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Investigations into the Use of BIM Technology for Collision Detection in the Comprehensive Layout of Building Electrical and Mechanical Pipelines

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Abstract. Collisions in the overall design of mechanical and electrical pipelines have become more noticeable as building functions have grown more complex. Conventional two-dimensional designs frequently result in construction rework and project delays because they are unable to coordinate conflicts among multidisciplinary pipelines efficiently. By using intelligent algorithms and three-dimensional visual modelling, Building Information Modelling (BIM) technology offers an effective way to detect collisions. Hard clashes, soft clashes, and dynamic clashes are three common collision problems that are the subject of this paper's methodical investigation of BIM technology application techniques and implementation effects. The technical concepts and implementation results are examined by integrating hybrid AABB-OBB algorithms, rule engines, laser scanning, and augmented reality technology. BIM technology can greatly reduce collision issues and mitigate economic losses, as shown by case studies of the Guangzhou CTF Finance Centre and Shanghai Tower. The study also suggests future optimization paths, such as creating a digital specification library for automated compliance checks, improving cloud-based collaborative mechanisms, and developing intelligent detection algorithms to enhance the recognition accuracy of complex components. According to the research, BIM technology can greatly enhance the mechanical and electrical pipelines' design quality and construction efficiency, propelling the construction industry's intelligent transformation.

Keywords: Building Information Modeling (BIM), Collision detection, Mechanical and electrical pipelines, Construction optimization

1. Introduction

The intricacy of electrical and mechanical pipeline layouts has drawn more attention in contemporary building engineering systems. Cross-construction of pipelines for HVAC, plumbing, electrical systems, and other disciplines has become commonplace as building functions diversify. Conventional two-dimensional pipeline designs have serious limitations and are insufficient for fully coordinating spatial conflicts among multidisciplinary pipelines. Design disputes can result in rework in mechanical and electrical engineering, which delays projects in the construction sector.

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This has a negative influence on project timelines in addition to causing significant financial losses. These occurrences draw attention to problems with cooperative design and construction optimization in the field of construction engineering.

Building Information Modelling (BIM) technology has advanced recently, offering fresh approaches and innovations to these problems. By using intelligent algorithms and three-dimensional visual modelling, BIM technology makes it possible to digitally simulate and detect conflicts in pipeline systems. Significant advancements have been made in the creation of intelligent collision algorithms based on BIM, such as automatic conflict classification using machine learning and rule-based reasoning. For instance, hybrid approaches have classified structural-mechanical, electrical and plumbing (MEP)clashes with an accuracy rate of 96% [1].

Offering fresh approaches for the whole layout planning of mechanical and electrical pipelines, BIM technology is a crucial component in the change of the construction sector to digitalization. According to recent studies, pipeline collision problems can be identified more frequently during the project planning stage when BIM technology is used [2]. Nevertheless, there are currently insufficient systematic studies on the suitability and efficacy of BIM technology in collision detection for various project sizes and types. Thus, the main focus of this study will be on how BIM technology can optimize algorithms to solve three common collision problems: hard clashes, soft clashes, and dynamic clashes. This will provide theoretical underpinnings and technical references for industry practices.

2. Methods and case studies of BIM technology in solving different collision problems

2.1. BIM technology for hard clashes

Hard clashes are a common problem in the field of construction engineering. Physical overlaps between pipelines, machinery, or structural elements of various disciplines in three dimensions are referred to as "hard clashes." These issues are frequently hard to identify in the conventional two-dimensional design stage and only show up during construction, resulting in significant on-site alterations and rework that negatively affect project progress and quality assurance [3]. This problem can be solved with BIM technology.

2.1.1. Detection algorithms

Advanced geometric detection algorithms are the main tool used by BIM technology to find and fix hard clashes. Bounding volume algorithms, particularly the Oriented Bounding Box (OBB) and Axis-Aligned Bounding Box (AABB), are the most popular techniques. By creating a minimal six-sided box that is aligned with the coordinate axes, the AABB algorithm streamlines collision detection, according to research, requiring only six coordinate comparisons for intersection testing. In contrast, the OBB algorithm employs bounding boxes that are oriented arbitrarily, and it uses the covariance matrix of the model to determine the ideal orientation. Its tightness is noticeably superior to AABB, despite the fact that 15 possible separating axes must be tested. When objects differ significantly in size, hybrid AABB-OBB algorithms have shown a 40–50% increase in detection efficiency over pure OBB algorithms. This hybrid approach, which strikes a balance between efficiency and accuracy by using OBB for precise detection at the lower level and AABB for quick exclusion of non-colliding objects at the top level, works especially well in densely piped areas [4, 5].

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2.1.2. Case study

BIM technology produced impressive results in resolving difficult conflicts in the Shanghai Tower project. Using a hybrid AABB-OBB algorithm for multiple rounds of collision detection, the project team created a thorough BIM model that included the main steel structure, curtain wall system, and mechanical and electrical pipelines. The first collision detection in Functional Area 3 found 1,604 hard clashes, including collisions between the internal curtain wall panels and the curtain wall supports and the steel structure. The number of clashes decreased by 60.8% to 630 after design coordination and model optimisation. This single area prevented about 976,000 yuan in economic losses, assuming an on-site modification cost of 1,000 yuan per clash [6].

2.2. BIM technology for soft clashes

2.2.1. Algorithms for detection

Soft clashes are more complicated than hard clashes, involving problems like inadequate maintenance space or pipeline spacing that go against long-term maintenance requirements or construction standards [3].

Rule engines and dynamic analysis are two ways that BIM technology tackles these issues. "Rule engines" are used by BIM software to automatically verify that designs adhere to industry standards. In BIM software, researchers translate regulatory requirements into logical rules that can be understood by computers. The system automatically flags conflicts when the model deviates from these guidelines, which minimises human error in manual checks [7]. Furthermore, a crucial element of BIM technology, dynamic construction simulation, adds a temporal dimension to allow 4D simulation of construction processes. This effectively anticipates conflicts that may arise from various construction sequences and offers a scientific foundation for improving construction plans [8].

2.2.2. Case study

BIM technology proved even more useful in handling soft conflicts during the Shanghai Tower project's operational phase. In order to guarantee a high degree of consistency between the model and the actual space, the operations team not only used the BIM model from the construction phase but also applied 3D scanning technology for gathering spatial data. They scanned the leased areas three times: before decoration, after the completion of decoration, and after concealed engineering acceptance. The system could automatically identify soft clashes like inadequate pipeline spacing or non-compliant maintenance access by putting in place a strong rule engine [9].

2.3. Dynamic clashes

There are more "dynamic clashes" in construction projects than the typical "hard clashes" and "soft clashes." Because they are transient and unpredictable, dynamic clashes are defined as unforeseen conflicts brought on by temporary facilities (such as scaffolding or lifting equipment), design modifications, or on-site adjustments during construction or operations. For instance, scaffolding may block the pipeline path during the installation of air conditioning ducts, which causes common dynamic clash. Temporary facilities are the source of many construction conflicts, and traditional BIM models are unable to capture real-time on-site changes. An additional illustration would be a

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recently installed exhaust duct that was added during a building renovation and encroaches on cable tray space, resulting in long-term maintenance problems [10].

2.3.1. Solutions

At the moment, dynamic clashes are addressed by two primary technologies:

Technology 1: On-Site Scanning in Real Time and Model Updates

This entails laser scanning the building site every day, automatically comparing the data with the BIM model, and sending out alerts right away if there are any differences. Photogrammetry is another application for drones that allows for the rapid collection of extensive on-site data and the creation of discrepancy reports.

Technology 2: Mobile Collaboration and AR/VR Apps

Construction workers can overlay BIM models in real time to alert of possible conflicts with the help of augmented reality on-site. Real-time updates for all stakeholders are made possible by cloud-based model synchronization, such as that provided by platforms like BIM 360, which guarantees model consistency with the site [11].

2.3.2. Case study

The Guangzhou CTF Finance Center's mechanical and electrical installation phase presented the project team with dynamic clash challenges that are specific to super-tall buildings. The project used IoT sensors in conjunction with BIM technology to create a dynamic clash management system: To track their positions in real time, workers attached Radio Frequency Identification (RFID) tags to climbing formwork. The system set off automatic alarms when the formwork got within an unsafe threshold of permanent mechanical and electrical pipelines. After construction, maintenance workers were able to view spatial margins in pipeline-dense areas using AR tablets thanks to a lightweight BIM model that was integrated with indoor positioning systems, which greatly increased efficiency.

The dynamic clash management system decreased rework rates during pipeline modifications and enhanced clash detection rates when compared to conventional manual inspections that depend on experience [12, 13].

3. Conclusion

This study thoroughly examines how BIM technology is used in mechanical and electrical pipeline collision detection, demonstrating its substantial advantages in quality enhancement, schedule management, and cost control.

First, BIM technology is very good at settling difficult conflicts. By identifying physical overlaps, geometric detection algorithms like hybrid AABB-OBB significantly reduce construction rework. When compared to conventional techniques, case studies demonstrate that BIM technology dramatically reduces rework rates and improves construction efficiency.

Second, soft clash optimization is another area in which BIM technology shines. Dynamic construction simulations and rule-based automatic detection efficiently uncover hidden conflicts, such as inadequate pipeline spacing or limited maintenance access, enhancing pipeline layouts and long-term operational quality.

Future developments should concentrate on three main areas to further improve the use of BIM in collision detection:

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The first area is the technical level. Creating more intelligent detection algorithms that will make it faster and more accurate to spot conflicts between intricate parts, particularly in big projects with asymmetrical pipelines and equipment intersections.

The second area is standards and specifications. Reducing manual verification efforts by automating compliance checks with a comprehensive digital rule library.

The third area is collaborative mechanisms. To increase coordination efficiency, use cloud platforms for real-time, multi-stakeholder collaboration. This allows designers, contractors, and maintenance teams to access and update model data at the same time.

In conclusion, pipeline collision detection has demonstrated the usefulness of BIM technology. This technology will propel the construction sector towards true intelligent transformation by consistently enhancing detection methods, standards, and teamwork, resulting in more accurate and efficient engineering projects.

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