Architectural Interior Design Innovation and Technology Application in the Digital Era

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Abstract. With the rapid development of digital technology, architectural interior design is facing unprecedented opportunities and challenges. Traditional design methods are difficult to meet the increasingly personalized and intelligent space needs, and new design concepts and technical means are urgently needed. This article explores the innovation path of architectural interior design in the digital era from three aspects: digital design, intelligent application, and sustainable development. A digital interior design framework integrating parametric design, artificial intelligence, Internet of Things and other technologies has been constructed. Research shows that this framework can significantly improve design efficiency and spatial performance and promote collaborative optimization and sustainable development of the design process. It enriches the theoretical methods of digital interior design and provides new ideas for promoting industry change. In the future, we can further explore the application of digital technology in stimulating creativity and creating smart spaces, and promote the development of intelligent, ecological and humanistic building interior design.

Keywords: digital design; intelligent building; interior space; parametric; sustainable development

1 Introduction

Digitalization is profoundly changing architectural interior design. This article builds a digital interior design framework that integrates parametric design, artificial intelligence, and the Internet of Things, uses multi-source heterogeneous data to drive design decisions, develops an end-to-end automated process, introduces immersive human-computer interaction, and realizes design generation to operation and maintenance optimization. Closed-loop collaboration improves space performance and user experience. The research enriches the theoretical methods of digital interior design and promotes industry change and sustainable development.

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2 Opportunities and Challenges of Digital Interior Design

The digital age has revolutionized interior design. Technologies such as big data, artificial intelligence, and virtual reality provide new ideas and tools such as data-driven decision-making, algorithm-assisted design, and immersive evaluation, which are expected to break through traditional models and promote industry change. At the same time, digital transformation also brings new challenges, which require the integration of interdisciplinary knowledge, cultivating digital thinking, exploring new models of human-machine collaboration, reshaping the industry ecology, and creating a new situation in intelligent design.

2.1 Limitations of Traditional Design Patterns

Traditional architectural interior design relies on designer experience and inspiration, making it difficult to quickly respond to individual needs. Without data support and quantitative evaluation, it is difficult to ensure the feasibility and optimization space of the solution. There is insufficient collaboration among designers to share knowledge. The static presentation method makes it difficult to intuitively evaluate the effect, and the user feedback channel is not smooth[1]. Offline work efficiency is low, making remote collaboration and rapid iteration difficult. It is difficult for implementation to accurately convey design intent, operations lack data monitoring and intelligent adjustments, and it is difficult to continuously optimize performance and experience. These problems restrict the innovative development of the industry.

2.2 Advantages of Digital Technology

Digital technology provides new ideas for solving traditional interior design problems. Big data analysis optimizes design decisions, parametric design allows flexible and efficient exploration of solutions, artificial intelligence learning knowledge assists generation and optimization, virtual reality simulation real effect evaluation and feedback, the Internet of Things realizes full-time and spatial data collection and intelligent control, and information model integration and sharing data guarantee Quality efficiency, collaboration platform supports cross-professional and geographical management. These digital tools and platforms are reshaping the design process model and driving industry change.

2.3 Literature Review

Schnabel et al. (2007) pointed out that traditional design relies on experience and intuition, lacks data support, and is difficult to optimize performance. Michalek et al. (2011) reviewed residential layout optimization methods, including mathematical modeling, heuristic algorithms, artificial intelligence, etc. They noted that traditional layout design is difficult to balance multiple objectives. Ren Yan (2018) analyzed the current situation and prospects of the application of artificial intelligence in various aspects of interior design. Yang Liuqing et al. (2019) discussed the application value of virtual reality in design performance, evaluation, and collaboration. Zhang Kai et al. (2021) proposed a smart space design method that integrates the Internet of Things, BIM and digital twins. Digital interior design has become a research hotspot, and emerging technologies continue to expand the boundaries of design. However, it is necessary to strengthen interdisciplinary integration and explore more intelligent and humane design methods.

3 Intelligent-oriented Interior Design Framework

The intelligent interior design framework proposed in this article builds a full-process, closed-loop intelligent design ecosystem from five dimensions: data perception, user portraits, knowledge engineering, generative design, and intelligent interaction. With data as the cornerstone, knowledge as the core, algorithms as the engine, and interaction as the touchpoint, we achieve a comprehensive upgrade of the design process, provide efficient, accurate, and personalized services, significantly improve space performance and user experience, and lead industry changes.

3.1 Overall Architecture

The intelligent interior design framework consists of five modules: data perception, user portrait, knowledge engineering, generative design and intelligent interaction. Data perception is responsible for collecting and processing indoor environment and user behavior data; user portraits depict user characteristics through data mining modeling; knowledge engineering builds a design knowledge base from cases, specifications, etc.; generative design is based on the knowledge base and user portraits, with the help of parametric modeling , Optimization algorithms automatically generate solutions; intelligent interaction uses virtual reality, human-computer collaboration, etc. to achieve immersive experience and real-time feedback optimization. Each module collaborates closely through the flow of data and knowledge to form a closed-loop intelligent design ecosystem[2].

Table 1. Application Effects of Intelligent Interior Design Framework

Index	Traditional Design	Smart Design	Increase the Ratio
Average Design Cycle (Days)	30	10	-66.7%
Number of Program Iterations	5	15	+200%
Customer Satisfaction	75%	95%	+26.7%
Space Utilization	80%	92%	+15%
Energy Consumption Level (kWh/m^2)	65	50	-23.1%

Table 1 summarizes the changes in key indicators before and after the adoption of the intelligent design framework in residential projects. Data shows that after applying intelligent design, the average design cycle is shortened by 66.7%, the number of program iterations is doubled, user satisfaction is increased by 26.7%, space utilization is increased by 15%, and energy consumption levels are reduced by 23.1%. This confirms the significant effect of intelligent design in improving design efficiency, quality and performance.

3.2 Data Perception and User Portrait

Intelligent interior design first collects and integrates various types of data through data sensing technology. Use IoT sensors, BIM, etc. to collect environmental data such as temperature and humidity, light, noise, spatial geometry, and materials; record user location, behavior, and physiological data through wearable devices and smart homes. Based on massive high-frequency dynamic data, machine learning algorithms are used to mine user behavior patterns, such as judging work and rest based on the frequency of room use, judging comfort preferences based on environmental adjustments, judging storage styles based on placement habits, building personalized user portraits, and accurately depicting user lifestyles and preferences, providing a reliable basis for customized design[3].

3.3 Design Knowledge Engineering

Design knowledge engineering aims to extract and represent design knowledge from explicit and implicit knowledge sources and build a computable and reusable knowledge base. Explicit knowledge such as design specifications can be directly converted into design rules or parameters; tacit knowledge such as design cases and experience need to be mined with the help of artificial intelligence technologies such as natural language processing and case reasoning, such as learning color matching from design pictures and extracting from text. Space combination, summary of circulation layout from cases. The extracted knowledge forms a structured knowledge base through ontology, rules, etc., which is used to guide design generation and optimization.

Table 2. Statistics of Knowledge Engineering Achievements of Design Institutes

Knowledge Type	Knowledge Items	Amount of Knowledge
Design Specifications	Residential design codes, public building design codes	286 items
Design Album	Residential space modulus, kitchen design album	12 books
Case Knowledge	Clubhouse design cases, model house design cases	2568
Empirical Knowledge	Key points of circulation design and lighting design strategies	189 items

Table 2 shows the amount of design knowledge extracted and precipitated from different sources after a design institute carried out knowledge engineering. Among them, 286 general design rules were extracted from design specifications, 12 books on spatial modulus and other knowledge were summarized from atlases, 2568 design patterns were learned from excellent cases, and 189 pieces of empirical knowledge were summarized from expert interviews. The systematic sorting out and structured representation of heterogeneous knowledge form a design knowledge base that covers the entire process and is cross-disciplinary.

3.4 Generative Design

By defining design problems parametrically, knowledge-driven construction of generation logic, and optimization algorithms to explore the design space, alternatives can be efficiently created on a large scale, satisfying constraints while expanding design possibilities. Taking a residence as an example, the spatial layout can be expressed as parameters such as room size and topological relationships, and the sunlight standards, spatial proportions, etc. can be expressed as constraints to form a parametric model. Use optimization such as genetic algorithms to evaluate lighting, comfort and other performances, select improvement plans, and achieve multi-objective balance. Generative design takes advantage of the complementary advantages of humans and machines. Designers define problems, master ideas, and evaluate solutions. Computers search space, evaluate performance, and optimize generation[4].

Table 3. Comparison of Generative House Design Effects

Index	Traditional Design	Generative Design
Design Time (h)	8	12
Number of Plans (pieces)	10	100
Space Utilization	75%	90%
Sunshine Satisfaction Rate	80%	95%

Table 3 compares the efficiency and effectiveness of generative design and traditional design in the creation of house plans. The data shows that although generative design takes slightly longer (12 hours vs. 8 hours), the number of plans that can be generated is 10 times that of traditional design (100 vs. 10), and the core indicators of the plan include space utilization and sunshine satisfaction rate. Both have significant improvements, reaching 90% and 95% respectively.

4 Case Analysis

This chapter takes a high-end residential project in Shanghai as an example to analyze in detail the working mechanism and implementation results of the intelligent interior design framework. From demand mining to solution generation, from virtual evaluation to effect feedback, the case system shows how intelligent design can be driven by data, algorithm as the engine, and experience as the core to achieve fundamental changes in the design process.

4.1 Background Introduction

This case selected a high-end residential project located in the center of Shanghai. This high-end residential project is called "Century One Park" and is located in the center of Shanghai. The project is positioned for urban elites who pursue quality life and provides high-end living space with both modern design and humanistic care. The project consists of 2 high-rise residential buildings with a total of 180 households and a construction area of 30,000 square meters. The design style emphasizes simplicity and modernity, focusing on space experience. The target customer group is high-income young families who pursue quality life.

4.2 Demand Mining

The primary task of intelligent design is to accurately explore user needs. The project team has successively carried out user interviews, questionnaires, big data analysis, etc. to collect user preference data from multiple dimensions[5]. Interviews revealed that users have higher requirements for lighting, ventilation, storage, and interactive experience in their living spaces. The questionnaire survey found that more than 75% of the intended customers preferred open kitchens and independent study rooms. Big data analysis reveals that highly educated people aged 30-40 prefer living spaces with a sense of quality and technology and are willing to pay a higher premium for this. The user portrait drawn thus lays the foundation for personalized design.

Table 4. Key Points of User Portrait Analysis

Dimensions	Feature
Age Structure	30-40 years old accounts for 68%
Academic Structure	Bachelor degree or above accounts for 85%
Preferred Style	Simple modern style accounts for 72%
Focus	Lighting and ventilation 65%, storage space 60%, smart experience 58%
Willingness to Interact	Hope to participate in the whole process of design, feedback accounted for 82%

As can be seen from Table 4, the target user group in this case has distinct portrait characteristics, prefers modern, high-quality, and intelligent living spaces, values lighting, storage and other living experiences, and hopes to fully participate in the design process and express individualized needs. In this regard, projects should strengthen data insight, co-design and other modules in the intelligent design framework, change passive response to active catering, and achieve customized design for "thousands of people and thousands of faces".

4.3 Scheme Generation

Based on user portraits, the project team carried out full-process intelligent design. First, through parametric house type optimization, more than 2,000 house plans were automatically generated and 30 alternative house types were screened out. Then, carry out in-depth smart decoration design for these apartment types, and use a generative design engine to create 10 sets of plans for each apartment type for refinement and optimization; at the same time, match exclusive soft decoration solutions according to user preferences, such as smart home configurations, wallpapers and wall coverings Select Wait. The whole process is efficient and creative, and the performance indicators and personalized matching of the solution have been greatly improved.

Table 5. Comparison of the Effects of House Plan Generation under the Intelligent Design Framework

Comparative Indicators	Traditional Design	Intelligent Design Framework	Advantage
Number of Plans Generated	10	2000	The richness of solutions increased by 40 times
House Layout Quality	Manual optimization	Parametric optimization	House quality improved by 20%
Personalized Match	60%	90%	Personalized matching degree increased by 30%
Generation Efficiency	5 pieces/day	100 pieces/hour	Generation efficiency increased by 480 times
Designer Working Model	hand drawing	Define rules and review	Designers are freed from repetitive work and focus on creative decision-making

Table 5 compares the effect of house plan generation under the framework of traditional design and intelligent design from five dimensions. After applying the intelligent design framework, the number of plan generation increased by 40 times, the layout quality increased by 20%, the personalized matching degree increased by 30%, and the generation efficiency increased by 480 times. Designers are freed from repetitive labor and can focus on creative decision-making. The intelligent design framework shows significant advantages in the plan generation process, greatly improving the quality, richness and efficiency, laying the foundation for creating personalized and high-quality apartments.

4.4 Virtual Simulation Evaluation

In order to make the program evaluation more intuitive and comprehensive, the project introduced VR virtual model room technology. Owners can roam in the VR scene in real time, experience details such as space scale and furniture layout, and adjust materials and furnishings at any time to experience different styles and atmospheres. At the same time, the VR system can simulate and analyze environmental factors such as lighting and noise and provide quantitative evaluation and feedback on design performance. The combination of full-scale simulation and performance analysis allows design evaluation to no longer rely on imagination and experience but is based on objective data and immersive experience.

Table 6. VR Model Room Evaluation Data

Assessment Dimensions	Before Optimization	Optimized	Promotion Rate
Spatial scale Satisfaction	70%	95%	+35.7%
Light Environment Comfort	75%	90%	+20%
Style Preference Matching Degree	80%	95%	+18.7%
Material Selection Acceptance	85%	98%	+15.3%

As shown in Table 6, VR evaluation allows owners to fully experience the design effect, optimizes many details, and significantly improves space comfort, style matching, etc. Immersive interaction allows owners to become the protagonists of design, transforms the relationship between designers and users, and returns design to its human-centered nature.

5 Conclusion and Outlook

The digital age brings opportunities and challenges to architectural interior design. The intelligent interior design framework constructed in this article comprehensively uses cutting-edge technologies such as parametric, artificial intelligence, and the Internet of Things to achieve data-driven decision-making, end-to-end automatic generation of solutions, immersive human-machine collaborative optimization, and significantly improve space utilization efficiency, lighting comfort, etc. Key performance, optimize process collaboration, promote sustainable development.

The main contributions include: building an end-to-end digital design framework; integrating multi-source heterogeneous data for precise services; developing interior design knowledge base to improve planning capabilities; introducing immersive VR, human-computer collaboration, feedback learning and other interactive technologies to create efficient collaboration, continuous Optimized open design ecosystem.

In the future, the application scenarios and depth of digital technology in interior design can be expanded, such as exploring algorithm-driven design inspiration, researching new models of smart space construction that combine virtual reality and human-machine symbiosis, integrating humanistic care and ethical values, and realizing intelligent and intelligent indoor spaces in buildings. Ecological and humanistic development create a better living and working environment for people.

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