GRAPH-BASED INTELLIGENT DECISION-MAKING IN THE EARLY STAGE OF ARCHITECTURAL DESIGN

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ABSTRACT

Traditional design decision-making is usually a process of adapting and reusing the paradigm at the architect's disposal based on intuition and experience, which helps to provide acceptable solutions to known design problems quickly but makes it challenging to generate new spatial types beyond the existing paradigm. Proposing a graph-based design decision-making framework to solve complex behavior-driven problems effectively, this research will help to integrate research and design effectively, improve the efficiency and accuracy of design decision-making.

Keywords: decision-making, open space, spatial design, graph theory, deep learning.

1 INTRODUCTION

In the era of digital transformation in architecture, the interplay among multiple factors in architectural design has become increasingly complex, transforming design into a multifaceted decision-making problem. Traditional design processes, dominated by personal cognition and reliant on experiential problem-solving, often fall short in addressing the complexities of modern architectural planning and design. While statistical and mathematical methods have been employed in the analysis of urban and architectural issues, they struggle to effectively aid the design process. Consequently, the need for intelligent design decision-making tools is more critical than ever.

This is particularly true for the early stages of public building design, where spatial layout issues present a complex web of interrelated parameters and hard-to-quantify evaluation metrics. The combination of continuous and discontinuous spaces, as highlighted by Rahbar et al. (2022), adds further complexity to these challenges. In public spaces where users exhibit high levels of autonomy, the multitude of users, the variability of their behaviors, and minimal spatial restrictions mean that spatial layout is no longer dictated by fixed functional distributions. Instead, it is evaluated based on its effectiveness in supporting spontaneous user activities.

However, there remains a significant gap in the analysis of spontaneous behaviors and the spatial support conditions they require. Addressing this gap requires more than just empirical summaries of element correlations; it calls for an intelligent method capable of adjusting spatial layouts based on behavioral information. Such a method would not only enhance the reliability of design decisions but also provide a foundation for subsequent research in construction, usage evaluation, and other areas.

Therefore, this study aims to combine artificial intelligence technologies to construct a methodology based on the integration of multi-source data and the iteration of data across different stages. This methodology will generate and optimize the spatial layout of public buildings, thereby enhancing the reliability of

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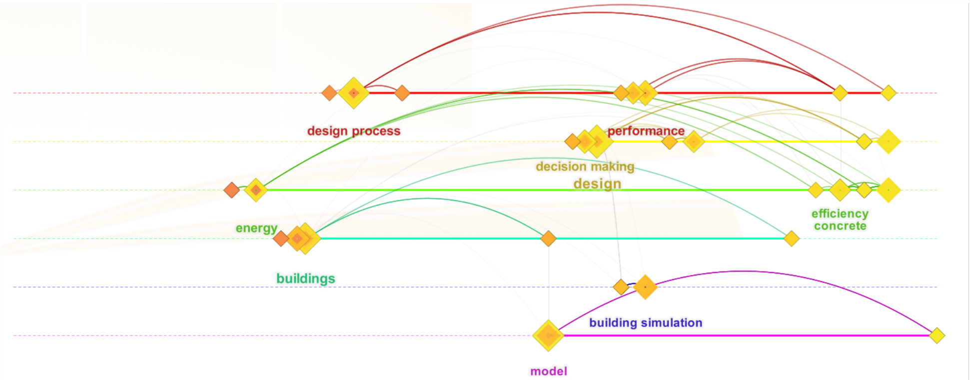


Figure 1: Cynefin Framework (Cognitive-Edge 2019) , [1].

decision-making in complex design problems and offering innovative solutions for the challenges faced in public space design.

2 LITERATURE REVIEW

2.1 Design Decision-making

This study examines the current trends in research on architectural design decision-making, with an emphasis on the integration of artificial intelligence into design decisions. In the field of architecture, decision-making issues have traditionally focused on energy consumption and construction. However, decision-making in the design process is increasingly becoming a prominent area of exploration. Design decisions can be summarized as the process where designers, in the specific context of a project, determine the key conditions of a plan by synthesizing credible research evidence, considering the client/users' needs, preferences, resources, and their own design experience (Figure 1) [2, 1]. The content of the decision mainly refers to determinations in specific design issues that have advantages, disadvantages, and even right or wrong choices, such as siting, types and layouts of buildings and facilities, massing and programming, furniture specifications, etc. [3].

At present, a variety of qualitative and quantitative methods have been applied in the design decision-making process. Qualitative decision-making processes primarily involve summarizing cases, designer experiences, and user perceptions to identify key design elements and corresponding strategies for certain types of architecture. These elements and strategies are further evaluated, such as assessing their weight and necessity, to provide operational guidelines in a list format. Model-based simulation evaluations are often used in these processes to gather stakeholder feedback, guiding the iterative development of design plans. However, these methods are typically limited by the scope of the research samples and cannot be easily generalized to other design problems. The experiences and solutions derived are often not universal but are rather optimal solutions based on specific user and designer experiences.

In contrast, incorporating data for quantitative analysis often leads to more universally applicable design principles. Analytical methods like convex polygons in space syntax and visibility analysis effectively represent, analyze, and interpret specific spaces. These methods are widely used for analysis in the early stages of design and for validation and iteration in the later stages. Many researchers combine quantitative analysis with qualitative design decision-making workflows. Following preliminary conclusions from quantitative analysis, they use personal experience for design. Moreover, the combination of agent-based evolutionary algorithms and simulation has made it possible to quantitatively link analysis and generation, obtaining relatively optimal spatial layouts through simulation. However, assessing the realism of these simulations is challenging, often requiring a comparison of simulated data with data collected in actual spaces to further refine and calibrate algorithm values. From this perspective, a fully quantitative design decision-making process typically results in solutions for simulated problems, which may not align with real-world design challenges. Therefore, there is still a need for research that can effectively integrate qualitative and quantitative methods, particularly suitable artificial intelligence technologies, to achieve more optimized spatial layout in design decision-making processes.

2.2 Graph-based methods

The application of graph theory in the fields of architecture and decision-making has gained significant traction. Decision influence graphs, functional zoning diagrams in architectural design, and flowcharts are essentially logical diagrams of points and lines representing connections.

With the advancement of graph theory-based techniques, topological diagrams can be converted into richer and computable data structures like adjacency matrices and triplets. This transformation allows architectural problems to be converted into computational and reasoning tasks on graphs, which can be solved with algorithms. The properties of graph theory enable high-dimensional representation of information related to architectural layouts. Weighted graphs can represent the strength and type of connections between architectural spaces, directed graphs can illustrate the flow relationships between rooms, heterogeneous graphs can represent how users utilize spaces, and dynamic graphs further reflect how this usage changes over time.

In architectural layout problems, graph theory-based algorithms have been applied across different stages, including case analysis, layout solving, and generative reasoning. During the case analysis phase, topological diagrams aid in establishing the topological representation of plans of similar types of buildings, further allowing structural and property analysis through graph algorithms. In the layout solving phase, design problem constraints are translated into geometric constraints, enabling the derivation of solution sets through graph algorithms. During the generative reasoning stage, neural networks can be trained to predict correlations between the topological relationships of spatial layouts and design goals, such as livability, assisting in generating space layouts that better meet specific requirements.

The powerful representational capability of graph theory facilitates establishing connections among the myriad factors in design problems and effectively evaluating architectural layout based on constraints. This could lead to the development of a new method in design decision-making. However, the current application of graph theory in architectural layout is relatively isolated. Its efficacy is reflected more in solving specific tasks or enhancing performance in a particular aspect, rather than achieving more optimal layouts tailored to specific design problems. Additionally, due to limitations in data availability and representation methods, current research mainly focuses on residential buildings. These buildings, typically separated by clear walls, are easier for both researchers and algorithms to recognize spatial separation logic, thereby establishing corresponding topological representations.

Therefore, further research is needed to develop graph theory representation methods suitable for the open spaces of public buildings and to identify graph properties that can evaluate spatial efficacy. This research will provide a foundation for effectively applying graph theory-based intelligent methods in solving design decision-making problems in public architecture.

3 RESEARCH CONTENTS

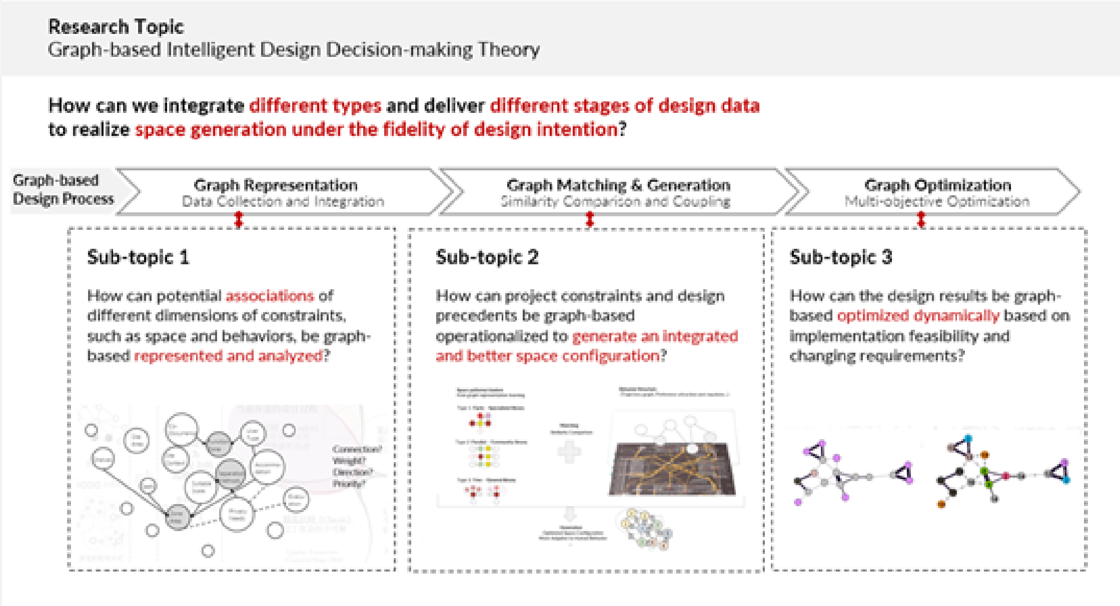
The study focuses on three main aspects within a graph-based design process, targeting the integration of various design data types and stages for space generation true to design intentions.

Graph-Based Correlation Analysis: This phase involves analyzing the interrelations among design constraints. It includes creating a representation mechanism for open public building spaces, compiling a list of design elements through reviews and interviews, and applying machine learning to determine element weights and correlations. The goal is to construct a network mapping these element correlations and their relationships to spatial configurations using deep learning models.

Coupling Generation: This stage aims to generate optimal design solutions based on project constraints and prior design experience. It translates specific design goals into functional representations, applied to a network of design elements and case correlations derived from previous analysis. The objective is to produce relatively better spatial configurations for specific design challenges.

Dynamic Optimization: The final phase focuses on predicting and optimizing design decisions in response to changing requirements and implementation feasibility. It involves developing predictive models for user behavior and feasibility, and mapping these changes to existing design decision proposals for proactive adjustment.

In summary, the research integrates analysis, generation, and optimization within a graph-based design framework to enhance the adaptability and efficacy of architectural design processes.



Research Topic
Graph-based Intelligent Design Decision-making Theory

How can we integrate different types and deliver different stages of design data to realize space generation under the fidelity of design intention?

How can potential associations of different dimensions of constraints, such as space and behaviors, be graph-based represented and analyzed?

How can project constraints and design precedents be graph-based operationalized to generate an integrated and better space configuration?

How can the design results be graph-based optimized dynamically based on implementation feasibility and changing requirements?

Figure 2: Design decision-making model, [1].

4 RESEARCH METHODS AND CHALLENGES

The integration of environmental-behavior and spatial data will be the fundamental step to carry out the research. On the one hand, plans of cases and related attributes need to be collected and represented as graph structures. On the other hand, behavioral data that can be used to modify and assist in generating optimized spatial structures needs to be collected, analyzed and integrated. These behavioral data consist mainly of text-based user requirements (questionnaire and interview data, comment information) and design constraints (specifications, guidelines, etc.) with a higher semantic dimension, image-based scenes (obtained from VR/AR experiments) and positioning information (obtained from UWB) that can be used to analyze users' spatial usage patterns.

Following the data collection and cleaning process, a combination of deep learning, Bayesian networks, and statistical analysis methods will be employed. These methods will be used to calculate co-occurrence relationships, correlations, and conduct causal inference among the design elements. The network of elements, established based on co-occurrence, correlation, and causation, will be input into graph neural networks. This serves as a reference and criterion for adjusting and evaluating spatial layouts, facilitating the development of more effective and user-responsive architectural designs.

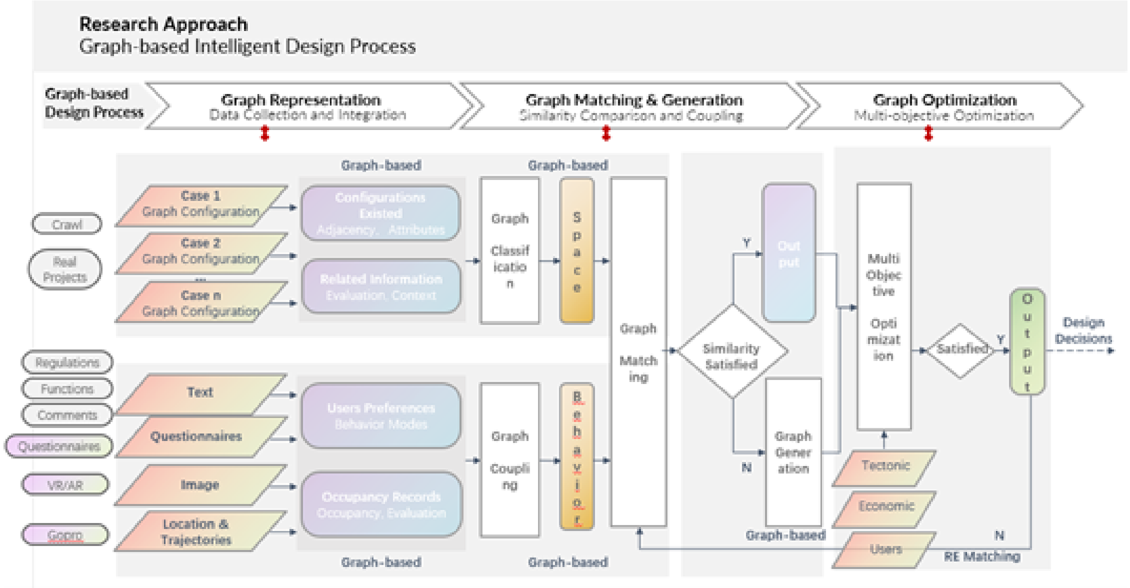


Figure 3: Design decision-making model, [1].

5 EXPECTED OUTCOMES AND INNOVATIONS

The anticipated outcomes of this research include a theoretical framework for intelligent planning and decision-making in architecture, empirical studies focusing on key decision-making processes in informal learning spaces, and the application and evaluation of case studies.

The innovations of this study lie in constructing a complex decision-making theory and process for intelligent planning, establishing graph representation rules for open space structures, proposing graph representation methods for design decision constraints, and introducing a method for generating spatial concepts based on behavior-space coupling. A significant contribution will be the development of an integrated multi-algorithmic architectural planning intelligent decision support system.

6 CONCLUSION

This research aims to make a substantial contribution to the field of architectural design, particularly in the planning of public spaces. By introducing novel methodologies and leveraging advanced technologies, it seeks to address the challenges of modern architectural design, thereby enriching the field with new theoretical and practical insights.

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