Design and implementation of construction prediction and management platform based on building information modelling and three-dimensional simulation technology in industry 4.0

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Abstract
In competitive growth and Industry 4.0, construction prediction and management have a key role. To find a way to provide a simulation method for the damage assessment of buildings and Industry 4.0, building information modelling technology is the most suitable choice. This work presents and analyses the building material from design modelling to model information extraction, virtual construction, and an imported virtual simulation engine. A simulation system has been built to understand the force and material collision detection of buildings, and a three-dimensional (3D) simulation platform is developed based on the Unity3D engine. A 3D display of building model and simulation data is realized in this work based on the simulation software platform. The results show that the building 3D simulation images constructed by the designed system are high definition, take little time, and have excellent performance. The outcomes are realized in terms of the engineering cost ratio and have energy consumption and efficiency values of 20% and 40%, respectively, which are much better than the traditional method. Efficiency has also improved to 76% from the traditional method using the proposed method, which makes it a robust platform for construction prediction and management in industries. The virtual simulation technology is applied to solve problems of building design and damage assessment. The influence of this technology on the overall design of the building is discussed, followed by future development directions for industrial automation.

1 INTRODUCTION

With the rapid development of the economy, industrial automation and the continuous improvement in people’s living standards, the construction industry has also had prosperous trend. A high-quality architectural planning method can greatly reduce project costs and speed the progress of design, construction, Industry 4.0 manufacturing operations, and other stages. On the basis of this, it also ensures building quality. However, with advances in the construction industry, the environment is also being badly affected owing to natural destruction, air pollution and other serious hazards [1]. To overcome these adverse effects on the environment, various measures have been taken, including energy conservation and structural maintenance [2].

The cost of construction prediction and management has a vital role in various fields of applications. There are certainly numerous attributes as this technology expands in almost in every area [2]. A representation of various fields in which the cost of construction prediction and management finds an application is shown in Figure 1.

A system appreciated by the construction industry as well as governmental environmental protection departments is building information modelling (BIM) [3,4]. This is a revolutionary technology that has provided the opportunity to architects to improve the effectiveness of the construction industry by creating sustainable, environmentally friendly building models [5]. Combined with an optimal modelling platform, BIM technology provides the choice of an environmentally friendly and economically suitable...
building material for constructing green buildings [6–8]. The implementation of BIM in Industry 4.0 has promoted agreement between the construction industry and the sustainable green building architectural environment [9,10]. The key part of the architectural planning method is the three-dimensional (3D) modelling method of the architectural landscape. Therefore, it is of great practical value to find an effective method for building a 3D simulation model of the building landscape [11]. The sustainable design offers flexibility in providing effective early designs considering an energy and performance analysis for architectural design and construction in terms of the building material, setting and technical support required [12,13]. The BIM process flow is depicted in Figure 2.

Figure 2 shows that the 3D building design relies on 3D modelling as well as BIM coordination to resolve clashes involved in sustainable construction prediction, management and environment friendliness. There are various applications of BIM technologies, listed in Table 1 [13].

This work contributes to designing a 3D simulation system based on BIM technology. This BIM technology integrates the Industry 4.0 architectural component information, address location, facility information and spatial information of design and construction prediction and management stages of building projects. This integration novelty ensures that a shared and continuous application is developed using this information to maintain and monitor the entire life cycle of the project. Unlike traditional designs, this platform provides effective decision-making for the sustainable design development of buildings in the early design and preconstruction stages. With this effectual approach, there is no need for traditional design stages such as drawing and documentation. This contribution provides accurate location and display of information in terms of the 3D model.

The rest of this article is arranged as follows. Section 2 presents a literature review of state-of-the-art methodologies used by previous researchers. Section 3 presents the research methods used for this work followed by results and a discussion. Section 4 details the system development and implementation along with the results obtained. Section 5 provides concluding remarks for the article specifying future research directions.

2 LITERATURE REVIEW

BIM is based on relevant information data about the construction project as the foundation of the model, as well as assembling the building model and simulating real information about the building through digital information. In the past, building drawings were drawn on the computer-aided design (CAD) line according to drawing rules, that is, plane 2D drawings [14]. The BIM application brings the process from 2D to 3D. Through BIM technology, it can integrate architectural component information, address location, and facilitate attribute information and spatial information in the design and construction stages of building projects to ensure the sharing and continuous application of information throughout the life cycle of the project. What the user sees is no longer traditional design drawings or documents but the accurate location and information display in the 3D models. However, there are some shortcomings in the current 3D simulation system of building landscapes. For example, the HCAD building simulation system mentioned in the literature based on a three-party software platform such as AutoCAD carries out two developments of the building simulation system. However, this method has a limitation to develop and design construction buliding drawings. The shortcomings of this method are that the technology maturity is low in 3D simulation and it can carry out only simple 2D building planning, drawing and other work [15]. The practicality is not high. LIU designed the OpenGL building landscape simulation system and added geographic information data into the building landscape simulation system so that the 2D design and geographic information could be closely integrated. The simulation effect of the building landscape is better displayed. However, in the process of building the landscape simulation, the calculation of the system is larger, the architectural design cycle is extended, and the cost consumption is increased [16].

Dan-Dan proposed designing the architectural landscape based on a genetic algorithm. This method represents the design of the architectural landscape simply and abstractly as a mathematical function model. The relationship between variables in the architectural landscape is obtained through calculation. According to the correlation, building model design [17] the method of Jianhua and Liu cannot clearly express the relationship among variables in the building model, and the analysis of the impact between the architectural landscape and the variables is not clear, so it cannot meet the needs of current architectural landscape design [18]. Migilinskas et al.
[19] and Tulenheimo [20] presented a case study to identify the advantages of using BIM technology for industrial design, signifying benefit in team coordination by providing a sustainable environment with reduced work error, saving material resources and providing an information-based design environment. Several investigations revealed that the major advantage of BIM over traditional approaches is that it provides a convenient and modified design platform that can be implemented for a construction simulation [21–23]. The main factor that hinders the development of BIM was reported by Eadie et al. [24]; that study revealed that the surplus training time and higher cost of human resources in BIM is the major drawback in its practical implementation. Other gaps were revealed by Caroline [25]: the deficiency of management support, the minimum acceptance ability of the designers, as well as a culturally biased environment. Zhou and Yang [26] also pointed out some limitations in the practical implementation of BIM development in China. These were the higher application cost, insufficient government provisions, and a lack of market motivation. However, it was noticed that there existed certain countermeasures to mitigate these obstacles, such as the establishment of a unified workflow, strengthened government policies, improvement in BIM software training, and the establishment of long-term promotional goals [27,28]. Table 2 lists research areas for various publication in the field of BIM integration.

Therefore, this literature finds the various advantages as well as drawback of the BIM technology for 3D modelling in promoting the design and construction of green buildings. Most existing work have focussed on specific projects and provides a collective overview on the limited number of investigators without highlighting the opinions of BIM stakeholders. Thus, this work mitigates these challenges and promotes the application of BIM in Industry 4.0 manufacturing and building construction prediction and management. This research provides an in-depth analysis of building materials and construction prediction and management using BIM technology and a 3D simulation platform to identify the key contributions of BIM technology to green building.

This article proposes a 3D simulation system based on BIM technology. Through BIM technology, integration is possible for architectural component information, address location, facility attribute information and spatial information in the design and construction stages of building projects. This ensures the sharing and continuous application of information in the life cycle of the project. What users see is no longer traditional design drawings or documents. It provides accurate location and display of information in the 3D model.

### RESEARCH METHODS

This section presents research methods including the main features of BIM technology, Autodesk Revit series software and the Unity3D virtual simulation engine used in this work for construction prediction and management.
### 3.1 Main features of building information modelling

A collaborative work environment based on BIM is sustainable and transparent. In this environment, component information can be duplicated and verified in the environment so that all participants can communicate in a timely manner throughout the life cycle of construction projects. Information can be shared in an accurate and timely manner among participants. Each participant can make a scientific analysis through designing information shared by different design professionals, and make corresponding decisions to manage the project better. The 3D design process based on BIM technology has many outstanding characteristics compared with the traditional design method [29].

1. **Visual design:** First, the most critical feature of BIM is the ‘what you see is what you get’ visual design. This is greatly important to every major component of architecture. As the scale, shape and function of buildings become increasingly complex, the building system becomes more complex. To meet the corresponding space requirements, BIM can realize visual design so that designers can intuitively understand the space of key parts, to arrange the corresponding pipe fittings rationally, make better use of limited space, and effectively improve the efficiency and quality of design [30].

2. **Space collision detection:** BIM is the ability to carry out space collision inspection, which is helpful for the design work of various professional buildings. With the increasing complexity of building systems, the efficiency of building space is becoming increasingly important. The BIM model can directly observe the relative spatial relationship among pipelines, buildings and structures from different angles. We can check only the more important parts and not carry out macromanagement of the whole project [31]. After adopting BIM technology, we will hand over the responsibility for finding collision problems to the computer and check the whole project model with the powerful computing power of the computer. Although we cannot ensure that space collision is completely avoided, we can minimise the occurrence of such problems.

### 3.2 Autodesk Revit series software

Autodesk Revit series software was developed by the world’s leading digital design software supplier, Autodesk, is a 3D parametric design software platform for the architectural design industry. Autodesk Revit series software includes Autodesk Revit Architecture (Revit architecture version), Revit Structure (Revit structure version) and Revit MEP (MEP: Mechanical Electrical &Plumbing Revit equipment version of a device, electrical, water supply and drainage) three professional design tools. The AutodeskRevit2013 version of the three software is integrated into software that can meet the needs of different professional design applications. Revit MEP software is based on BIM technology’s basic ideas and ideas. The 3D simulation Revit Architecture software, which is developed for the modelling of plumbing, electrical, heating and other related equipment, is suitable for the architectural design specialty. The software has powerful parametric modelling function and can be built quickly.

The parametric equations can be introduced by the helical curve equations presented in Equations (1–3):

\[
\begin{align*}
x & = a \cos(t) \tag{1} \\
y & = a \sin(t) \tag{2} \\
z & = b(t) \tag{3}
\end{align*}
\]

The instruction of implicit and explicit methods depends on the explicit parametric equations stated earlier to model the helix curve. However, other parametric equations can also be used to solve the explicit method. The parametric equations of torus curves are given in Equations (4–6):
where parameters \( t \) and \( u \) vary between 0 and 2\( \pi \), and \( R \) and \( r \) indicate the major and minor radius, respectively.

The explicit method also uses the butterfly curve, whose equations are given by Fay [32] and are presented in Equations (7) and (8):

\[
\begin{align*}
x &= \sin(t) \left( e^{\cos(t)} - 2 \cos(4t) - \sin^5 \left( \frac{t}{12} \right) \right) \\
y &= \cos(t) \left( e^{\cos(t)} - 2 \cos(4t) - \sin^5 \left( \frac{t}{12} \right) \right)
\end{align*}
\]

These equations can be solved simply by substituting the equations and keeping the similar structure for Revit or API programme structure.

Revit Structure is 3D design software specially developed for structural designers. The software provides a large number of structural components to meet the design requirements of structural designers. The three pieces of software together use powerful data exchange capability among them to build a collaborative design platform and easily realize multiprofessional 3D collaborative design [33]. Various types of BIM software can be used for building applications, some of which are listed in Table 3.

Architects can use Revit Architecture to build BIM models. The software has a powerful data driving function. It can store all parameter information of the components in the database of the model. When providing a clear and intuitive BIM model for participants, it can also give statistics on materials and materials according to the statistics of the internal components of the database. Revit MEP software can provide BIM models for all pipeline systems, such as the water supply, drainage, electrical system, and heating, ventilating and air-conditioning for the construction enterprises and owners. The BIM model contains all parameter information about the pipeline system; the software can be used for all pipeline systems [34]. There are detailed settings for the information software, such as pipeline spatial location parameters and pipeline material properties. After establishing the BIM model of the pipeline system, the software can comprehensively arrange the pipelines, make the spatial relationship between the pipeline system and the building and structural models more reasonable, and the Revit MEP software has the function of collision detection. The designer can optimise the layout of the pipeline system. The software can also be used in conjunction with Navisworks software to complete collision detection between the specialised piping of the supporting equipment [35].

### 3.3 Unity3D virtual simulation engine

Unity3D is a multiplatform integrated game development tool for 3D video games, architectural visualization, real-time 3D animation and other interactive contents. It is a fully integrated professional game engine. It only needs one effort to develop target products, and it can be configured in iOS, Windows, Android and other flat platforms. For different information terminals, communication provides great convenience. Although Unity3D is popular in the game field, building visualization has an important role as well. The development mode of Unity3D is visualised. With a more detailed Attribute Editor, it can operate conveniently, reducing the workload of repairing BUGs, and Unity3D has a fully functional physical engine. It can simulate all kinds of physical phenomena, so it is widely used to create a virtual world. In the realization of a 3D virtual construction schedule, Unity3D mainly provides cross-platform and convenient programming characteristics [36–40].

### 4 RESULTS AND DISCUSSION

The complete idea of system development as well as implementation is presented in this section, which details results and a discussion of the outcomes obtained.

#### 4.1 System development

Unity3D has a deep cooperation with Autodesk. We can import Revit data directly into Unity3D, so we can import data from the world’s leading building information modelling tool into the industry-leading 3D simulation engine and convert it into the final visualization solution for a real-time interaction experience. Its development process is shown in Figure 3.

In the system development of a BIM tool for an industry-leading 3D simulation engine, initially, building information is defined in the AutoCAD platform. The BIM model is built and is further subjected to 3D simulation modelling using the Unity 3D software platform. The two different platforms used in this

| Table 3 |
| --- |
| **Category of functionality** | **Various IFC input–output supporting software** |
| Architectural drawing modelling | AutoCAD architecture, Revit architecture, Bentley architecture |
| Structural modelling and analysis | Tekla structures, Sia Enginee, SDS/2 |
| Structure design and drawing | Tekla structures, Sia Enginee, SDS/2 |
| HVAC design | AutoCAD MEP, MagiCAD |

Abbreviations: BIM, building information modelling; HVAC, heating, ventilating and air-conditioning; IFC, industry foundation classes. To Cop
work encourage the growth and development of a construction prediction and management scenario in an Industry 4.0 environment and provide improved efficiency.

4.2 System implementation

By analysing the information needs of building construction prediction and management, combining the definition of building information by IFC standards and establishing model standards consistent with IFC data entities, we can establish the BIM model of engineering progress required by engineering according to the standards. After building the model, we directly import Revit model into Unity3D through inserts, and organise further development in the 3D simulation engine. BIM technology emphasises the convenience of engineering management. Virtual reality technology focuses on performance; virtual reality technology provides better user interaction, enabling users to invest in a computer simulation environment, which can touch users’ real senses and give them the feeling of immersion.

Based on the characteristics and advantages of the Navisworks software platform in BIM technology, the two-development function of the 3D simulation system of the architectural landscape is designed, and the 3D simulation system of the large-scale building landscape is completed. The 3D simulation system of the large-scale building landscape based on BIM technology has a human–machine interface and the advantages of simple operation and easy maintenance.

Implementation of the 3D simulation system for a building landscape is as follows: according to the characteristics of the architectural landscape and the surrounding hub situation in the building landscape project, the 3D simulation model for the design of the 3D simulation project of the architectural landscape is formulated, and the 3D simulation model is added to the Navisworks software platform for rendering. The dynamic simulation data of the 3D simulation model can be transformed into a file format that can be read by the Navisworks software platform. After planning the time parameter information and attribute information, the two-development function of the Navisworks software platform is applied to complete the 3D simulation and simulation of the large-scale building landscape. The specific process is shown in Figure 4.

The main functions of the 3D simulation system for a large building landscape described in Figure 4 are a dynamic demonstration of construction prediction and management of 3D simulation modelling of the building landscape, dynamic demonstration of subitem modelling, engineering construction status, and visualization of simulation data in building landscape modelling.

4.3 Construction landscape 3D simulation of construction prediction and management process dynamic demonstration

The TimeLiner module in the Navisworks software platform dynamically demonstrates construction prediction and
management of the 3D simulation of the architectural landscape. The TimeLiner module integrates the 3D simulation digital model of the user uploaded with the construction progress, and uses the entity handle as the identifier to formulate the initial external state and task type. The 3D animation of building landscape 3D modelling and construction is generated. The cruising animation in the construction scene is completed by the Animator module. The cruise animation can be linked to the TimeLiner animation, so that users can examine the dynamic construction of the 3D simulation of the building landscape from different angles and grasp the concrete construction prediction and management progress of the 3D simulation of the architectural landscape.

4.4 | Time-consuming analysis

The experiment uses the traditional analytic method and the method of this article to carry out the 3D simulation of the experimental architectural landscape. In the process of the experiment, the time consumption demonstrated by the two methods is shown in Figure 5. The 3D simulation map of the architectural landscape constructed by the traditional analytic method can be obtained by analysing Figure 5. It has high processing efficiency.

4.5 | Design performance analysis

To verify the superiority of the method presented here, the design performance of this method is analysed. The experiment uses the traditional analytic method and the method presented here to carry out the 3D simulation of the architectural landscape, and to compare the parameters among them to analyse performance. The experimental results are compared with the traditional analytical method in Table 4.

| Indicators       | Traditional analytical method (%) | Current method (%) |
|------------------|-----------------------------------|-------------------|
| Engineering cost ratio | 45                                | 20                |
| Energy consumption | 70                                | 40                |
| Efficiency       | 41                                | 76                |

FIGURE 5 Comparison of time consumption of different methods

FIGURE 6 Comparative analysis of the proposed approach with the traditional method
Table 4 shows that the proposed approach reduces the engineering cost ratio from 45% to 20% and energy consumption is also reduced from 70% to a much better value of 40%, which is comparatively a much feasible outcome for sustainable building construction prediction and management. Efficiency has also improved from the traditional method using the proposed method to 76%, making a robust platform. A much better comparative analysis is depicted in Figure 6 for the traditional and proposed approach in terms of engineering cost ratio, energy consumption and efficiency.

Analysis of Figure 6 shows that in the process of building landscape design, the traditional analytical method has a high engineering cost, high energy consumption, low efficiency and poor performance, and cannot meet the needs of various performance indicators.

In the design process, the performance index of this method is better than that of the analytical method, and the design performance is obviously better than the traditional analytical method, which has a high advantage.

5 | CONCLUSION

The BIM information of the building can be visually displayed through the 3D simulation interactive system. Later, it can expand freely in the simulation engine according to the needs of the application. CAD solid modelling technology is used to model the building 3D simulation system, and errors and design defects can be found before the design is submitted. The design review process is no longer limited to experts who can read drawings or view models in Revit. Through the use of collision detection and a physical engine, we study problems related to building damage assessment, discuss the impact of this technology on the overall design of buildings, and look forward to the future development direction. The building 3D simulation image constructed by the designed system has high clarity, short time consumption and excellent performance. The proposed approach improves efficiency to 76% compared with the traditional method and encourages the growth and development of construction prediction and management in the Industry 4.0 scenario through its effectiveness. Future study will highlight the deployment of the proposed simulation model to analyse the actual scenario of construction prediction and management industry.

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