Establishing an Educational Framework for Senior Architectural Design Courses Integrating Computational Thinking from Programming, Shaping to Optimization

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Abstract: The emergence of digitization, artificial intelligence (AI) has already brought changes to the thinking methods and processes of architectural design including Scheme Programming, Scheme Shaping, Structure and Performance Optimization. However, the integration of Computational Thinking and Computational Design Content in Architectural Design Courses is still far from sufficient, especially in the Computational Design of junior's course. This study discussed the issue mentioned above for junior students of four-year architecture education university. By integrating four modules named " Computational scheme programming", " AI-assisted generation", "Structural optimization" and " Performance optimization", this study implants the concept of Evidence-Based Design (EBD), reconstructs the computational teaching content, and runs computational thinking through the whole process of scheme programming, generation, optimization and expression. Through 2 years of course practice, it can be seen from the teaching process and design works that: (1) The cultivation of computational thinking can help students approach and solve the entire process problems of programming, shaping and optimization more rationally, but students should avoid falling into the cult of data and algorithms. (2) AI can help improve efficiency, but how to guide students train their own AI model and expand AI capabilities is the next teaching task. (3) The educational framework has stimulated students' interest and enhanced their ability to solve technical problems, but how to integrate personal creative ideas and computational results to improve the scheme is the correct direction of teaching. The implementation process of this study can provide reference for relevant teaching research and practice.

Keywords: Educational Framework; Computational Thinking; Scheme Programming; Scheme Shaping; Scheme Optimization; AI-assisted Generation

1. Introduction

The emergence of generative Artificial Intelligence (AI) and big data has brought impact to various disciplines. Architecture is the one that is highly affected by the developments of these technologies [1]. Under the background of industry transformation, architectural design education must actively respond to it. Research shows that AI-assisted architectural design may contribute to improved time management and reduced anxiety levels [2].

On the other hand, the amount of data produced globally will raise up to 150 zettabytes by the end of 2024[3]. An important part of this data is about built environment and human activities which are the focus of architectural design.

In the era of generative AI and computable big data, architecture is in desperate need of support from computational technologies and AI [1]. The education needs to think deeply about teaching framework and design thinking training.

2. Background

2.1 Course Overview

Juniors' architectural design course is an important carrier for the cultivation of ability to "solve comprehensive architectural technical problems"[3]. Students need to complete a series of basic procedures and methods for the design of complex public buildings, such as investigation and planning, scheme shaping or generation, program optimization and expression. This course focus on improving students' ability to use new technologies and ideas, such as "computational design thinking" to creatively solve "architectural comprehensive technical problems".

2.2 Situation and Difficulties

At present, Juniors' architectural design course has the following problems.

More experience rather than empirical evidence. For a long time, the teaching method of architectural design has been dominated by "experiential output with teachers' personal feelings"[4] which is accompanying with disadvantage of "easy to be affected by teachers' subjective factors", and students' independent innovation is weak. In the scheme planning stage, there is a big amount of data for the designers to process: physical environment analysis, user's needs, functional requirements, etc. These are all about data that needs to be processed [1].

However, there is a lack of educational method supported by quantitative analysis and empirical data in the computational age.

Aesthetics rather than technology. Architectural education always emphasizes aesthetics rather than technology. Meanwhile, least attentions are on technical matters, construction courses, which cannot stand separate from the design process [5]. Architectural is a combination of art and technology, aesthetics is by no means the only mission of architecture.

Less technical content results in the fact that students' schemes can only deal with the initial technical problems.

With the emergence of intelligent software and the weakening of disciplinary barriers, it is necessary to improve students' advanced technical design ability.

Detaching from smart new technologies. In many architecture colleges, intelligent tools such as generative AI are rarely used.

The emergence of AI and large models has given birth to intelligent construction and generation design. However, the digital and intelligent transformation of architectural courses is a little slow. Students spend a lot of time and energy on improving the expression of schemes.

Generative AI, algorithmic or parametric design tools can help students quickly generate and accurately optimize the scheme [6]. How to teach students computational design methods and cultivate computational design thinking is an urgent problem.

Reflection on " difficulties ". In view of the " difficulties ", this study will consider the following questions: Can students enhance their ability of "independent innovation decision-making" based on rational confirmation? Can students advance to new technical design capabilities? How to inspire students' computational design thinking?

3. Strategy and Method

In view of the above thinking, the research carried out the education reform from the following aspects.

3.1 Embed EBD Design Concept

Evidence-Based Design (EBD) is a design philosophy based on evidence-based medicine and environmental psychology that emphasizes the use of scientific research and empirical data to guide decision-making in the design process [7]. The core of EBD lies in using the "best evidence" to make informed design decisions. This evidence comes not only from published research, but also from actual site-specific, project-specific research to ensure appropriate design solutions for specific environments.

In this study, the EBD method is implanted in the steps of base investigation and program planning. EBD provides scientific basis and empirical basis for design through the combination of quantitative and qualitative research methods. Students' program design is based not only on the qualitative rules taught by teachers, but also on the comprehensive application of design theories, regulations, and empirical data analysis results.

3.2 Computational Teaching Content

To equip students with the necessary computational knowledge, we have rearranged the teaching content and teaching modules (Figure 1).

Interdisciplinary co-operation should start at an early stage of the project n [8]. In order to enable students to synthesize knowledge from various disciplines at an early stage of project generation, students have gained the knowledge of environmental psychology, building structure, building physics from the previous courses.

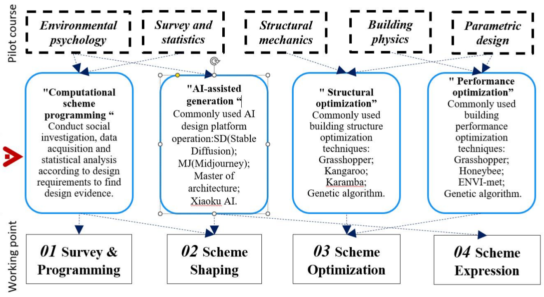

Figure 1. Implanted Teaching Modules

Four teaching sections of "Computational scheme programming", "AI-assisted generation", "Structural optimization" and "Performance optimization" are implanted and students are instructed to complete the corresponding four trainings in their own schemes.

3.3 Computational Design Process

Create an educational process of "Computational Thinking" integrated design. Integrate computational technology and means into the whole process of student program design which can achieves more accurate and higher quality design schemes than traditional educational process. Establish a data-driven design workflow integrating human factors technology into computational thinking. Embed tools like ErgoLAB (physical environment monitoring), Tobii Glasses (eye-tracking), and PsyLAB (behavior observation) into the Survey and programming process (Figure 2).

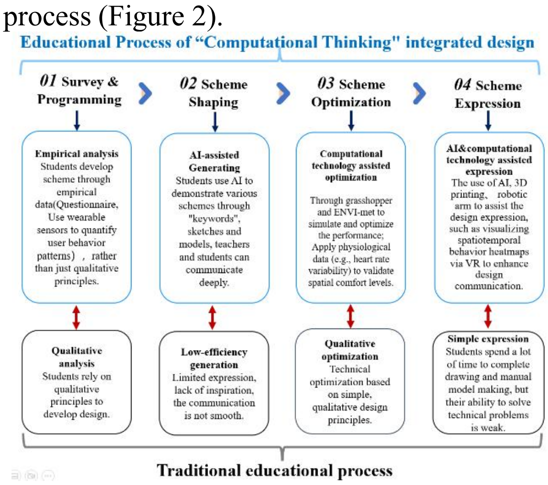

Figure 2. Comparison Between Computability and Traditional Design Teaching Process

3.4 Cultivate Decision-Making Ability Driven by "Computing + Emotion"

Under the traditional teaching mode, students' thinking about architectural problems mostly relies on "personal emotions", namely, the spatial problem solving based on personal value judgment. In the teaching of this course, "computational rationality " is used to correct "personal emotion", and "personal emotion" is used to lubricate "computational rationality", to cultivate students' decision-making ability driven by "calculation + emotion " and establish innovative thinking in the data era.

4. Teaching Steps and Implementation

Some examples of each step are shown in Figure 3, and the detailed flow of a student assignment is shown in Figure 4.

Figure 3. Some Examples of Each Step

4.1 Step1 Survey and Programming

Guide students to conduct data investigation and data analysis, to conduct architectural programming based on analysis results rather than subjective judgment. The generation of detailed design assignment using empirical method is acquired.

4.2 Step2 Scheme Shaping

Help students master the design process of AI-assisted scheme generation, so that they can integrate personal creative thoughts and AI tools for scheme deliberation and decision-making. In the process, students will understand the efficiency and limitations of AI design tools, and the ability to identify whether

AI-generated solutions can cope with real architectural problems.

4.3 Step3 Scheme optimization

Parametric design tools such as Grasshopper are used for structural shape finding and performance optimization, to equip students with abilities of optimizing building performance according to the preliminary scheme and data about "acoustic, optical and thermal ". Currently, there are many "parametric" tools that are accessible such as Ladybug, Honeybee, Geco, and Heliotrope-Solar [9]. This step enables students to integrate individual creative ideas and "parametric" tools for optimization of structural and performance.

4.4 Step4 Scheme Expression

Use AI tools, laser cutting machine, 3D printing and VR to assist the expression of design schemes, including drawings, animations, models, etc. Through this step, students can master the good connection between computational design and digital expression.

Figure 4. The Complete Process of a Student's Work

5. Feedback (Charts and Award Examples)

Before the reform, 98% of the students relied on qualitative analysis in the program planning, but after the reform, 95% (40%+55%) of the students had used the method of EBD to guide the generation of scheme. Similarly, the percentage of AI-assisted building solutions has gone from 2% to 100%, and 46% (36%+10%) of students are able to deeply refine or even train their own AI models. According to the traditional architectural design teaching model, only 13% students consider the structure and performance using computational design solutions. After the reform, almost all students will perform parametric simulations to optimize the scheme, with 89% (45%+44%) able to simulate and deeply optimize at least two properties in structure, sound, light and heat (Figure 5).

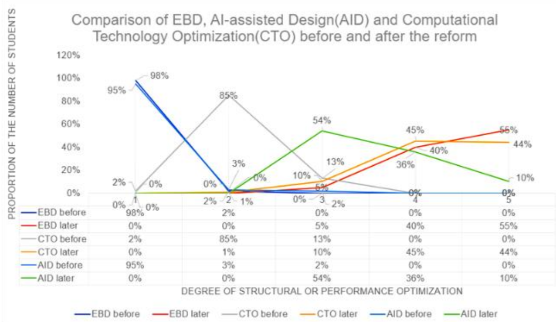

Figure 5. Feedback of Students

Students also have fun exploring new computational knowledge, inspiring many new ideas and leaving comments in the background of the classroom software.

6. Discussion and Conclusion

6.1 Computational Thinking and Data

Computational design thinking and innovative approaches in digital fabrication bring new demands for the rethinking of educational pedagogy for the new generation of architects in the digital age. The first step of computational thinking training is to start from the program planning, guide students in thinking "What can the data tell me? Why do I design this way, and what do I base it on?" In the era of big data, we should seek answers from data mining instead of merely following teachers' "perceptual logic" and subjective qualitative judgment. However, rigorous, and scientific data acquisition methods and the validity of analysis results are the key to the survey and programming stage. When using

AI tools, how to ask questions and dialectically treat the results generated by AI are also key. Both data and AI should be utilized but should not be completely relied on and trusted.

6.2 Limitations of AI Tools

In terms of the tools currently available to students, AI-assisted design tool can quickly generate a scheme in the concept stage, which is convenient for them to discuss the plan, but also easy for students and teachers to communicate. However, some AI platform such as “Stable Diffusion”, “Master of architecture” and “Xiaoku AI” are all not accurate enough to identify the line draft and model, and the input of multiple keywords may not generate the scheme exactly according to the designer's intention, and it is also necessary to further train students to train the AI model by themselves. The current teaching focuses on the generation of appearance effect, but the generation of plan and AI-assisted performance optimization also depend on the development of related software and platforms, which is the next step in architectural design teaching.

6.3 Combination of Personal Ideas and Computational Results

The use of computational thinking and data thinking to optimize the scheme is the core of computational design, but how to integrate personal creative ideas and data optimization results to improve the scheme is the correct direction of teaching. Architectural education combines scientific rigor with innovation and intuition. Students should not rely solely on personal aesthetics, preferences, and inaccurate qualitative principles to create solutions, as is traditional, nor should they fall into a fascination with computational technology and software. How to use AI and computational tools for precise design is key.

Architectural education is responsible for equipping students with proper tools to tackle new problems of society. It is hoped that this educational framework can provide inspiration for architectural design teaching.

Acknowledgments

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