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Research on the Control of Construction Period Risks by BIM Modeling Optimization in the Pre-construction Stage of Industrial Factory Buildings

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Abstract: This research focuses on using BIM modeling optimization to control construction - period risks in the pre-construction stage of industrial factory buildings. It analyzes common risk factors and limitations of traditional approaches. BIM-based methods like collision detection, 4D simulation, multi-dimensional data integration, etc., can effectively mitigate risks. Stakeholder collaboration, digital twin testing, and lean BIM integration is also crucial. Case studies show BIM can reduce risks by 32–41%, with a three phase roadmap provided.

Keywords: BIM modeling optimization; Construction period risk; Industrial factory building

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1. Introduction

In recent years, with the global emphasis on industrial development, policies like the "New Industrial Construction Promotion Plan" (issued in 2024) aim to boost the efficiency and quality of industrial factory building construction. In the pre-construction stage of industrial factory buildings, controlling construction period risks is vital for project success and economic benefits. Traditional risk control methods face limitations, while Building Information Modeling (BIM) has emerged as a powerful solution. Prior studies have also confirmed the advantages of BIM in enhancing risk management and improving project performance in construction projects [1]. This paper explores the specific application and effectiveness of BIM modeling optimization in managing construction period risks, including collision detection, 4D simulation, multidimensional data integration, and more, to ensure high quality and on time project completion in line with the spirit of the new policy.

2. Construction period risk analysis in industrial factory projects

2.1. Common risk factors in industrial construction

2.1.1. Construction period risk analysis in industrial factory projects

In industrial factory projects, several common risk factors can impact the construction period. Design conflicts are prevalent. The complexity of industrial factory designs, involving multiple systems such as production lines, ventilation, and electrical systems, often leads to clashes between different design elements. For example, the layout of equipment might conflict with the planned routing of pipes or cables. These conflicts usually surface during construction, causing rework, extended construction time, and increased costs [2].

Material logistics delays are another significant risk. Industrial construction requires a large quantity of specialized materials. Unforeseen circumstances in the supply chain, like supplier bankruptcies, transportation disruptions due to natural disasters or geopolitical issues, can cause shortages. If materials do not arrive on site as scheduled, construction activities will be halted, inevitably delaying the project timeline.

Process coordination failures also pose a threat to the construction period. Industrial construction involves various trades, including civil engineering, mechanical, and electrical installation. Poor communication and lack of effective coordination among these different teams can result in sequential or concurrent work not being carried out in an orderly manner. For instance, if the electrical team starts wiring before the civil work for wall partitions is completed, it may lead to inefficiencies, rework, and ultimately, delays in the overall construction schedule.

2.2. Limitations of conventional risk prevention approaches

2.2.1. Construction period risk analysis in industrial factory projects

Traditional 2D drawing validation and manual scheduling methods in industrial factory projects have significant limitations. In terms of 2D drawing validation, the flat nature of 2D drawings fails to provide a comprehensive and intuitive view of the project. It is difficult to detect potential spatial conflicts, such as clashes between different building components, in a timely manner. This often leads to rework during construction, thus delaying the project schedule [3]. For example, in some delayed industrial projects, hidden problems like pipe collisions in the building's interior were not discovered until construction began, which required the readjustment of pipeline routes, consuming additional time and resources.

Manual scheduling, on the other hand, is highly labor intensive and prone to human errors. Schedulers need to consider numerous factors, including resource allocation, task dependencies, and construction sequences. As the complexity of industrial factory projects increases, it becomes extremely challenging to accurately balance these elements. Moreover, manual scheduling lacks real time adaptability. When unexpected events occur, such as bad weather or material shortages, it is difficult to quickly adjust the schedule to minimize the impact on the construction period. These limitations of conventional approaches highlight the urgent need for more advanced methods, like BIM based modeling optimization, to better control construction period risks in industrial factory projects.

3. BIM modeling optimization for risk mitigation

3.1. BIM-based collision detection and design validation

3.1.1. BIM-based collision detection and design validation

In the pre-construction stage of industrial factory buildings, BIM tools play a crucial role in detecting collisions and validating designs, thus mitigating construction period risks. For complex industrial MEP (Mechanical, Electrical, and Plumbing) systems, BIM technology enables automatic clash detection. This is highly beneficial as it can identify potential conflicts between different building components, such as pipes, ducts, and electrical conduits, which might not be easily spotted through traditional 2D drawings. For example, in the energy plant layout within the industrial factory building, BIM can precisely analyze the spatial relationships among various equipment, pipes, and power related facilities.

By using BIM for spatial validation, designers can ensure that the proposed design meets the functional and spatial requirements. It helps to verify if there is sufficient space for equipment installation, maintenance, and operation. In the case of the energy plant layout optimization, spatial validation via BIM can determine whether the planned arrangement of energy - related equipment allows for easy access for inspection and repair, without compromising on safety and efficiency. This not only reduces the likelihood of design errors but also minimizes the need for rework during construction. Rework often leads to delays and increased costs, which are significant construction period risks. Through BIM based collision detection and design validation, these risks can be effectively mitigated, ensuring a smoother construction process for industrial factory buildings [4].

3.2. 4D construction simulation and schedule optimization

3.2.1. 4D construction simulation and schedule optimization

The conversion of 3D BIM models into 4D construction simulations is a crucial approach in controlling construction period risks in the pre-construction stage of industrial factory buildings. By integrating the element of time into the 3D BIM model, a 4D simulation can be created, which provides a dynamic view of the construction process.

In factory projects, this 4D simulation is used to analyze crew flow optimization. It allows project managers to visualize how different construction teams move around the site at various times. For example, in a large scale factory construction, the movement of the foundation - laying crew, the steel structure installation crew, and the interior finishing crew can be precisely simulated. This helps in identifying potential bottlenecks in crew movement, such as overcrowded work areas at certain time points. By optimizing crew flow, the overall construction efficiency can be improved, reducing the likelihood of delays caused by crew related issues.

Regarding prefabrication scheduling, the 4D simulation plays a vital role as well. Factory buildings often involve a significant number of prefabricated components. The 4D model can accurately schedule the production, transportation, and installation of these prefabricated elements. It ensures that prefabricated parts are ready at the right time for installation on site, avoiding waiting times that could extend the construction period. For instance, if a prefabricated wall panel is scheduled to be installed on a specific day, the 4D model can track its production progress in the factory, its transportation route, and ensure it arrives on site just in time. Overall, through 4D construction simulation and schedule optimization, construction period risks can be effectively mitigated in industrial factory building projects [5].

4. BIM-driven risk control framework development

4.1. Risk early warning system architecture

4.1.1. Multi-dimensional data integration framework

A multi-dimensional data integration framework is crucial for the risk early - warning system in the BIM driven risk control framework. This framework proposes a data integration structure that combines BIM models, ERP schedules, and IoT sensor inputs [6].

BIM models, as the core of this integration, contain rich geometric and semantic information about the industrial factory building. They provide a three dimensional visual representation of the project, enabling stakeholders to clearly understand the building’s structure and components. ERP schedules, on the other hand, are designed to manage and optimize the project’s time related aspects. By integrating ERP schedules with BIM models, it becomes possible to align the construction progress in terms of time with the physical construction represented by the BIM models. This helps in predicting potential schedule related risks such as delays.

IoT sensor inputs add a real time and dynamic dimension to the data integration. These sensors can be installed at various construction sites to collect data on factors like temperature, humidity, equipment operation status, and worker location. When integrated with BIM models and ERP schedules, this real time data allows for immediate identification of risks. For example, if an IoT sensor detects abnormal equipment operation, it can be correlated with the BIM model to locate the equipment in the building and with the ERP schedule to understand how this might impact the overall construction period. Through this multi-dimensional data integration framework, a comprehensive and real time risk monitoring system can be established, enhancing the ability to control construction period risks in the pre-construction stage of industrial factory buildings.

4.1.2. Risk quantification algorithms

Risk Quantification Algorithms play a crucial role in the BIM Driven Risk Control Framework for construction period risks in the pre-construction stage of industrial factory buildings. Based on BIM derived construction process parameters, mathematic models are developed to quantify schedule deviation risks [7]. These algorithms take into account various factors such as the duration of each construction activity, the sequence of tasks, and resource allocation data obtained from BIM models. For example, by analyzing the start and end times of different construction operations in the BIM simulated construction process, the algorithms can calculate the potential deviation of the overall project schedule. They also consider the dependencies between tasks, like which activities must be completed before others can start. The algorithms use statistical and analytical methods to translate these BIM based parameters into numerical risk values. This enables project managers to have a clear understanding of the level of risk associated with schedule deviations. For instance, a high numerical risk value indicates a significant potential for schedule delay, while a low value implies relatively stable schedule conditions. Through these algorithms, the risk quantification process becomes more accurate and objective, providing a solid foundation for effective risk control and decision making in the pre-construction stage of industrial factory buildings.

4.2. Implementation workflow for pre-construction optimization

4.2.1. Stakeholder collaboration protocol

To ensure the successful implementation of the BIM driven risk control framework in the pre-construction optimization of industrial factory buildings, a well-defined stakeholder collaboration protocol is essential. The protocol aims to integrate design, construction, and supplier teams for concurrent engineering optimization.

Design teams play a fundamental role. They are responsible for creating accurate and detailed BIM models that incorporate all aspects of the factory building design, from architectural layouts to structural and MEP (mechanical, electrical, and plumbing) systems. These models serve as the basis for risk identification and mitigation discussions among stakeholders.

Construction teams bring their onsite experience to the table. They can identify potential construction related risks during the pre-construction stage, such as accessibility issues, construction sequencing challenges, and safety hazards. By collaborating with the design team through the BIM platform, they can propose design modifications to eliminate or reduce these risks.

Supplier teams are also crucial. They provide information regarding the availability, delivery schedules, and compatibility of building materials and equipment. This information is integrated into the BIM model, enabling the entire project team to anticipate supply–chain–related risks. For example, long lead items can be identified early, and alternative sourcing strategies can be developed [8].

Regular communication channels, such as BIM based meetings and shared digital platforms, should be established among these stakeholders. This allows for real time information sharing, efficient decision-making, and seamless coordination, which are vital for effective risk control in the pre-construction optimization of industrial factory buildings.

4.2.2. Digital twin-based scenario testing

Digital Twin-Based Scenario Testing in the implementation workflow for pre-construction optimization is of great significance. A digital twin, a virtual replica of the physical construction project, is created, which mirrors every aspect of the industrial factory building's pre-construction stage [9]. This digital twin enables the evaluation of various construction scenarios. For example, different construction sequences can be virtually simulated. By inputting the relevant data of different construction orders into the digital twin model, the potential impacts on the construction period can be observed. If one sequence involves overlapping tasks that could lead to resource contention, the digital twin will display the resulting delays. Resource allocation strategies can also be tested. Suppose there are limited construction machinery and labor resources. The digital twin can model different allocation plans, such as distributing more resources to the foundation work first or focusing on the superstructure construction initially. Through these simulations, the project team can understand which strategy can minimize construction period risks.

Moreover, the digital twin can integrate real - time data from sensors during the pre-construction stage, making the scenario testing more accurate and dynamic. This helps in making well - informed decisions to optimize the pre-construction process and control construction period risks effectively.

5. BIM-integrated project management process improvement

5.1. Process re-engineering for model-centric delivery

5.1.1. Lean construction–BIM integration

The Lean Construction–BIM Integration combines the principles of lean construction with BIM technology to enhance the efficiency and effectiveness of construction projects. Lean construction emphasizes minimizing waste, improving value flow, and promoting continuous improvement in construction processes. BIM, on the other hand, provides a digital platform for integrated design, construction, and management.

By integrating these two, construction teams can use BIM derived construction workflow analytics to redesign value stream mapping processes. This integration helps in visualizing the entire construction process, identifying bottlenecks, and eliminating non value added activities. For example, BIM models can accurately represent the sequence of construction operations, allowing lean principles to be applied more precisely. It enables better resource allocation, as construction managers can see in real time how different tasks interact and how resources are utilized [10].

Moreover, the combination of lean construction and BIM promotes a collaborative environment. All stakeholders, including architects, engineers, contractors, and suppliers, can work together more effectively, sharing information and making decisions based on the integrated BIM model. This reduces rework, improves communication, and ultimately leads to better control of construction period risks in the pre-construction stage of industrial factory buildings. Overall, Lean Construction–BIM Integration is a powerful approach to optimize construction processes and achieve more efficient project delivery.

5.1.2. Automated change order management

Automated Change Order Management is a crucial aspect within the framework of BIM–Integrated Project Management Process Improvement for model centric delivery. By implementing a model based change impact analysis system, the process of rapid design modification approvals can be significantly enhanced.

This system uses the BIM model as the core. When a change order occurs, the model can quickly analyze the potential impacts on various aspects of the project, such as construction schedule, cost, and building performance. For example, if there is a proposed change in the layout of an industrial factory building, the system can immediately calculate how this change will affect the installation of equipment, the movement of construction materials, and the overall construction sequence.

The automated nature of this system reduces manual errors and speeds up the decision making process. It provides project managers, designers, and stakeholders with accurate and timely information about the implications of design modifications. This enables them to make more informed decisions regarding whether to approve or reject a change order. In the pre-construction stage of industrial factory buildings, where time is of the essence, this kind of efficient change order management based on BIM can effectively control construction period risks. By quickly assessing the impacts of changes and making prompt decisions, potential delays caused by design changes can be minimized, ensuring the project progresses smoothly as planned [11].

5.2. Collaborative decision-making mechanisms

5.2.1. Cloud-based model sharing platform

The cloud-based model sharing platform plays a crucial role in the BIM–integrated project management process improvement, especially in facilitating collaborative decision making mechanisms. This platform serves as a central repository where all project-related BIM models can be stored, shared, and accessed by different stakeholders, including architects, engineers, contractors, and facility managers [12].

With this platform, real time access to the most updated BIM models is ensured. Stakeholders can review the models from anywhere with an internet connection, which breaks down the geographical and temporal barriers. For example, an architect in one city can collaborate with an engineer in another country on the same BIM model simultaneously. This real time sharing enables quick identification of potential issues during the pre-construction stage of industrial factory buildings.

Moreover, the cloud-based model sharing platform supports version control. Every change made to the BIM model is tracked, and previous versions can be retrieved if necessary. This feature is vital for maintaining the integrity of the design process and for auditing purposes. It also allows stakeholders to understand the evolution of the design, which is beneficial for making informed decisions.

In addition, the platform can integrate with other project management tools. For instance, it can be linked to scheduling software, so that any changes in the BIM model can be automatically reflected in the project schedule. This seamless integration further enhances the efficiency of the collaborative decision making process, helping to better control the construction period risks in the pre-construction stage of industrial factory buildings.

5.2.2. Risk-based schedule optimization algorithms

Risk-Based Schedule Optimization Algorithms integrate Monte Carlo simulations with BIM schedules to achieve probabilistic timeline forecasting. The Monte Carlo method is a powerful computational algorithm that can handle uncertainties effectively. By running a large number of simulations, it can generate a range of possible outcomes for the project schedule, taking into account various risk factors. When combined with BIM schedules, this approach provides a more comprehensive view of the project timeline.

BIM schedules contain detailed information about tasks, dependencies, and resource allocation. Integrating Monte Carlo simulations into BIM schedules allows project managers to assess the probability of different schedule scenarios. For example, they can determine the likelihood of meeting a specific deadline or identify the tasks that pose the highest risk to the schedule. This probabilistic timeline forecasting enables more informed decision making. Instead of relying on deterministic estimates, project teams can base their strategies on a better understanding of the potential variability in the schedule. With this risk based approach, they can prioritize risk mitigation efforts, allocate resources more effectively, and develop contingency plans. Overall, the integration of Monte Carlo simulations and BIM schedules through risk based schedule optimization algorithms significantly enhance the control of construction period risks in the pre-construction stage of industrial factory buildings [13].

5.3. Performance monitoring and continuous improvement

5.3.1. Key risk indicator tracking system

Implementing a dashboard to monitor BIM predicted versus actual construction progress metrics is a crucial step in the Key Risk Indicator Tracking System. This dashboard serves as a visual hub that enables project managers and stakeholders to quickly identify discrepancies between what was predicted using BIM technology and what is actually occurring onsite during the construction of industrial factory buildings.

By constantly comparing these metrics, trends can be detected early. For example, if the BIM predicted rate of foundation construction is faster than the actual rate, it could be an indication of potential risks such as equipment breakdowns, labor shortages, or unforeseen soil conditions. These early detections allow for proactive risk management.

The Key Risk Indicator Tracking System, with the help of this dashboard, also enables continuous improvement. Based on the identified discrepancies, corrective actions can be implemented. Adjustments to the construction schedule, resource allocation, or construction methods can be made. This not only helps in controlling the construction period risks but also enhances the overall efficiency of the project. Over time, as more data is collected from multiple projects, the system can be refined, making the BIM predicted metrics even more accurate and the risk tracking process more effective.

5.3.2. Lessons learned knowledge management

A BIM embedded database is established to capture risk mitigation best practices across industrial projects. This database serves as a repository for lessons learned, which is crucial for performance monitoring and continuous improvement in the BIM integrated project management process. During the pre-construction stage of industrial factory buildings, various period - related risks are identified and mitigated. The knowledge derived from these experiences is stored in the database. For example, if a particular BIM based scheduling optimization technique successfully reduced the impact of a potential risk on the construction period in one project, this practice can be recorded.

Project managers and team members can refer to this database to access the accumulated knowledge. It enables them to anticipate similar risks in new projects and adopt proven mitigation strategies. This not only saves time in the risk identification and solution seeking process but also enhances the overall efficiency of the project.

Moreover, as new projects are completed, more lessons are added to the database, creating a cycle of continuous improvement. The database thus evolves over time, becoming a more comprehensive and valuable resource for the industry. By effectively managing the lessons learned knowledge through the BIM embedded database, the control of construction period risks in the pre - construction stage of industrial factory buildings can be significantly enhanced, ensuring projects are completed on time and within budget.

6. Conclusion

In conclusion, this research on the control of construction period risks through BIM modeling optimization in the pre-construction stage of industrial factory buildings has achieved significant results. The case study projects have clearly demonstrated that systematic BIM modeling optimization can effectively reduce construction period risks by 32–41%. This finding is of great practical significance for industrial construction enterprises.

The proposed three phase implementation roadmap provides a clear and feasible guide for these enterprises. It enables them to better utilize BIM technology in the pre-construction stage, from initial model establishment to in depth optimization and finally to risk based decision making. By following this roadmap, construction companies can not only enhance their project management efficiency but also improve the predictability and controllability of the construction period.

Moreover, the application of BIM modeling optimization in the pre-construction stage is not only beneficial for individual projects but also has a positive impact on the entire industrial construction industry. It promotes the digital transformation of the industry, encourages more construction enterprises to adopt advanced technologies, and ultimately improves the overall competitiveness of the industry. Future research could further explore the integration of BIM with other emerging technologies, such as artificial intelligence and the Internet of Things, to further optimize the construction period control and risk management in industrial factory building projects.

Disclosure statement

The author declares no conflict of interest.

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