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Comparison Between New Architectural Design Concepts and Traditional Methods from the Perspective of Digital Architecture

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Abstract: Traditional design methods have problems such as low efficiency of multidisciplinary collaboration. We built a multidisciplinary collaboration database based on the BIM platform, integrated multi-source professional data using the IFC standard, and developed an automatic collision detection plug-in using the Revit API. We used GA and PSO algorithms to drive the generation of architectural forms, and performed multi-objective optimization calculations on the Rhino.Compute cloud cluster. We further used GCN to extract features from historical project data, train GAN, and output innovative solutions that meet regulatory constraints. The new design concept shortened the design time; in terms of innovation scores, the new design concept scored the highest 5.0 in all tasks.

Key words: IFC; GA; PSO; innovativeness score; design time

1. Introduction

This paper explores the advantages of new concepts in improving design efficiency, enhancing design innovation, and optimizing the energy-saving effect of building operation and maintenance. Through actual case analysis, it quantitatively demonstrates the achievements of new design concepts in improving efficiency, enhancing innovation, and saving energy and reducing consumption. This paper first outlines the development background of digital buildings and the significance of this study, and sorts out related work to lay the foundation for comparative analysis; then introduces the research methods and technical routes used in this paper; then compares the differences between new design concepts and traditional methods through specific data; finally, summarizes the entire article and extracts the research conclusions.

2. Related Work

New design concepts and construction management models are constantly emerging in the field of construction. Wang Jianjun[1] discussed new architectural design methods and cooperation platforms related to "Internet+". Yao Jianjun and Guo Jianjun[2] discussed the innovative application of new waterproof materials in architectural design. Liao Zhiqiang[3] discussed modern architectural design based on new decorative materials. Tong Zhiqiang[4] analyzed new ecological building materials based on actual cases. Xu Jianjun[5] put forward optimization suggestions for the application of new fireproof materials in architectural design. The above research has laid the foundation for the digital transformation of the construction industry. However, there are still large differences between traditional architectural design methods and new design concepts. From the perspective of digital architecture, this paper compares the differences and functions of new design concepts and traditional methods to promote the high-quality development of the construction industry.

3. Method

3.1 BIM platform builds a multi-disciplinary

3.1.1 Application of IFC standards

In view of the application of IFC standards, a multidisciplinary data model is constructed based on the IFC 4.3 standard, and the semantic expression of professional data such as architecture, structure, and electromechanical is realized through entities (IfcWall), relationships (IfcRelConnects), and attribute sets (Pset_StructuralLoad). The data model is defined in the IFC EXPRESS language. In the process of interdisciplinary data exchange, the structural discipline exports the IfcStructuralAnalysisModel to the BIM platform and performs spatial relationship mapping with the IfcSpace entity of the building. The MEP discipline defines the pipeline topology through the IfcFlowSegment entity and realizes the geometric collision logic association with the IfcOpening element of the building.

3.1.2 Implementation and effect of developing an automated collision detection plug-in using Revit API

When developing an automated collision detection plug-in using the Revit API, the C# language is used to call the ElementIntersectsFilter class of the Revit API to implement geometric collision detection. To improve detection efficiency, a quadtree spatial index algorithm is constructed to reduce the time complexity of collision search from O (n^2) to O (n log n).

3.2 Parametric design tools and algorithms

In parametric design, Lunchbox and Owl offer distinct capabilities, with Owl specializing in multi-objective optimization using algorithms like GA and PSO. Utilizing Owl's library, we set multi-objective functions encompassing performance and economic targets, employing GA for global search with specific strategies and PSO for local optimization to enhance efficiency.

3.3 Application of deep learning technology in architectural design

In the field of architectural design, the joint application of GCN and GAN can achieve deep mining of historical project data and automatic generation of innovative designs.

By extracting historical project data from the BIM database and converting it into a graph structure JSON format, GCN is used for hierarchical feature aggregation. In the first layer of GCN, the geometric features and functional features of directly adjacent nodes are aggregated; in the second layer of GCN, cross-level semantic associations are captured. Finally, the high-dimensional features are mapped to a two-dimensional space through the t-SNE algorithm:

$$\mathrm{H}^{(l+1)} = \sigma(\widetilde{\mathrm{D}}^{-1/2}\widetilde{\mathrm{A}}\widetilde{\mathrm{D}}^{-1/2}\mathrm{H}^{(l)}\mathrm{W}^{(l)}) \quad (1)$$

$\mathrm{H}^{(l+1)}$ and $\mathrm{H}^{(l)}$ are the node feature matrices of the l+1th and l-th layers, respectively; σ is the nonlinear activation function; $\widetilde{\mathrm{A}}$ is the adjacency matrix after adding self-loops; $\widetilde{\mathrm{D}}$ is the corresponding degree matrix; and $\mathrm{W}^{(l)}$ is the learnable weight matrix.

In GAN, the architecture of the generator and discriminator is designed. By designing a loss function that combines adversarial loss and normative constraint loss and adopting a progressive training strategy, a basic plan that satisfies a single specification is first generated, and then multiple constraints are superimposed for fine-tuning:

$$L = \mathrm{L}_{\mathrm{adv}} + \lambda\mathrm{L}_{\mathrm{reg}} \quad (2)$$

L is the total loss function; $\mathrm{L}_{\mathrm{adv}}$ is the adversarial loss; $\mathrm{L}_{\mathrm{reg}}$ is the norm constraint loss; and λ is the balancing coefficient.

The generated solutions are controlled for diversity through latent space interpolation and imported into the BIM platform for automatic specification review. Figure 1 shows the GAN operation architecture:

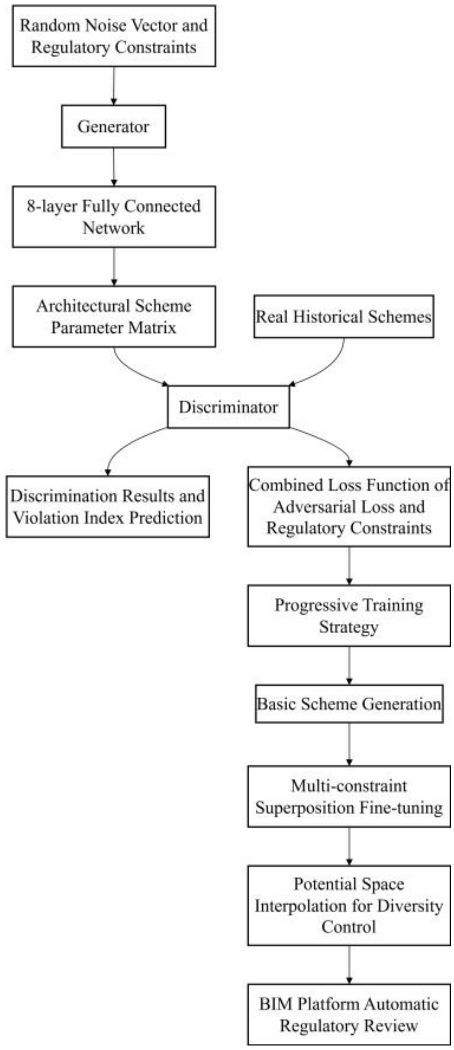

Figure 1. GAN operation architecture.

3.4 IoT and digital twin technology

With the help of Unity digital twin engine, lightweight import of BIM model and construction of real-time data-driven engine are realized, and Revit model is converted into glTF 2.0 format through IFC parser. Material library mapping rules are built in Unity to ensure high consistency between virtual model and real building. In addition, Unity PhysX engine and Ray Tracing technology are integrated to simulate natural ventilation effect and sunlight shadow change.

In terms of interactive visualization interface, multi-view dashboard is built, which supports 3D scene superimposed heat map, line chart and warning pop-up window and other display forms, providing users with intuitive and comprehensive building operation status information.

4. Results and Discussion

4. 1 Comparison with traditional design methods

This study selected a large-scale cultural complex project as a benchmark case, and compared and analyzed the parallel implementation results of the traditional design process (2D CAD manual collaboration + static experience decision-making) and the new digital construction method (BIM-parametric-AIoT technology chain). The comparison indicators include design time, form innovation score), energy saving rate parameters, etc. The results are shown in Figure 2, Figure 3, and Figure 4 respectively:

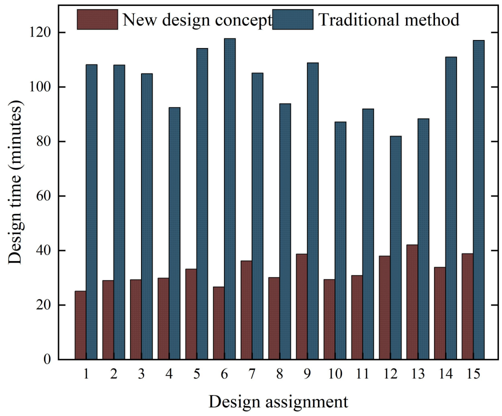

Figure 2. Design time.

By comparing the design time of the new design concept and the traditional method in each design task in Figure 2, in Task 1, the design time of the new design concept is 25.1 minutes, while the design time of the traditional method is as high as 108.2 minutes, a difference of up to 83.1 minutes, showing the efficiency advantage of the new design concept. This trend is also obvious in other tasks. The new design concept greatly shortens the design cycle and improves overall work efficiency by integrating BIM technology, parametric design tools and intelligent algorithms.

As shown in Figure 3, by comparing the innovation scores of the new design concept and the traditional method, the maximum innovation score of the new design concept is 5.0(tasks 7, 10, 14 and 15), while the highest score of the traditional method is only 4.4(task 6), showing the significant advantage of the new design concept in innovation. In terms of minimum values, the new design concept has a minimum score of 4.2 (tasks 4 and 8), while the traditional method has a minimum score of 3.3 (tasks 5, 8, 10, and 11), which further indicates that the new design concept maintains a higher bottom line in terms of innovation score. This result demonstrates the potential of the new design concept in promoting architectural design innovation and supports its promotion in practical applications.

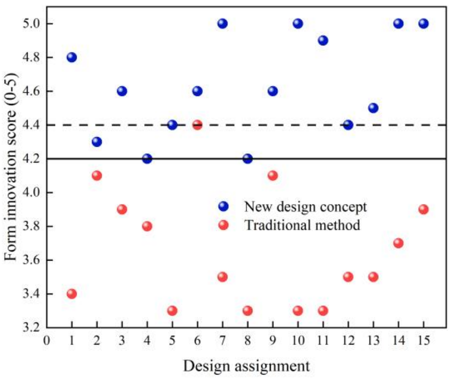

Figure 3. Innovation score.

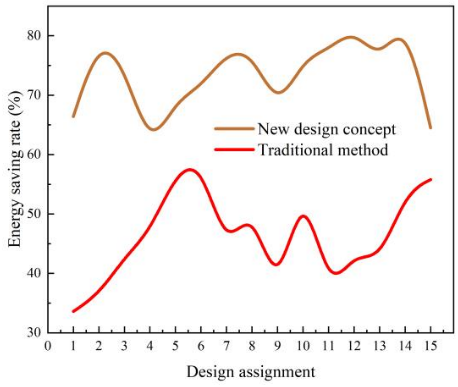

Figure 4. Energy saving rate.

The data in Figure 4 show that, from the average value, the average energy saving rate of buildings under the new design concept is 73.44%, while the average energy saving rate of traditional methods is 46.3%. This result shows that the new design concept is better than the traditional method in energy saving effect, reflecting its advantage in energy utilization efficiency. In contrast, traditional design methods are often based on static assumptions and fixed operation strategies, lack flexibility and adaptability, and are difficult to cope with complex and changing actual environments. Not only does it cause energy waste, it may also affect the comfort of the building's internal environment and the health and well-being of users.

4.2 Comprehensive benefits

The digital architectural design concept has achieved all-round breakthroughs in efficiency, sustainability and other dimensions through technology integration and process reconstruction.

The efficiency improvement data is shown in Table 1:

Table 1. Efficiency improvement data

Efficiency indicator	Traditional method	Digital method	Improvement/ Reduction
Design cycle (for supertall projects)	12-18 months	8-12 months	33% shorter
Professional collaboration time share	35%	15%	57% reduction
Construction rework rate	7%-12%	< 2%	80% reduction
Operational response speed (fault handling time)	> 4 hours	Real-time alerting + autonomous decision-making < 30 minutes	8x efficiency increase

The design cycle of super high-rise projects under traditional methods is 12-18 months, but after adopting new digital methods, the design cycle is shortened to 8-12 months, an increase of 33%. The time spent on professional collaboration has also been greatly reduced, from 35% of the total cycle to 15%, a decrease of 57%, mainly due to real-time collision detection and IFC data interoperability technology. The construction rework rate has also been greatly reduced, from the industry average of 7%-12% to less than 2%, a decrease of 80%, thanks to the application of BIM construction simulation and AR on-site guidance technology. In addition, the operation and maintenance response speed has also been greatly improved. The fault handling time has been shortened from more than 4 hours of real-time warning plus autonomous decision-making to less than 30 minutes, and the efficiency has been increased by 8 times.

5. Conclusion

This paper discusses the advantages of the new concept in improving design efficiency, enhancing design innovation, and optimizing the energy-saving effect of building operation and maintenance. The paper does not conduct an in-depth discussion on the cost-benefit analysis of the new design concept in practical applications, the need for talent training, and the integration path with traditional design concepts. Future research can further focus on the application effect of the new design concept in complex scenarios such as super high-rise buildings and smart cities.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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