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Exploring Digital Visualization Methods in Urban Public Building Space Design

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Abstract: Digital technology has driven the innovation of architectural design methods and tools, applying digital techniques to allow greater possibilities for more innovative and scientific design of public building spaces. This article first analyzes the characteristics of digital visualization and its advantages in the design of urban public building spaces, including aspects such as visualizing three-dimensional expression, rational analysis of building space, Virtual Reality Experience, and integration of design and construction processes. Subsequently, by introducing digital design methods such as parametric design, algorithmic generation, nonlinear design, and artificial intelligence-assisted design, it explores the methods and implementation approaches of digital visualization in the design of public building spaces. The aim is to offer insights and references for the deeper integration of digital technology into architectural design practices.

Keywords: Public building; Space design; Digital visualization; Methods

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1. Introduction

Urban public buildings are an essential component of city architecture as their functions involve various aspects of the lives of people. Public buildings can be categorized based on their service functions into office buildings (such as office towers), commercial buildings (such as commercial complexes), tourist buildings (such as hotels, visitor reception centers, etc.), scientific, educational, cultural, and medical buildings (such as schools, sports arenas, libraries, museums, hospitals, etc.), as well as transportation buildings (such as airports, train stations, etc.). The design of public building spaces is a crucial element in public building design. Because public buildings serve the general public, the consideration of human behavior and experience is paramount in public space design. Therefore, in the design process, different building materials should be selected and adequate spatial environments should be arranged based on different functions and environments to achieve an optimal living area [1]. Additionally, public building spaces must have distinct practicality and adhere to the principles of rationality. This requires designers to fully leverage their design capabilities in three-dimensional space during the design process [2]. Traditional two-dimensional design methods often cannot comprehensively express the three-dimensional spatial information and spatial organizational plans of buildings, nor can they provide an immersive spatial effect. The development of digital technology has brought significant design changes to the field of architecture, driving the evolution of methods and approaches in architectural space design [3]. Digital visualization technology is a technique that utilizes computer information technology to convert data into three-dimensional graphics, that can be used to convey three-dimensional graphics and specific ideas [4].

2. Advantages of digital visualization in the design of public building spaces

2.1. Visualizing three-dimensional representation

Urban public buildings with their public service attributes are more complex in design and use compared to residential buildings. Public building spaces often feature large spans, diverse structures, multifunctionality, multiple specialties, and high human traffic. The design of public building spaces requires not only detailed floor plans and elevations but also numerous sections and detailed drawings to convey the design intent of the entire building. This often results in designers spending a significant amount of time on drawing annotations and detailed drawings, as 2D drawings cannot fully express three-dimensional spatial information.

By leveraging digital visualization technologies, such as creating Building Information Modeling (BIM) using software like Revit, two-dimensional drawing information can be transformed into three-dimensional model information. The use of 3D models enables relevant design personnel to promptly and accurately understand the design intent. It provides a clear presentation of all construction information for project components and stages, along with their corresponding spatial information. This ensures that communication among various disciplines becomes more intuitive [5]. Additionally, the visual representation in 3D facilitates a clear expression of spatial arrangement information between different disciplines. This is particularly beneficial in the installation of mechanical and electrical systems and interior decoration, effectively reducing professional conflicts and clashes, thereby avoiding complex rework and waste.

2.2. Space rationality analysis

Architectural space refers to the collective term for the internal and external spaces formed by various architectural elements used to meet certain production or living needs [6]. Architectural space design organizes independent spaces into a unified spatial ensemble through a series of spatial processing methods [7]. Architectural space also externalizes human psychological space by analyzing individual needs to some extent [8]. Therefore, it is necessary to design architectural space layouts of public buildings based on the service functions and psychological needs of the users. In traditional architectural space design, designers generally create scaled-down physical models to simulate spatial layouts, functional allocations in areas, and environmental analyses. Although physical building models have their advantages, with the development of digital technology in the field of architectural design, digital visualization software can not only create three-dimensional models but also perform building performance analyses, including daylighting, ventilation, air quality, equipment consumption, and even visual analyses of the rationality of safety passages. Digital visualization technology greatly enhances the rationality and scientific nature of architectural spatial design solutions, promoting advancements in the field of architectural design.

2.3. Immersive experience in visualization

Virtual Reality (VR) technology is an advanced technique that utilizes computer graphics systems and various interfaces, including reality and control devices, to generate interactive three-dimensional environments on computers, providing an immersive experience [9]. Immersive interactive experiences are a distinctive feature of digital visualization, where virtual reality technology helps designers transform flat lines into three-dimensional spaces, enhancing the interactive visual experience of space. In traditional flat design methods, architects often need to create rendered images to highlight the design effects, presenting the overall rendering effects, spatial three-dimensionality, and the space between the surrounding environment. However, constrained by the flat form, renderings still cannot accurately depict the space between the environment, nor can they facilitate interactive testing of human behavior with space. Virtual reality technology effectively addresses this issue as shown by **Figures 1 and 2**. Designers can experience the effects of their designs in virtual reality environments through different perspectives, heights, flow lines, and movement rates, allowing for a multi-angle evaluation of their designs [10]. Additionally, construction workers and users can use virtual reality technology to view the effects and details of architectural designs, especially in terms of decorative material effects, spatial organization effects, and spatial construction effects in space design.

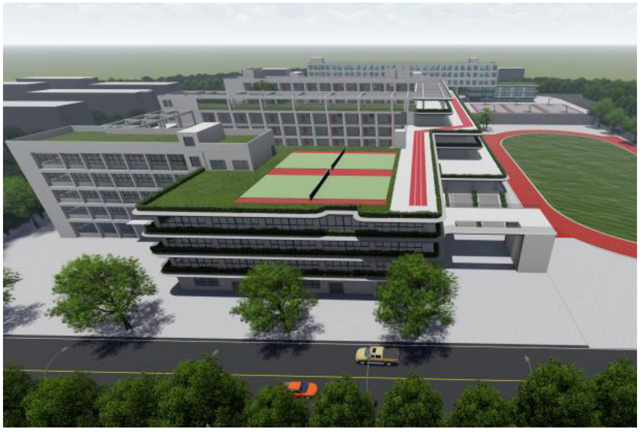

Figure 1. Overall Space

Figure 2. Partial Space

2.4. Integration of design and construction processes

With the continuous development of the industry and the division of management levels, the integration of design and construction processes has become a trend in engineering project development with the increasing promotion of prefabricated construction. Digital visualization undoubtedly plays a central role in the integration of design and construction processes. The integrated process of design and construction requires effective coordination between designers and engineers to ensure project information is accurately conveyed throughout its lifecycle. This helps avoid information disconnections, engineering errors, additional changes, rework, and disputes during the construction process.

Through digital visualization technology, designers and engineers can not only engage in technical communication based on three-dimensional models for architectural solutions but can also establish a visual representation throughout the entire design and construction process. This allows for supervision and acceptance of key aspects and building information at each design stage. This approach contributes to the improvement of construction quality and efficiency [11]. Digital visualization effectively integrates the processes of design and construction, facilitating coordination and collaboration among various project stakeholders to ensure the quality, safety, and rationality of the project, thus greatly enhancing the management and overall effectiveness of the project.

3. Digital visualization methods in public building space design

3.1. Parametric digital design

With the rapid development of urban public buildings, there is an increasing number of unconventional architectural design plans. The linear form of buildings is changing to curves, and there are variations in building facades from various angles. It is challenging to comprehensively design the spatial geometry and positional relationships of unconventional buildings using the conventional CAD flat drawing method. The design approach based on flat line drawing also limits the innovation of architects in constructing building spaces. A method of parametric digital design is proposed using digital technology and methods to address the design requirements for the spatial form of unconventional buildings. Parametric design involves refining design essentials into different variables. This process is similar to mathematical function relationships, where a series of variables, through function operations, generate a series of results. Although these results may differ, the operation process remains the same [12]. Parametric digital design combines digital technology with parametric design and influences the architecture or design output based on specific parameters. Digital tools such as software and manufacturing have become essential for designers in designing and producing buildings [13]. Parametric digital design allows for the parametric design of spatial forms and construction nodes, achieving a correspondence of a series of design solutions with a three-dimensional model and improving design efficiency.

3.2. BIM forward design

Traditional public building designs are based on point and line drawings, in which the information in architectural space design is expressed through 2D drawings and textual explanations. This design method is no longer suitable for the design concept requirements of the digital era. BIM forward design refers to the design method of modeling first before drawing based on BIM technology. This design approach differs from the traditional method of first using CAD for drawing and then using BIM software for 3D modeling. Instead, it transforms the use of 3D modeling as an assistance tool into the main designing software. BIM forward design requires designers to express design ideas first in a 3D model and then generate corresponding 2D drawings from the 3D model with relevant information [14]. Through BIM models, it is possible to accurately showcase architectural space details, including component nodes and decorative materials. This plays a crucial role in precisely controlling the quality of architectural design through the forward BIM design process [15]. BIM forward design is currently in the initial stage, so more improvement is needed and there is still a need to establish industry-recognized guideline documents. The guideline documents should align with designers' thought processes by focusing on the design process and guiding them section by section with useful illustrations [16]. Hence, BIM forward design can fully utilize the visualization of 3D models to effectively enhance the efficiency of public building space design.

3.3. Spatial performance design

In the spatial design process of urban public buildings, the design is typically divided into three stages: conceptual sketch design, preliminary scheme design, and detailed construction drawing design. Detailed construction drawing design requires the design to meet the level of detail required for construction and comply with various standards and regulations. The design focuses on green, ecological, and humanistic aspects, incorporating concepts of sustainability, ecology, and health. This requires designers to conduct design analyses of the spatial performance of the building during the design process. A core aspect of spatial performance design involves contemplating the relationship between space and the environment. Using relevant digital analysis software, architects simulate the multidimensional environmental impact of the proposed building.

This facilitates a quantitative analysis and optimization of architectural space performance through visualized environmental data. **Table 1** introduces several popular architectural environmental analysis software and their features. Additionally, Zhang argues that incorporating performance parameters as driving factors in the early stages of design can help architects explore building forms and construction approaches that are structurally lightweight, use fewer materials, and are more efficient to construct [18].

Table 1. Introduction to various building environment analysis software [17]

Software Name	Main functional purposes	Accuracy
EnergyPlus	Thermal comfort simulation and solar energy simulation analysis	High
Esp-r	Building thermal environment simulation analysis	High
Radiance	Light environment simulation analysis	High
Cadna/A	Acoustic environment simulation analysis	High
Ladybug, Honeybee	Sunlight, orientation, energy, thermal radiation, and airflow simulation analysis	Very high
Fluent	Wind environment simulation analysis	Very high
PKPM	Structural, energy-saving, and green building solutions analysis	Very high
Bentley	Energy, carbon, daylighting, energy consumption simulation analysis	Very high
Green Building Studio	Overall energy consumption, water resources, and carbon emissions of buildings analysis	Medium
Ecotect	Total energy consumption of buildings analysis	Low but quick

3.4. AI-assisted design

With the rapid development of artificial intelligence (AI) in recent years, the emergence of generative AI such as ChatGPT is profoundly influencing the development and transformation of architectural design. Yuan believes that as machine learning and deep learning technologies are increasingly widely used in architectural design, a new design approach with AI-assisted design can become a reality [19]. This undoubtedly will become another new architectural design paradigm following manual design and algorithmic design. With the assistance of artificial intelligence, designers can expand their thinking and creativity in spatial design. They can even generate architectural spatial solutions automatically and then compare the generated solutions. According to Sun, intelligent design systems collaborate with architects in the design process, enabling collaborative interactive design of solutions [20]. In addition, artificial intelligence can also assist designers in the visual effects design and creativity of architectural spaces. For example, architect Kaveh used artificial intelligence programs to visualize a series of impressive renderings of the Palace of Versailles adorned with feathers and minimalist golden exterior walls [21]. The integration of artificial intelligence enhances the interactivity and creativity of design, greatly increasing the productivity of designers.

4. Conclusion

Digitization is driving innovation and transformation in the methods and processes of urban public building space design, assisting designers in expanding design concepts and innovative solutions, and elevating the level and quality of public building space design. Digital visualization that allows three-dimensional visualization, rational analysis of architectural space, immersive experiential effects, and integration of design and construction processes, makes public building space design more efficient, rational, and intuitive. It also facilitates overall coordination, management, and collaboration in projects, better improving the lifecycle of buildings. Thus, the implementation and application of digital visualization in public building space design can be achieved through methods such as parametric design, algorithmic generation, nonlinear design, and AI-assisted design.

Disclosure statement

The authors declare no conflict of interest.

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