearly, BIM software has a positive

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impact in the realm of improving building and bridge design, as well as improved and cost-effective construction management (Nsimbe & Di, 2024). BIMs are designed to handle the project from start to finish of the project life cycle (Ling Ma & Ding, 2014). BIMs are increasingly being applied to various bridge construction projects, including those involving complex geometries like long-span suspension bridges and those requiring detailed structural analysis and optimization. BIM's visualization, simulation, and clash detection capabilities are particularly useful for projects with intricate designs and challenging construction processes (Chahrour *et al.*, 2021). Bridges in Bangladesh are quite fragile and are prone to collapse due to lack of daily maintenance (Choudhury & Hasnat, 2015). BIMs can easily create a digital 3D model of a bridge which can be tested virtually to various scenarios. This greatly enhances structural analysis and allows real-time adjusting of a project. According to the 3D simulation created by the BIM software, engineers can adjust accordingly to achieve the most optimal design for a bridge (Shim *et al.*, 2011). BIM software can greatly aid in improving structural accuracies of complex bridge structures like cable reinforced bridges. This also allows for enhancement safety and construction step management, ensuring every step is being executed to a pre-fabricated plan. In conclusion, the usage of BIM software can greatly improve bridge design, and this can greatly improve its longevity and long-term structural integrity (Islam & Ali, 2024a).

Scopes and Objectives

The potential of BIM software induced construction management and bridge designing is undoubtedly vast. The various areas of application of BIM software makes it a versatile tool for producing dependable and durable structures which promotes efficiency and cost effectiveness. Based on the context of the research, some scopes and objectives have been mentioned below in the light of BIM induced bridge design and enhanced construction management:

- Understanding the effectiveness of BIMs in terms of bridge designing and optimized construction management.
 - Understanding how BIM software can help with accurate structural modelling to reduce cost.
 - Shedding light on optimization practices of bridge design and construction steps through tools like BIMs.
- The above scopes and objectives were formulated based on the best interest of the current research context. The scopes and objectives should help shed light on the overall effectiveness and integration of a tool like building information modelling in terms of bridge design and construction management.

Rationale and Novelty of the Research

The research carried out on this paper is in the context of finding BIM or building information modelling induced solutions for more accurate bridge design and enhanced

construction management. The awareness of tools like BIM software is highly crucial for industrial engineers and construction maintenance crews as it can greatly accelerate workflow, improve quality of the project and lower costs and waste production. Bridges are a vital component of any country or locality. In Bangladesh, there are many bridges that have been constructed with poor materials and inaccurate design which can lead to eventual collapses. Therefore, the usage of BIM software can greatly help Bangladeshi bridge projects to be more structurally accurate and longer-lasting compared to previous projects. The construction projects initiated by Bangladesh with the help of BIM software has seen promising results, like the Jamuna Rail Bridge which used Autodesk Revit BIM software for accurate designing. The research conducted on this topic is sourced from already verified sources to understand and explore the effectiveness of a BIM-induced bridge design. This is why China's Cocodala Bridge was chosen to showcase how BIM software can be wielded effectively to produce a highly dependable bridge that can last for decades. Perhaps Bangladesh can take some tips regarding how BIM software can be used to produce dependable and safe bridges like in China that has long-term durability and produces less waste in its construction steps.

LITERATURE REVIEW

The usage of Building Information Modelling software or BIM was initially geared towards structures like building complexes. Eventually, the versatility of BIM software has pushed its usability and integration into other infrastructures like bridges. BrIM or Bridge Information Modelling software was eventually formulated as a result of advanced BIM integration combined with civil engineering workflows (Mohammadi *et al.*, 2022). Such BIM integrated software specialized for bridge designing allows engineers and maintenance staff to produce 3D, 4D and even 5D models; along with clash detection analysis, cost reduction estimations and overall project lifecycle management (Rehman, 2025). According to various sources online, ArchiCAD was the first commercially available BIM software tool developed by Graphisoft which was first released in 1987 (Raiman, 2022). The BIM software tool allowed architects, engineers and designers to virtually create 2D and 3D geometric models of structures to test various aspects of the infrastructures, making BIM a highly reliable tool for accurate designing and lower waste production. The early BIM software used CAD files to store relevant building information, which stands in the core foundation of BIM and its integration (López *et al.*, 2018). The development of various infrastructures including bridges using BIM tools saw a sharp rise from the early 2010s (Belcher & Abraham, 2023). In recent years, various powerful BIM tools emerged as a result of technological progress and global digitization practices (Singh, 2025). Some prominent BIM tools which are widely used for various complex projects are: Autodesk Revit, ArchiCAD, AutoCAD, BIM 360,

Tekla Structures etc. All of these modern BIM software tools allows 3D / 4D rendering of complex buildings and bridges and allows for seamless analysis integration which improves workflow, improves risk management and supports the entire project from start and finish (Tran & Nguyen, 2024). BIM models can also be integrated with BMS or Bridge Maintenance System through various sensors and actuating devices to monitor structural health and adjust some physical properties of the structure to ensure better risk management and operational control (Panah & Kioumars, 2021).

Case Study: The Role of BIM integration in the Construction of Jamuna Rail Bridge of Bangladesh

Jamuna Rail bridge is a vital component of daily transportation in Bangladesh (Islam & Ali, 2024b). Its vitality does not only originate from common transportation needs, as the bridge also plays a vital role as a major route for trade and business. As a result, Bangladesh gave great importance to this project and in collaboration with JICA or Japan International Cooperation Agency and through the usage of Autodesk Revit BIM software tool; an efficient 3D model of

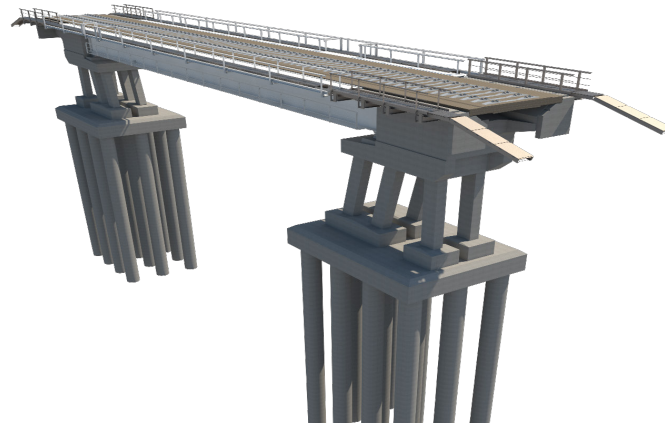


Figure 1: 3D Model Rendering of Jamuna Rail Bridge of Bangladesh using BIM
(Source: Autodesk.com, 2024)

Jamuna Rail Bridge was produced (Datta *et al.*, 2023). BIM clearly played a huge role for ensuring seamless and efficient designing of Jamuna Rail Bridge through acute precision driven execution.

The above given Figure 1, shows the 3D model rendering of Jamuna Rail Bridge as seen in the BIM software tool Autodesk Revit. The BIM software effectively renders the accurate model of the bridge either via CAD files or data files; or can be manually rendered by inputting precise parameters and textures (Akanbi & Zhang, 2022). The BIM software allowed Bangladeshi engineers and Japanese collaborators to induce simulations (4D modelling), formulate clash detection and gather real-time updates from start to finish of the project. This resulted in enhanced risk management, lower waste production and improved operational efficiency. It is safe to say that BIM software is extremely effective when used properly. The Jamuna Rail Bridge of Bangladesh remains an acceptable example of proper BIM usage in Bangladesh for Bridge designing and improved construction management. But, the implementation of BIM software can be improved with better usage of BIM tools and less faulty data.

Research Objectives

Upon the review of literature and exploring a solution based on BIM software integration, it is clear that the potential of BIM tool usage is highly versatile and dependable. Especially, when combined with BMS or building management system for enhanced operational control and construction management. In the context of

the research topic, some research objectives have been mentioned below:

- Explore a solution using a capable BIM software to design a bridge as seen in Cocodala Bridge of China.
 - Understanding the effectiveness of combining a bridge BIM model with BMS (Bridge Maintenance System).
 - Formulate some recommendations for better bridge design and enhanced construction management using BIMs.
- The above research objectives were formulated based on the best interest of the current research. The practical usefulness of BIM software can be understood on a higher scale through the completion of the mentioned research objectives.

MATERIALS AND METHODS

The methodology approach adopts a qualitative method from verified sources that encompasses the effectiveness and implementation of a BIM software tool (Autodesk Revit 2017 Version) for producing an accurate structural model of China's Cocodala Bridge for enhanced operational monitoring, optimized construction steps and bridge design. This bridge was chosen particularly for its effective usage of BIM tools that perfectly showcases the capabilities of bridge information modelling software to enhance bridge design and construction management. The methodology has been conveniently split into 3 sections. These sections have been further explained in detail below:

Data Collection

The Cocodala bridge is exactly 1767 meters across, which runs over the Ili River located in Cocodala city of China. The main part of the bridge is prestressed concrete cable bearing an H-shaped double-plane tower of 600 meters long with 3.25 meters thickness and 1.5% bidirectional slope. The more acute details about the bridge can be collected to produce a 2D model of the bridge as seen in the above Figure 2. A simple BIM model can now be

created with the Autodesk Revit 2017 software through parameterization method. After which, the contour lines in the drawing components can be extracted to produce a 3D BIM model of the bridge. Similarly, other more detailed objects of the bridge can be rendered in 3D using contour values. As the Cocodala bridge consists of many components, the 3D model can be adjusted or changed accordingly as seen below:

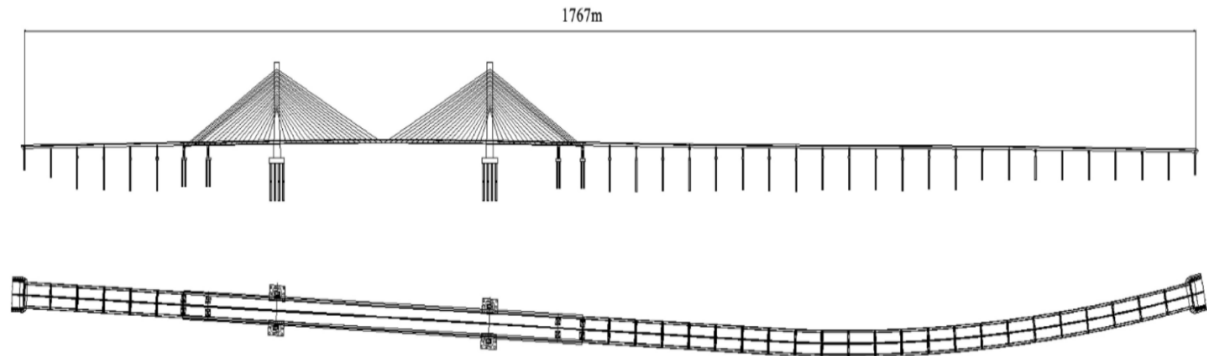


Figure 2: 2D or Linear Representation of Cocodala Bridge of China
Source: Nature.com (2023)

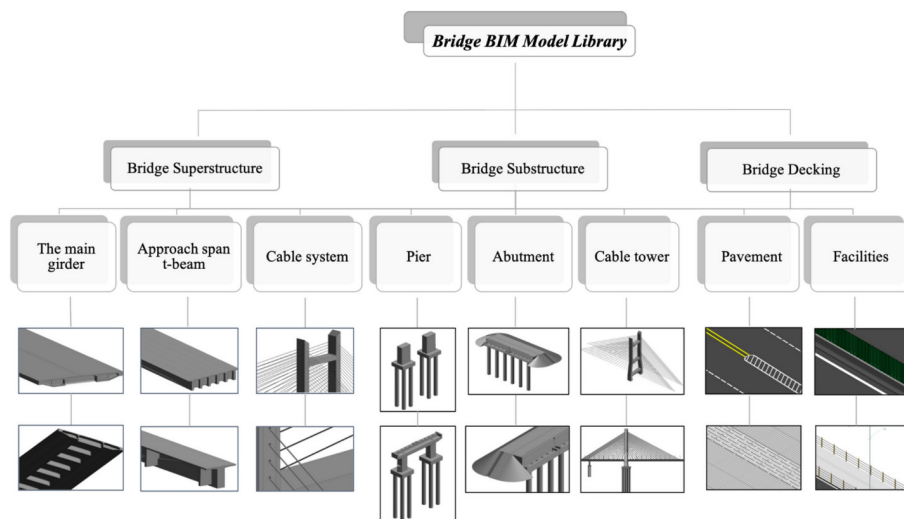


Figure 3: BIM Bridge Model Rendering Components Library (Autodesk Revit, 2017)
Source: Nature.com (2023)

The above given Figure 3 shows the diverse component library that can allow engineers and designers to produce any type of modern bridge imaginable. Using the library and the physical data of the Cocodala bridge, a full 3D model is rendered according to ideal layout and composition. Furthermore, as the BIM model can be combined with a BMS or a bridge management system, various sensors like: tilt sensor, crack sensor and temperature sensors can be installed to gather real-time data to store in a cloud for enhanced operational control and construction management. Now that the basic data of the bridge has been collected, an accurate 3D model can be rendered through the BIM software:



Figure 4: 3D Model Render of Cocodala Bridge using Autodesk Revit 2017
Source: Nature.com (2023)

The above give Figure 4 shows the detailed rendering of the bridge as a result of data inputs and model library integration along with lighting, shading and other environmental factors. A 4D (3D model combined with time) simulation can be initiated to test the current capabilities of the bridge model virtually. Now that the data has been gathered, the data needs to be pre-

processed before data analysis can take place.

Data Pre-Processing

The gathered data must be pre-processed for generating accurate results in the context of BIM usage for bridge modelling and enhanced construction management. The steps have been described below:

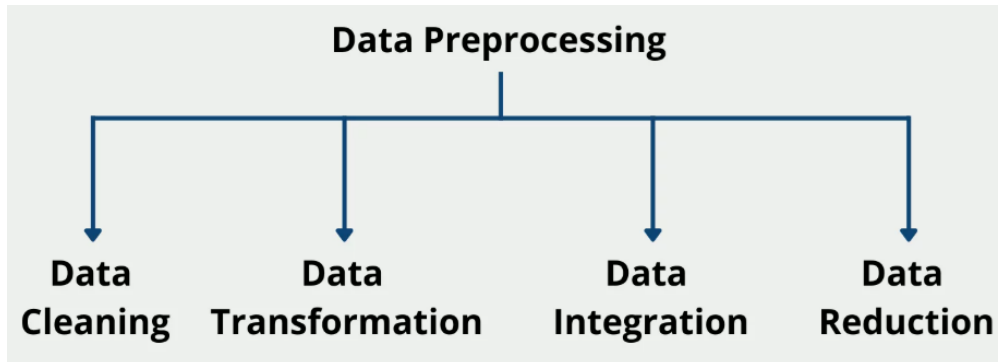


Figure 5: The Four Steps of Data Preprocessing

Source: DataBaseCamp (2024)

In the first step of data pre-processing, the data needs to be cleaned by removing potential duplicate data and omitting missing values. Then the data can be transformed by applying scaling and encoding techniques to make the data readable by a machine learning model. The next step is to join and merge the data for more efficient processing; a step commonly known as data integration.

And finally, the filtered data is reduced for maximizing efficiency by sampling and dimensionality. These steps ensure the integrity of the gathered data which results in accurate outputs.

Data Analysis

To locate possible faults and defects of the physically

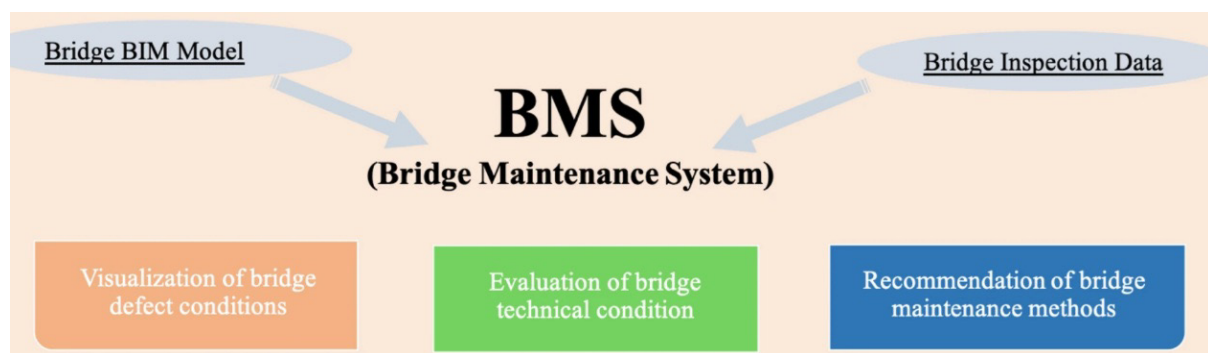


Figure 6: BMS or Bridge Maintenance System of Cocodala Bridge Combined with BIM Model

(Source: Nature.com, 2023)

assembled Cocodala bridge design, the established BIM model has to be combined with a Bridge Maintenance System or BMS. Without the integration of BIM model with BMS, the effectiveness of BIM software cannot be fully appreciated. The mentioned BMS can not only identify defects, but also evaluate flaws and produce recommendations accordingly.

For the visualization of defects in the Cocodala bridge, the 3D rendered model that was produced based on the

physical and manual data gathered in the initial steps must be combined with the an already prepared ideal model of the Cocodala bridge. The ideal model can be easily 3D rendered using the same software where the dimensions of the bridge is perfect. The defect model (Original Model) can then be overlapped or combined with the Ideal Model to visualize the defects within the original model. After which, maintenance advices can be given according to defect priority as seen below:

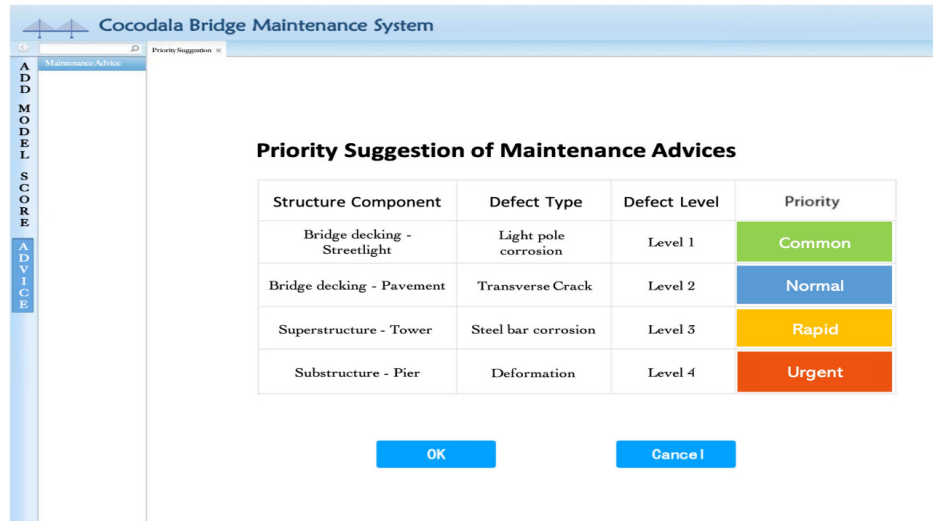


Figure 7: Priority Hierarchy of Maintenance Advices in BMS

Source: Nature.com (2023)

The above Figure 7 shows the defect priority chart of detected flaws compared to the defect model to the ideal model. Based on these data, engineers and designers can further shape the bridge to a more stable state, promoting

optimization and reducing cost. An example of a defect detection using this method has been given below for further clarity:

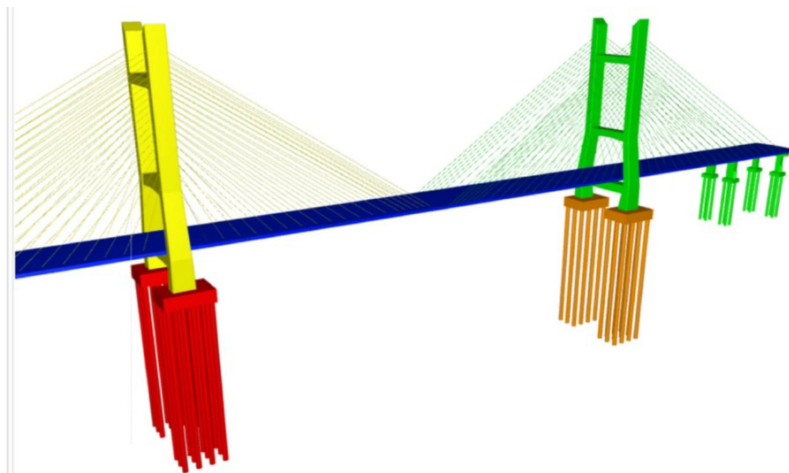


Figure 8: Simulation of Defect Detection as a result of Ideal and Original Model Combination in BMS using BIM models

Source: Nature.com (2023)

The above 3D render in Figure 8 shows various color codes as previously mentioned in Figure 7. The comparison of the models revealed that the lower portion of the Cocodala bridge requires urgent maintenance as it is defect level 4 according to the software. Another area of concern is the upper portion of the bridge where the cables are reinforced, appearing in bright yellow indicating rapid maintenance with a defect level 3 according to BMS. The green (Level 1 Defect) and blue (Level 2 Defect) are considered benign or normal.

RESULTS AND DISCUSSION

Based on the review of literature and methodological discussions, it is clear that BIM software can greatly improve bridge design, identify and even solve defects when combined with BMS and also promotes optimized

construction steps while reducing costs. The Cocodala bridge of China was used as a reference point to understand the use case and effectiveness of BIMs in terms of bridge design and enhanced construction management. Bangladesh still has a lot to learn when it comes to BIM usage for optimized bridge designing, planning and defect detection. In the context of the research conducted in this topic, the findings and results has been discussed below in further detail:

Acute 3D / 4D Virtual Designing, Testing and Model Simulation

The usage of BIM software allows accurate 3D and 4D (3D + Time Simulation) model simulations with lighting and other environmental factors to test the longevity of the bridge. Such visualization of data can allow industrial

engineers and designers to better understand the best practices for designing and maintaining the bridge. Such features of BIMs promote acute observation of the construction processes and omits unnecessary steps in construction maintenance. Furthermore, 3D models allow its users to see and inspect every corner of the bridge to find flaws and defects. According to the findings from research methodology, accurate BIM models (True to Scale) can be combined with BMS to automatically find defects and even formulates maintenance recommendations to solve those defects. Simulation modelling also allows designers and engineers to test the bridge in various scenarios to make necessary changes to better bridge health.

Optimized Construction Management as a Result of BMS Integration

As seen from the BMS of Cocodala bridge in China, BIM becomes highly useful for detecting design flaws. Bridges can lose its structural integrity overtime, which indicates that the values or parameter data of the bridge changes slightly. These defects can be found out easily using BIM software like Autodesk Revit by comparing defect model with an ideal model. This effectiveness can be taken much further with the incorporation of sensors like crack sensors, temperature sensors, tilt sensors etc. The BMS system can be coupled to a database to store relevant bridge health data. The sensors can also dynamically provide real-time data to the BMS so that the system can keep engineers and maintenance crew updated about bridge health condition (Gabbar *et al.*, 2021). Such integration of BMS and BIM Models promotes cost-effectiveness by reducing waste production, providing acute monitoring and even scans for defects.

The above findings and discussions are based on the methodology and review of literature in the light of the research. BIM can be a great tool for bridge designing and construction management if used efficiently.

Limitations

The research conducted in BIM application for bridge design and construction management was derived from already existing and verified sources. The realm of BIM integration is vast and ever-changing with the lightning pace of technological revolution. The potential of BIM software in the realm of bridge design is limitless and this research covers only a fraction of what BIMs are capable of. The usage of BIM in Bangladesh is still relatively new, but some projects integrated BIMs in great success like the Jamuna Rail Bridge. Clearly more in-depth research is required in the context of Bangladesh's industrial Engineering field to find better and more optimized solutions using tools like BIM software.

Recommendations

Upon the research conducted in BIM application for bridge design and construction management, it is evident that Bangladesh still does not actively integrate

optimized solutions using BIM software. It is clear from the methodology conducted on Cocodala bridge in China that BIM integration can greatly help with structural maintenance, acute bridge health monitoring and supporting the project through its entire lifecycle. Based on this context, some recommendations have been given below:

- Adopt open BIM standards—such as IFC and BCF—for transparent, multi-platform collaboration. BrIM benefits most when data exchange is seamless across disparate design and construction tools.
- Explore more solutions using advanced tools like various AI and ML algorithms to find better optimization practices through BIM platforms.
- Making BIM software more accessible and familiar to engineers and maintenance crew in Bangladesh so that BIM induced designing can become more common.
- Conduct more collaborative research to produce more BIM software capable rendering accurate simulations to perform enhanced predictive analysis.
- Initiate more projects using BIM platforms to lower costs and produce more structurally accurate models to build physically.
- Bangladesh should initiate BIM software training programs to construction crews, architects and engineers. In this way, the software can be used effectively to produce better design, dramatically improving overall bridge health in Bangladesh.

The above recommendations were formulated to enhance already existing solutions produced by BIM tools. As a result of new integration practices with BIM, more optimized solutions can be formulated in the future.

CONCLUSIONS

Virtual rendering and digitization surround modern and everyday life. Designing complex structure like bridges and mega building complexes requires a lot of collaborative work between various engineers and architects. There are tools like BIMs that can help these designers to better understand how structures can be designed to last for decades with minimal defects. Bangladesh is still relatively new to advanced 3D/4D model simulation software like BIMs. However, Bangladesh is slowly adjusting to newer technologies like BIMs and AI as time progresses. The research conducted on the application of BIMs for bridge design and construction management has clearly highlighted the exceptional features of BIM tools to virtually test and design structures like bridges. Bangladesh can greatly benefit from such tools as it can greatly boost structural lifespan of buildings and bridges. Therefore, more research is required to understand tools like BIM for better structural health and lowering cost.

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