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Simulation of the Construction of a Swivel Bridge Using BIM 4D

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Abstract

The AEC (Architecture, Engineering, and Construction) industry is gradually shifting away from 2D CAD drawings and toward Building Information Modeling as a result of the fast development of science and technology (BIM). The BIM idea's introduction emphasizes the need to specify a building in a single building model with adequate information to suit its different needs rather than defining it in fragmented documents. This research work aims to use the BIM 4D for the simulation of the construction sequence of a Swivel Bridge. For that, the software Revit was used to make the 3D model of the bridge, and the software Navisworks was used for the 4D construction simulation of the project. The results demonstrated that BIM technology could help reduce delays and problems with the schedule and improve communication among stakeholders, and BIM visualization and simulation features were very useful compared to traditional planning methods.

Keywords

BIM 4D, Swivel Bridge, 4D Simulation, 3D Model

1. Introduction

BIM emerged around the 1970s. It was not until Autodesk, a giant American software company, released its findings on technology construction in the 1990s that it became increasingly popular [1] [2]. According to the National Building Information Model Standard Project Committee in the United States, "BIM is a digital representation of physical and functional characteristics of a facility. A BIM is a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life cycle; defined as existing from earliest conception to demolition" [3]. BIM allows for the integration of data in varying dimensions, from 3D to 8D [4] [5].

All over the world, civil engineering firms are taking advantage of building information modeling (BIM). Multiple industries' projects have reaped the benefits of this technique at various points in the construction process. That being said, the concept has been used less frequently in some industries than others. In particular Bridge Industry, however, research suggests that the implementation of BIM has benefited bridge building in numerous ways, including reducing the time necessary to estimate construction resources, visualizing new perspectives, and enabling a better knowledge of the projects. But even though 3D BIM applications have several pluses over 2D drawings in terms of time savings and improved coordination, Because of how quickly industries are changing, 4D simulation is necessary for long-term project visualization [6].

The construction team can benefit from 4D Bridge Information Modeling (BIM) in the aspects of management, keeping track of the project, supply of materials, enhanced construction calendar paperwork, and overall cooperation. The widespread use of building information modeling (BIM) for a variety of bridge constructions is widely recognized and sometimes referred to as BrIM [7].

In addition to a wide variety of data types, BIM also facilitates the execution of various applications over those data sets. BIM models are utilized at many stages of a project's lifecycle, mostly for visualization. Conflict detection, cost estimation, supervision, synchronization, and management of resources and safety [8]. The need for complex bridges has risen, and the application of BIM technology in bridges includes three aspects: design, construction, Maintenance, and operation phase.

The design of a bridge project is often complicated, involving many structural components to satisfy structural stability criteria. A massive structure such as a bridge requires the participation of different stakeholders from different disciplines: Architects, Structural engineers, and MEP engineers, so it's not uncommon to come across collision problems. Using just 2D drawings, it is challenging for designers to spot and eliminate such design issues in advance, resulting in a significant rework rate.

Bridge projects require both a preliminary and a detailed design; integrating Building Information Modeling (BIM) into a bridge project's design process requires a 3D model of the bridge by converting 2D CAD drawings into 3D. BIM is mostly about modeling, analyzing, detecting collisions, checking design problems, and getting feedback; the BIM group and the project manager would be informed of any issues that arise. The design is reworked as often as necessary until no errors are detected before the beginning of the construction phase. Parametric design is a fascinating option for overcoming those problems mentioned above because using a parametric method of bridge design lets architects and engineers find the best possible compromise between form and function [9]-[15]. Several bridge designs have already benefited from using BIM [16] [17] [18]. The benefits and needs of using BIM technologies aided in the design and construction of a long-span steel-box arch bridge project by replacing the traditional 2D design process with 3D information modeling，the authors argue that BIM has the potential to improve the efficiency and effectiveness of design and construction of mega-complex bridge projects [17]. Using 3D bridge information modeling compared to traditional 2D drafting, include some benefits: higher quality, faster delivery, and more economical cost [19].

In the construction phase, BIM incorporated data such as Schedule, Cost, also known as BIM 4D and BIM 5D. To analyze the feasibility of construction sequences, scheduling, and resource allocation and optimize the construction plan, construction processes are simulated visually using BIM 3D model developed during the design phase. When a problem arises, the construction process is re-simulated to solve it; this improves the efficiency of building bridges and guarantees their high quality and timely completion. By combining the 3D model, they had already made with knowledge of the project's schedule, they were able to generate a 4D model using information modeling throughout the construction phase [20]. They paid particular attention to bettering risk assessment, material supply, project control and surveillance, improved construction schedule, paperwork, and teamwork. and found that the PPC (planned percentage complete) in the project values increased from 26.5 to 56.4 percent. A 4D simulation and clash detection for the construction of a steel bridge, allows to discover spatial issues and make required modifications prior to the start of work [21]. Employing BIM for the construction of two bridges in Denver might save between 5% - 9% of the total construction expenses [22].

In the Maintenance and Operation phase, a database containing all the information about a bridge project's components is built; any information can be easily accessed and shared among stakeholders. Maintenance and Operation work can be completed quickly and easily reported in the database; it is easy to spot a defective component because each object has a unique ID resulting in significant time and money savings for engineers. Many research has been conducted on the health monitoring and maintenance of bridges using BIM models [23] [24] [25] [26]. A BIM-based application in which HoloLens is used from the office to improve and ease the execution of bridge inspections and maintenance operations [27], the program was given the name HoloBridge by the authors. The research focuses on the inefficiencies of decision-making during inspection and maintenance activities, which are often performed on hard-copy sheets and 2D drawings. The capacity of BIM technology to help for the rehabilitation of the bridge located on the Krishna River who was damaged during floods in August 2019 was studied, the research was conducted by using three software Revit for 3D modeling, Staad. Pro for structural analysis and Navisworks for the 4D model. The authors conclude that the period necessary for a cost-effective rehabilitation approach is 76 days [28].

In recent years, the use of BIM models associated with others technologies (VR, GIS, IoT, Laser scanning, etc.) has seen a significant growth in attention among scholars, particularly in the bridge sector [27] [29] [30] [31]. Lately some authors have broadly adopted the BIM approach for digital information models for a variety of bridge types, including cable-stayed bridges [32], prestressed concrete bridge [33] [34] and Steel truss arch bridge [35]. Compared to the kind of bridge mentioned above, the components of the swivel bridge are more complex, so a better visualization is necessary in order for the client to have a better understanding of the project. Based on the literature, this paper uses the swivel construction of the crossing Jinshan railway and Longshan railway as an example to builds the parametric models of the bridge with Revit 2020 software, the construction simulation by Navisworks manage 2020 and finally compared the application of BIM 4D and some traditional scheduling methods.

2. Engineering Background

This study focuses on the Beijing-Harbin high-speed railway, one of the main passages of the "eight vertical and eight horizontal" high-speed railways and one of the busiest railway lines in China. It has always had high requirements for the quality of the lines. The bridge adopts a prestressed continuous box Girder Bridge consisting of three spans with a total length of 241 m (61 m + 119 m + 61 m). It has fourth piers (2#, 3#, 4#, and 5#), among which the turntable is set at the bottom of the3# and 4#. The 61 + 119 + 61 m prestressed concrete swivel continuous box girder adopts a single-box three-chamber section. Due to the fact that the bridge crosses the railway lines, the superstructure rotation method is selected, and the bridge is divided into two parts: Left and right. The left part crosses the Jinshan Railway at K431 + 235 with an intersection angle of 95˚, and the right part crosses the Longshan Railway at K429 + 666 with an intersection angle of 79˚. The rotation angles for the left and right part are 85˚ and 81˚ respectively.

3. Methodology

BIM Modeling

The most popular BIM core modeling tool in China is Autodesk Revit, which excels at creating complicated geometric structures [36]. The Revit 2020 Software was used to generate the 3D model simulation based on 2D drawings of the Bridge. Because Revit is commonly used for industrial buildings, this study created specialized families using the identical data from the 2D drawing received and organized all of the components into a project model. After that, the families were combined and set in place, and the main components' rebars, substructure, and box girders were attached to the structure. Family is a crucial concept in BIM which refers to a group of elements having identical parameters and visual representation [37]. The family model was completed by including the coordinated data on the materials.

Once a 3D model is created with Revit 2020, it's exported into Autodesk Navisworks to establish the 4D model. First, with the Clash Detective tool in the model, conflicts caused by design errors that may require rework during the project's execution stage can be identified. The procedure of detecting clashes in a federated BIM model, which is characterized as waste in the production system, is known as the clash detection or interference checking process [38]. It is one of several quality checks performed by the design team priorto product release [39]. The clash detection and resolution procedure entails discovering conflicts in a 3D BIM environment, which is accomplished by executing pair-wise comparison tests between a group of objects or disciplines [40]. Therefore, if these conflicts can be handled within the design phase of the project, therefore the time lost due to rework may be minimized. Second, Time Liner is used to connect the 3D model of the bridge and the schedule to obtain the 4D model. The 4D Time Liner tool is helpful for project simulation throughout the implementation phase. The project progression may be seen and contrasted with its actual progression using the 4D Time Liner. If there is a exceed in the schedule, the whole project may be assessed, and the contractor can be instructed accordingly. **Figure 1** shows the work flow of methodology.

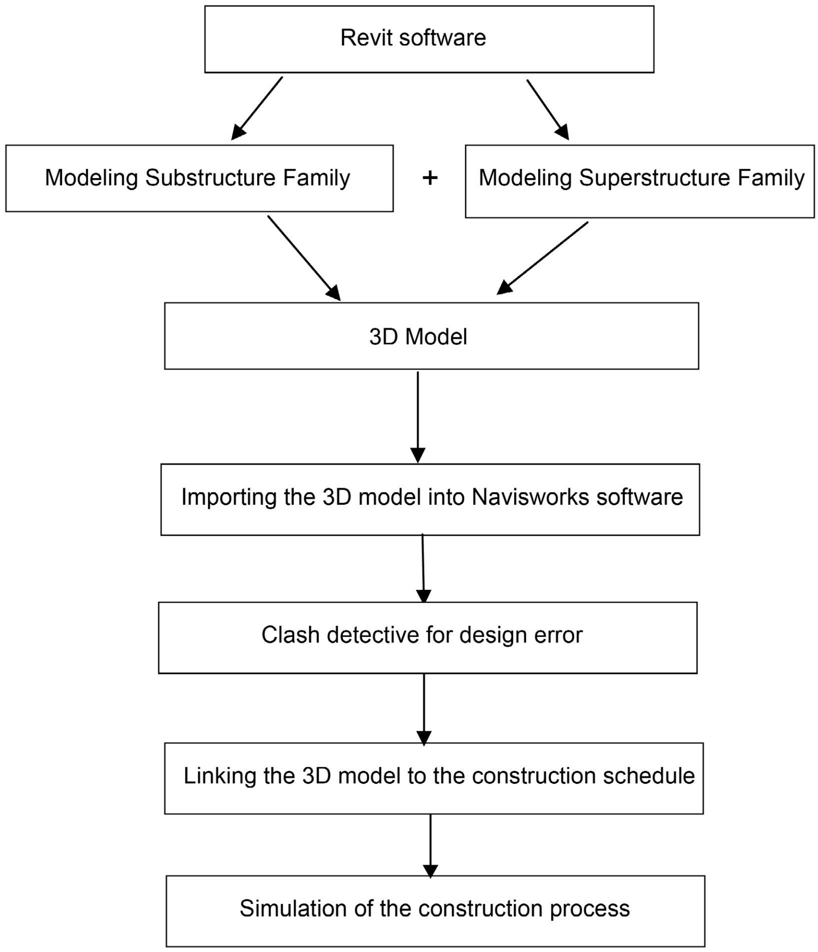

Figure 1. Work flow steps of methodology.

4. Results and Discussion

Based on the 2D drawings, the bridge components are built one by one and assembled to make the 3D model of the bridge by using Revit software version 2020 (**Figure 2**). Revit software lacks of bridge components so for modeling purpose soto create the 3D models, the authors separated the entire bridge into its component parts (**Figures 3-8**) and used parametric modeling. For illustration, the three-chamber box girder was broken down into its seven component parts: inner contour 1, inner contour 2, inner contour 3, inner contour 4, inner contour 5, inner contour 6 and Outer contour. A bridge is always built from the foundations to the deck [41]. Hence, therefore in need to get the full bridge, **Figure 1** presented the different step for its creation developed in the following order:

- 66 Pile foundations (Substructure step 1 of **Figure 1**)
- 2Upper turntable and 2 lower turntable (Substructure step 2 of **Figure 1**)
- 2Upper spherical hinge and 2 lower spherical hinge (Substructure step 3 of **Figure 1**)
- 4 Piers (Substructure step 4 of **Figure 1**)
- 51 Box girders (Superstructure step 1 of **Figure 1**)

Figure 2. 3D Model of the bridge.

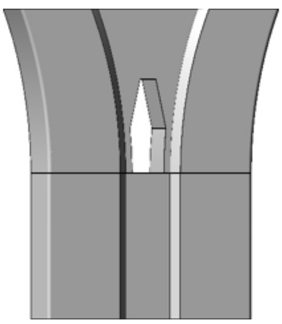

Figure 3. Pier.

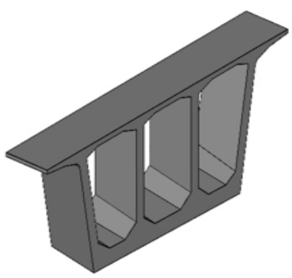

Figure 4. Box Girder.

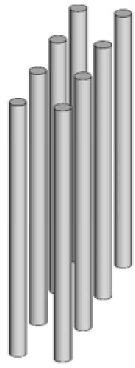

Figure 5. Pile.

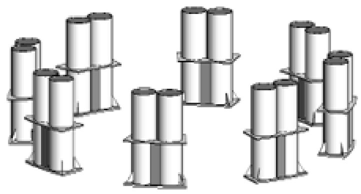

Figure 6. Foot support.

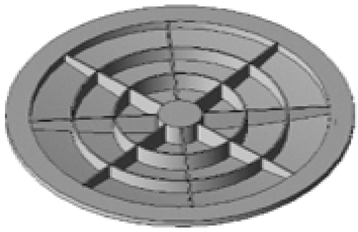

Figure 7. Upper spherical hinge.

Figure 8. Lover spherical hinge.

4.1. 4D Simulation

The construction simulation required the project construction schedule and the 3D model, it associate the construction schedule date with the model to realize virtual construction, check the rationality of the design and construction plan, and optimize the allocation of resources.The traditional construction progress management method is to use the on-site construction personnel to conduct daily construction progress statistics in the form of Gantt charts. Through BIM technology, the project can be imported into Navisworks software to simulate the project's 4D construction progress (**Figure 9**). Because Revit and Navisworks software are derived from the same company Autodesk, the simulation process

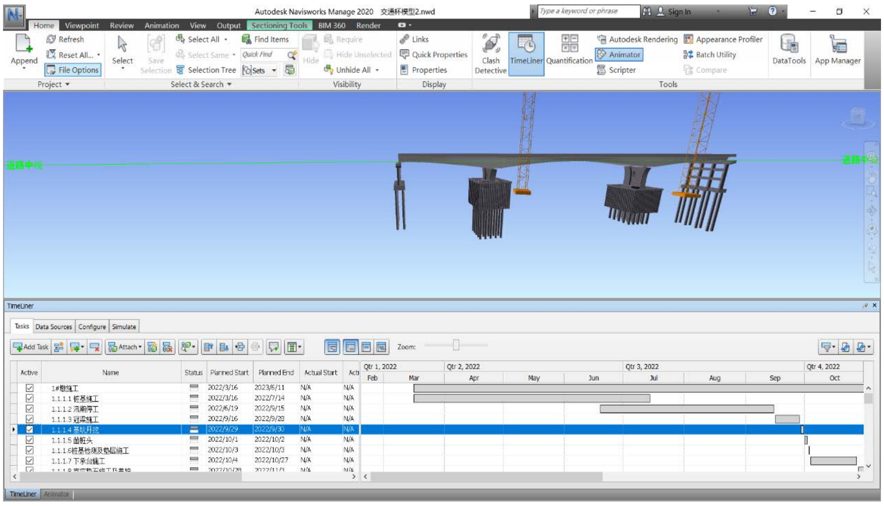

Figure 9. Construction simulation using Navisworks.

is the following:

- ➢ The 3D model of the bridge in Revit is exported as an NWC format
- ➢ This NWC file is imported into Navisworks and the TimeLiner tool is used to attach the construction task and time to carry out the construction simulation of the whole bridge.

After the construction plan was prepared in the early stages, its progress was represented in Navisworks through the modification of actual start and finish dates. The company can either postpone construction or continue following the established timetable. The following issues are common in traditional planning methods because of the poor efficiency of information presentation, collecting, processing, and communication among the project's stakeholders. The loss of data can occur, difficulty in identifying potential conflicts between multiple disciplines, and difficulty dealing with changes in construction schedules. Engineering construction can be dynamically simulated and tracked with the use of 4D models and offers a fresh approach to solving the issues mentioned above [42]. The BIM-based 4D construction simulation can significantly improve the ability to manage cost, construction schedule, and quality.

4.2. Comparison between Traditional Method of Planning and BIM 4D

The activities that must be performed at each phase of a construction project to accomplish its objectives must be determined in the planning phase. The next step is to break down the activities into smaller tasks that may be planned according to the project's technical, financial, and other requirements. Typically, the planning contains all the information about a project from start to end, the duration of a project and the required resource for each activity. In this way, it is feasible to provide a precise explanation on the project's development in detail. Project managers employ various project scheduling tools and techniques such as: The Critical Path Method (CPM), The Program Evaluation and Review Technique (PERT), The Line-Of-Balance Method, Gantt Charts, etc.

4.2.1. The Critical Path Method (CPM)

US adoption of the Critical Path Method dates back to the 1950s [43]. When the whole amount of time expected to complete a project is already known, CPM may be used to plan its execution efficiently. The CPM calculates the shortest possible project duration; this will aid in determining how much scheduling liberty is available on network paths.CPM applies a deterministic time estimate and relies on a single time estimate to determine how long a project will be completed; it is appropriate for a construction project but can be only used for a certain type of project. The critical path method is not helpful if you frequently have to improvise.

4.2.2. The Program Evaluation and Review Technique

In 1958, Program Evaluation and Review Technique (PERT) was created by the United States Navy, Booz, Allen and Hamilton to help Polaris missile and submarine development. It offers the convenience of making work scheduling more malleable [44]. When the whole amount of time expected to complete a project is not known PERT is useful. Unlike CPM, which controls time and cost, the PERT only focuses on time. The Project Evaluation and Review Technique (PERT) is widely used to plan and coordinate activities inside a project. PERT applies a probabilistic time estimate and relies on three estimate times to specify an approximate time frame for completing a job:

Most likely estimate (M):This estimate is based on how long the task is likely to take, given the resources that are likely to be used, realistic expectations of when they will be available, how productive people are, and how often the activity will be interrupted.

Optimistic (O): The task period is determined by analyzing the best-case situation for the work. This will let you know the minimum time a task should take.

Pessimistic (P): The task period is determined by analyzing the worst-case situation for the work. This will let you know the maximum time a task can potentially take.

So, the formula to calculate the PERT will be: $PERT = (O + 4M + P)/6$

PERT is appropriate for research and development projects. Even though it's not as rigid as the Critical Path Method, the PERT also has some disadvantages: updating, modifying, and maintaining the PERT diagram can be time-consuming, PERT requires uncertain time analysis of activities and may have an impact on the project's schedule for novices.

4.2.3. The Line of Balance Method

The line of balance method is beneficial for projects containing repetitive activities. For this kind of project, construction workers are frequently required to perform identical tasks in different areas of the project, transferring from one area to another. Because of this movement, schedule methods for repetitive construction projects attempt to ensure that work is continuous by allowing crews to move smoothly from one area to another as they complete their tasks without interruption. The line of balance is preferable to the critical path method for repetitive activities for high-rise buildings, bridges, tunnels, highways, and pipelines, even though it may also be used for non-repetitive projects. The Goodyear Company first created the Line of Balance method in the early 1940s [45], later the method was recognized and improved by the United States Navy in the early 1950s [46].

4.2.4. The Gantt Chart

Gantt chart is a horizontal bar chart used frequently in project management, representing your project scheduled overtime. Henry L. Gantt invented the Gantt chart in the early 1900s; then, not long after, the Gantt chart as it is known today was employed for planning military operations during world war I. The Gantt chart is frequently used when an exercise has a definite start and end. Gantt chart is a linear representation of the activities and timelines involved in a project; the x-axis shows the timeline, while the y-axis represents the tasks. The main advantage of the Gantt chart is the graphical overview which means the beginning and finishing dates of a project are shown; therefore, the team members and stakeholders can rapidly determine whether a project is progressing as scheduled. Despite its advantages, it also has some disadvantages: The amount of work is not shown by the length of the bar, and the critical path cannot be identified precisely.

4.2.5. BIM 4D

BIM describes all property information linked to a specific structure's whole lifespan, from its creation to its demolition such as facility design and development, construction schedule, and required information for buildings managers and stakeholders. Building information modeling (BIM) has permitted a broad variety of useful solutions, BIM 4D is one of them, BIM 4D requires connecting activities in a project to3D model to enhance project completion.

It is obviously dependent on the parties involved to decide which planning approach will provide the greatest results given the circumstances of the project and the competence of stakeholders. Nevertheless, it should be highlighted that only a small number of construction projects have successfully met their initial goals in terms of cost and time, even though these techniques have been in use for years [47].

Traditional planning methods are, therefore, extremely constrained and inappropriate when acknowledging the enormous amounts of data, the construction industry generates daily across several construction projects. As a result, the construction industry is increasingly using BIM and other IT-based technologies to create more complete, malleable, and efficient construction and planning practices [48]. Fischer and colleagues established the fundamentals of the 4D concept at Stanford University to facilitate visual planning and scheduling [49]. A more expanded perspective is provided by BIM 4D for planning, building, designing, maintaining, or creating a standard information model that contains all the necessary data for the project's life cycle.

An effective communication strategy, for instance, simulates work progression through time to show a customer how a project is progressing and the construction techniques being employed. As a matter of fact, 4D BIM-based visualizations give an excellent understanding of the construction process, allowing for greater communication and cooperation amongst all project stakeholders [50] [51]. With the use of BIM 4D software, virtual projects can be constructed and stimulated with various scenarios, providing a more precise image for project stakeholders to spot potential dangers early on and take precautions against them.

Compared to traditional scheduling methods, the BIM 4D is 40% more effective [52]. Project managers easily spot problems in planning when the digital model is linked to the construction schedule [51], considering that 70% of schedules made using traditional methods are inaccurate and not optimized [53]. Schedule deviations have obvious implications on the time and money invested in a project, and may also have unintended consequences for the final project's quality [54]. Unexcepted schedule extensions generally cause chaos in the workplace by forcing workers and managers to scramble to find solutions to new problems in a limited amount of time.

Unlike the traditional methods mentioned above BIM have the concept of Clash detective which can detect the error or collision between different disciplines in design phase (**Figure 10**).

Therefore, those issues can be solved prior to the actual construction phase, on the other hand design problems that may have risen for the traditional methods can only be detect in the construction phase, which cause delays. So, clash detective is very useful, the others benefit gained by implementing BIM 4D are

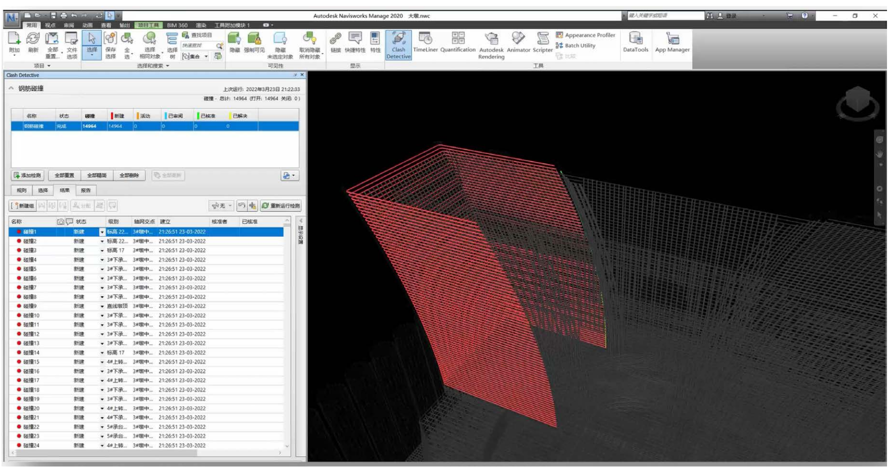

Figure 10. Clash detective.

visualization and simulation. Visualization allows all the parties involved in the project to see how the project will look once done before the construction, detecting which part of the project needs more attention during the construction phase, which is not available in traditional methods such as CPM and Gantt chart. The tremendous potential provided by BIM 4D is his skill in watching the animation sequence of the construction process. Even though Building Information Modeling (BIM) has gained widespread recognition, its adoption in Bridge Engineering is still immature.

5. Conclusion

The full construction process can be simulated in 4D and presented to the owner. This can help the owner comprehend the project's development and better control and manage all parties involved, while also providing highly helpful and beneficial presentation and marketing tools for the participants of the project. By using BIM on bridge projects, everyone involved, especially designers and owners, would have a clearer picture of the finished bridge, it will help stakeholders to detect which aspect of the construction need more attention. Yet, the application of Building Information Modeling in bridge projects has limitations because the common software used for modeling is more suitable for a conventional building project. BIM software developers still need to improve their products to make their software fully compatible with complex bridge modeling, including automated detection of the complex beam family, building a system that makes it easier to join rebars to the bridge's framework quickly, as opposed to doing it separately, etc. While the AEC industry anticipates BIM modeling to usher in a new era of digital design, it is still a novel method that requires more study before its full potential can be shown to all parties involved.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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