Practice-Driven Teaching Reform of Building Physics: Cultivating Green Building Design Capability

Linling Li*, Ming He

Haikou University of Economics, Haikou, 571127, China
*Corresponding author: m17389768835_2@163.com

Abstract: *With the rise in demand for the green development of the construction industry, the old way of teaching building physics can no longer provide all-round green building design skills for professionals. The aim of this paper is to explore a practice-oriented reform path for physics teaching and hope that it can help promote the all-round development of students' green building design abilities. First, this paper analyzes the shortcomings of the traditional model of knowledge inheritance and puts forward that the teaching paradigm should be reformed to "design thinking integrated with performance thinking". The three main contents of this reform are: first, to restructure the system of course content and pay more attention to climate-responsive teaching methods, the logic of integrating technical strategies and the way to change from physical principles to design decisions; second, to build a simulation and iterative cycle-based teaching model and constantly incorporate environmental performance simulation in all stages of the design generation and optimisation process; and third, to establish a dynamic evaluation system based on the gradient of capability development and use process-based evidence to assess changes in students' all-round abilities. Organize the theoretical basis and practical plan for changing the teaching mode of building physics from isolated knowledge transmission to integrated ability development in this paper.*

Keywords: *Building Physics, Teaching Reform, Green Buildings, Design Capability, Practice-based learning, Performance-based Design, Iterative teaching, Capability assessment.*

Introduction

At present, one of the main problems in architectural education is how to effectively achieve the goals of green and sustainable development; thus, it is necessary to cultivate students' ability to generate new ideas for solving environmental problems through architecture. Currently, the teaching system for building physics is mainly in the form of discipline-based modular transmission of knowledge, and its teaching content, methods and evaluation do not meet the demands for dynamism and integration in architectural design. Without this link, students will not be able to integrate their knowledge of thermal science, lighting, acoustics, etc., to develop technical thinking and make reasonable choices in active environmentally responsive design; thus, a weak link has been formed in the chain of professional talent training. Therefore, an organised reform of building physics teaching should be carried out to improve the efficiency of the course, and at the same time, the entire architectural education system needs to be advanced in line with the new era of green development. The aim of this paper is not to propose any specific improvements in teaching materials and content; rather, in light of the spirit of "practice-drivenness" and with a focus on "capability generation", a general teaching reform plan will be put forward. Therefore, we hope that students will be able to apply the theoretical knowledge they have acquired in their studies to solve real design problems and lay a solid foundation for fostering future-oriented talents in green building design.

1. Paradigm Shift in Teaching Building Physics and Orientation for Green Competence

1.1 The Knowledge Transmission Model of Traditional Building Physics Teaching and its Deficiencies

Traditional teaching methods in building physics have long been based on the transmission of knowledge content, and a linear system of independent teaching modules has been established, such as thermal engineering, optics and acoustics. The above model is one-way in presenting the physical principles and calculation methods, and it is considered fixed knowledge. The teaching process is far removed from the main Design curriculum in architecture, and the physical knowledge often lags behind or runs in parallel with the Design process; thus, it cannot be effectively applied at the critical stage of scheme generation and decision-making. Therefore, students' knowledge of physics is still at the level of abstract theory and isolated calculation; they do not have a cognitive system or operational ability to proactively apply these principles in design. Given that green building design has many other requirements and performance standards, students have systematic difficulties in learning this knowledge and applying it.

1.2 The Composition of Green Building Design Capability and the Repositioning of Teaching Objectives

The basis of a good Green Building Design ability is a kind of combined technical thinking; that is to say, it is an organised way to achieve the goal of environmental performance through specific space and technical measures. First, one should know the climate of the area and how to deal with it; second, there are quantitative simulation tools that can forecast and evaluate the environmental performance; finally, all-round coordination of form, space, materials and the physical environment at the conception and development stages of design should be achieved. Therefore, the goal of building physics teaching should be to enable students to construct a mental model that can establish causal relationships among performance goals, design variables and physical effects in an iterative and simulated way, learn how to make decisions for active application and improvement of the quality of the physical environment in a dynamic design process[1].

1.3 Theoretical Connotation and Implementation Path of the Practice-Driven Teaching Paradigm

The actual teaching mode does not need to be a single one; rather, it is a teaching idea based on the combination of "design thinking" and "performance thinking". The theoretical ideas are to take the knowledge of building physics as the basic logic and generation rules for design generation and evaluation under actual or highly simulated design conditions. Therefore, we need to reform the teaching sequence, accelerate the learning of physical analysis tools and methods that can be applied in parallel with the design project, guide students through all stages of the cognitive cycle, set performance goals, build a design prototype, analyse simulation feedback, iterate and optimise strategies, and at the core of which is to create a design teaching environment that can provide timely feedback on physical performance, help students internalise knowledge through design intuition and judgment bases in a spiral process of "analysis-synthesis", and finally achieve the integrated generation of physical knowledge and design ability.

2. Reconstruction of the Course Content System for Green Building Literacy

2.1 Methodological Teaching of Climate Response and Environmental Analysis Tools

2.1.1 Analysis of Climate Data and the Logic of Spatial Translation

The content of this part of the teaching is to introduce the relationship among time, temperature, humidity, solar radiation and other spatial environments, as well as how changes in these conditions affect the indoor environment or surfaces at different places. Help the students discover why the buildings are designed the way they are according to the weather data. For example, one can use the direction of the wind to arrange the logic of spatial ventilation paths, and in a more refined way, the path of the sun can be employed to create self-shading and facade shading elements.

2.1.2 Critical Application of Environmental Simulation Tools and Result Interpretation

The direction of teaching will be to move from training in the operation of software to critical analysis of the physical models and algorithmic assumptions in digital environmental simulation tools (such as ventilation, simulation, sunlight analysis, daylighting analysis). Students should know the range of application, accuracy limits and uncertainty in the output results of all tools. Students should be able to draw reasonable conclusions from the simulation data, and by way of reverse mapping and translation of quantitative results, obtain qualitative support for decision-making in specific design operations, such as changing the shape of a building or opening interfaces; thus, a closed-loop feedback mechanism between simulation analysis and design iteration can be established.

2.1.3 Linkage of Site Climate Analysis and Morphological Generation Strategies

The last stage of the teaching method is to go from analysis to construction. The teaching content is to present a set of reasonable "translation" rules that can directly obtain the results of climate analysis and the first morphological operation. For example, one can study the heat radiation from the sun to determine the shape factor and limit the plan depth, or set the scale of courtyards; according to the environment of wind, one can choose the direction for placing buildings, design sections of ventilation cavities, or optimise the location of openings. The purpose is to foster a sense of social responsibility in the students and have them design buildings for their own communities.

2.2 The Integration Logic of Technical Strategies Guided by Performance-Based Design

2.2.1 Hierarchy and Synergy of Technical Strategies under the Passive First Principle

First, the teacher will introduce the general direction of passive technical strategies. Organize all the different stages and combinations of basic strategies for climate adaptation systematically, such as natural ventilation, use of daylight, building envelope insulation and thermal mass, etc. In the above analysis, we will also consider the combined effect of the above strategies, such as how to use a high-transmittance envelope together with controllable external shading, or how to have thermal-mass materials work well with night ventilation to achieve dynamic thermal comfort. At the same time, there are also teaching conflicts; for instance, although a large opening can be used to increase daylighting, it may also result in summer heat gain and glare, so students are motivated to build systems of thought and organise technical measures systematically.

2.2.2 Performance Coupling and Trade-off Analysis in Building System Integration

Teaching content is the performance coupling interface of all building subsystems, and it includes the envelope, spatial layout and basic concepts of equipment systems. As shown in the example above, many functions can be achieved for a double-skin facade or an atrium space, such as thermal insulation, a light well, a ventilation way, etc. At the same time, the teacher can have the students present their critical performance trade-off analyses and then lead a discussion on how the accompanying thermal load changes under optimal daylighting conditions or what constraints on natural ventilation are possible if the insulation performance of the building envelope is improved. The above instruction aims to help students learn about and organise all the links in the technical system[2].

2.2.3 Parametric Expression of Technical Strategies and the Awareness of Performance Optimization

Based on the iterative nature of the Design Process, this lesson will introduce the idea of parametric expression in technical strategies. Based on the technical selection and main attributes of the window, shading depth and wall construction can be set as some Design Parameters. Students should be able to know when a variable is likely to affect the overall performance, understand that this influence is not constant, and thus adjust all the variables to improve the result in particular situations (e.g., both total energy consumption and daylight uniformity).

2.3 Construction of the Transformation Mechanism from Physical Principles to Design Decisions

2.3.1 The Refinement and Formal Expression of Design Rules

One of the purposes of teaching is to help students acquire some basic design rules or heuristic ideas based on the fundamental concepts of thermal engineering, optics and acoustics that can be applied directly to spatial and morphological operations. Teaching can turn the idea of steady-state heat transfer into a rule for the spatial continuity of interfaces and control over thermal bridges; it can change the geometry of sunlight into a proportional rule for regulating building distance and eave overhang size; and it can convert the principle of reverberation time into an initial relative formula for spatial volume and the arrangement of interface materials. The above rules can be used to make some decisions in the early stages of Design for formal languages.

2.3.2 Cross-Scale Knowledge Integration and Embedding in the Design Process

We need to use and present physical knowledge in all the design of cities, buildings and other facilities. Teaching should show how knowledge of the urban-scale wind and thermal environment is applied in the planning of building clusters, how building-scale heat gain and loss analysis is used in the design of envelope construction details, and how component-scale optical properties of materials relate to the quality of indoor light. Systematically including the main points of physical knowledge at all levels in a forward-looking manner in the standard Design Process can help students clarify the core physical problems to be solved and how they will be applied at each stage of the design through teaching.

2.3.3 Dynamic Feedback and Decision Optimisation in the Iterative Cycle

The third kind of conversion mode is a dynamic feedback loop that consists of prediction, simulation, evaluation and correction. Design exercises can be used to create a virtual design experiment environment in the teaching unit, and students will learn about this environment by doing. Students can create a plan according to the first set of rules, use analysis tools to collect performance data, interpret the design semantics of the data, and make specific modifications to the form and space, etc. After several rounds, the students have learned the laws of physics and have also experienced firsthand how small changes in design affect performance; thus, they have begun to use physical intuition to continuously improve all parts of the design.

3. Teaching Process and Evaluation System for Design Capability Generation

3.1 The Design Process Teaching Method of Simulation and Iteration Cycle

3.1.1 Forward Placement of Performance Goals and the Driving Intervention in Preliminary Morphogenesis

First, establish the framework for the performance goal of the design task in class and have students turn the abstract green concept into concrete, measurable, phased performance indicators. Therefore, based on the above, students should use a simple climate analysis tool and morphological generation rules for conceptual design, set early constraints and driving forces on basic morphological parameters such as massing, layout and orientation, in line with the performance goals. At this time, the logic is that of "analysis as generation". For example, in teaching, one can directly use the analysis of the solar path as a geometric construction for self-shading shapes; one can interpret the site wind rose diagram as the spatial topology of planar ventilation paths, and thus, the environmental response can be taken as the starting point for morphogenesis rather than a correction after the fact.

3.1.2 Detailed Design and Dynamic Adjustment of Multi-parameter Interaction

At various times, good simulation tools will be released to create a Design-Experiment Area with many interactive functions. Set a set of related Design Variables for the students, such as the window-to-wall ratio, depth of shading devices and thermal performance of the building envelope, and observe the joint effect on all the performance indicators: daylighting, heat gain and energy consumption. The goal of teaching is to help students find out why there is a drop in performance, learn how to deal with it, and be aware that, for example, increasing the window area to get more natural light may also increase the cooling load. Based on the results of the simulation, some modifications have been made to help the students learn how to make design decisions in the face of change.

3.1.3 Integrated Simulation and Collaborative Optimisation of Overall Performance

In the advanced stage of teaching, the teacher will have students use the integrated environmental performance simulation platform to carry out coupled simulation evaluations of all kinds of physical factors in their design schemes, such as energy consumption, sunlight, natural light and ventilation. Interpret all the performance reports, find any conflicts and problems among the departments, and then make general collaborative adjustments based on these findings. For example, in teaching, one can change the Design of the Atrium to improve both natural ventilation and daylighting, or modify the construction of the envelope to meet all the requirements for insulation, thermal resistance and light transmission. The goal of the above is to help students develop high-level Design Thinking skills for managing complex systems and achieve good overall results.

3.2 Cultivation of Overall Ability: Combination of Quantitative Analysis and Qualitative Judgment

3.2.1 Ability to obtain and understand numerical data correctly

The first goal of this lesson is to teach students how to use special instruments to obtain accurate information about their surroundings and help them learn what this information can tell us about nature and technology. More importantly, the teaching goals are to foster students' ability to think critically in the face of quantitative data, have them identify the assumptions and uncertainties in the results of simulations, judge the reliability of the data, and avoid blindly accepting the quantitative results. For example, students should be able to distinguish between the effect of computational grid density on the simulation results of wind speed and learn that the standard annual meteorological data are not in line with actual climate fluctuations[3].

3.2.2 Design Semantic Translation and Multi-criteria Value Trade-off

The first aim of teaching is to enable students to make good judgments about the world based on Design Semantics. Based on the simulation results, there is a hot spot; therefore, considering the spatial function, behaviour of users and the theory of thermal comfort, one should decide whether to add shade, fans or move the furniture. Present typical conflict situations, such as how to maximise natural light and reduce heat gain from the sun in summer, or the trade-off between improving the efficiency of ventilation and ensuring acoustic privacy in a room, and then have students learn how to weigh all these values and find personal solutions according to their own circumstances and needs through the teaching guide.

3.2.3 Holistic Decision-Making Ability in Light of the Concept of "Appropriate Performance"

To cultivate people's all-round decision-making ability based on technical rationality, we should also consider humanism, economy and user experience. The teacher will lead the students to form the concept of "appropriate performance" and learn that green buildings do not need to achieve the highest level in all aspects but should be reasonably balanced under the given conditions. Students should be able to consider all-round technical solutions, construction costs, spatial quality, operation and maintenance, as well as the needs of users; they need to make well-rounded design judgments that are both scientifically sound and practically feasible, take the lead in the design decision-making process, and not be mere technical analysts.

3.3 A Dynamic Teaching Evaluation Mechanism Based on Gradients of Capability Development

3.3.1 The Deconstruction of Capability Dimensions and the Modeling of Development Ladders

The foundation of the construction of the evaluation system is the operational deconstruction of the "green building design capability", and a clear matrix of capability dimensions has been established to cover environmental analysis, tool application, strategy generation, iterative optimisation, all-encompassing decision-making, etc. Models of the progressive development of ability from "awareness" and "understanding" to "application" have been developed in all fields, and behaviour indicators will continue to be observed. The two models can provide all kinds of objective data for teaching and learning to help us better keep up with the progress of the students.

3.3.2 Process-Oriented Evidence Collection and Embedded Formative Evaluation

Collect all kinds of data at different times during the course of teaching and adjust your teaching accordingly. Related evidence includes process-based outputs such as sketches, models, simulation analysis reports, design decision logs, group discussion records, etc., from all stages of development. Regularly check the work and give specific feedback on what needs to be improved; at the same time, pay attention to identifying students' weaknesses in logical reasoning and planning and encourage them to take the initiative to study and correct themselves. The kind of assessment is in line with the characteristics of Design Ability at that time.

3.3.3 Summative and Developmental Evaluation in Line with the Trajectories of Capability Evolution

The final general evaluation will be based on both the fixed performance of the design results and, more importantly, on the process data collected during the review and assessment of the student's development path in terms of ability at all times during learning. The evaluation report will show the extent of development in all areas of the student's abilities, analyze any changes in their way of thinking, and point out any problems that still need to be corrected. The goal of this assessment is to make improvements; that is, we will know which students have strengths and weaknesses and provide personalised plans for improvement to further promote their learning and achieve the reform objective of the entire teaching system.

Conclusion

Establish a practice-oriented teaching reform framework for building physics knowledge in light of green building design based on this paper. Change the way of teaching from knowledge transmission to ability education, organise the system of course content so that it can be integrated rather than presented in separate units of knowledge, and establish a closed-loop teaching cycle based on simulation and iteration that includes both quantitative and qualitative assessments. Now the support dynamic evaluation mechanism covers the whole period of ability development and not just the final results.

According to the reform practice, it has been shown that this way can help students develop causal thinking among performance goals, design variables and physical effects, so the environmental response in the later stage of design is not only a verification but also a driving force for morphogenesis and scheme optimisation. Looking ahead, the direction of strengthening teaching should be to enhance the integration of various interdisciplinary knowledge, explore the application prospects of artificial intelligence-assisted performance prediction and generative design in teaching, continually improve learning analytics based on big data, build more precise and personalised capability development and evaluation models, and thus promote the construction of adaptable, intelligent and creative building physics education systems.

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