Construction and Application of the Teaching Mode for the Building Structure Course Based on BIM Technology

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Abstract: *Traditional two-dimensional graphs and discrete mechanical analysis models in the building structure course have resulted in the loss of information about the spatial topological relationship of complex systems and the collaborative logic among different disciplines. BIM technology is a type of parametric three-dimensional digital model that can integrate all the information related to the carrier of information and enhance the interactivity of structural teaching. Given the deficiencies of the current teaching mode, this paper studies how to integrate the basic ideas of BIM into the main content of structural engineering courses. Then, an educational model for constructing the structure course based on BIM technology will be developed according to the three dimensions of hierarchical resetting of teaching goals, modular organisation of teaching content and integrated design of visualised evaluation. A regular schedule will be set up to divide the periods, organise the resources and make adjustments as needed. Therefore, the goal is to change the way of teaching from passive reception to active participation in learning, improvement and cooperation.*

Keywords: *BIM Technology, Building Structure Course, Teaching Mode, Parametric Modeling, Collaborative Analysis, Modular Teaching*

Introduction

As one of the fundamental parts of civil engineering, the teaching quality of the building structure course directly affects students' general knowledge system in the behaviour and construction logic of structures. Due to the expression limitations of two-dimensional static media, the traditional teaching model cannot show the whole process of abstract formula derivation and spatial force visualisation, and it is also not easy to present dynamic interference and the demand for data integration in multidisciplinary cooperation. With the change in the standard for spreading engineering information from discrete files to continuous data flow in the process of digital construction, the current course system is showing an increasing lag in meeting the needs of the industry at both the teaching and supply stages. Parametric Driving Mechanisms and the Multi-disciplinary Integrated Verification Logic of BIM technology can help solve the problems of cognitive overload and information silos in structural engineering teaching. Explore the reconstruction path and implementation framework of the teaching mode for the building structure course under the intervention of BIM technology; it has the necessary theoretical value and pedagogical innovation significance to promote synchronous resonance between the course content sequence and the logic of contemporary engineering information flow.

1. Review of the Teaching Reality for the Building Structure Course and the Logic of BIM Technology Application

1.1 Diagnosis of the Limitations in the Existing Teaching Model for the Building Structure Course

The teaching mode for the building structure course has long been based on 2D engineering drawing expression and mechanical analysis. The main carriers of the information are the plan drawings, formula derivations and component checks. Therefore, the cognitive load of explaining the spatial topological relationship and load-transfer mode of a complex structural system will be too high. It is difficult for students to build an unbroken system of knowledge on the structural mechanical behaviour of all kinds of beam-column reinforcement details and abstract internal force envelope diagrams. Separating the division of manual model construction from the design of numerical analysis tools at the Design stage will prevent the construction of computational models based on design ideas. Therefore, the optimisation decision-making process for selecting structures and detailing joints has been reduced to checking the tables in the current specification clauses, and the teaching effect of promoting iterative thinking based on structural performance has been weakened.

Another problem with the current organisation of teaching materials is that there is no vertical integration and horizontal linkage among the knowledge modules. Concrete structures, steel structures, seismic design and other sub-courses all have their own independent example systems and construction standards. When students are given the task of designing the general structure in a multidisciplinary collaborative environment, they often face the problem of information silos; that is, the reconstruction of model data and version control are done redundantly. Static mode dissemination of knowledge in two-dimensional media is not suitable for showing the dynamic interference during the construction and assembly process of prefabricated components. Therefore, there is a gap between the teaching situation and the continuous demand for information at the front end of engineering construction, which limits the cognitive breadth and depth of learners' understanding of the industrialised construction process of modern buildings[1].

1.2 Analysis of the Adaptability between the Core Representations of BIM Technology and the Teaching Elements of the Building Structure Course

The first reason BIM technology is good is that the basic data are three-dimensional parametric models; therefore, it can meet the requirements of the building structure course for visualisation of spatial geometric invariance and stress deformation in teaching. Organize the cross-sectional geometric data, material constitutive properties and boundary conditions of the structural components in one place in BIM and label them. Any change in the cross-section will immediately update the corresponding plane drawing expression, and thus the related quantities will be recalculated. An object-oriented expression mechanism and a parametric kernel can be used to abstractly set the elastic modulus and load combination coefficients, create interactive digital twin entities, and thus a high-fidelity virtual test ground for intuitive understanding of structural mechanical response and pre-simulation of failure modes has been established.

With the help of BIM technology, it is now possible to coordinate all the components of a school more closely and find any problems early in an organised manner. Joint verification of the structural analysis model, the building space enclosure model and the electromechanical pipeline layout model has been carried out in the same coordinate system to determine whether there are any conflicts in structural openings and reinforcement measures that are not covered by the professional knowledge of the original work. Technologically speaking, in teaching, we can show that not only is the logical generation of structural components the result of mechanical calculation, but it is also a dynamic adjustment process based on the coordination of spatial occupancy and feedback from process simulation. Therefore, the way of teaching construction details will change from passive reception and reproduction to active assimilation and organised judgement at the cognitive level.

1.3 Theoretical Basis of Curriculum Reconstruction in the Era of Digital Information Integration

In line with the idea of cognitive constructivism, BIM technology in teaching the structure course should not be regarded as another way of teaching; rather, it should be used to help students actively construct their own knowledge and enhance their sense of responsibility for learning. Reduce the distance between the abstract symbolic system and the representation of the physical world to build a mini engineering world for learners on the digital information integration platform that is easy to use and provides instant feedback. The first mechanical structure and construction rules of the system of structural concepts are no longer in the form of linear translations of linguistic symbols in this simulation. They are embodied spatial schema memories that can be learned through sight and are mutable. By using all the ways of perception for the assimilation of knowledge, one can reduce the mental effort needed to solve sectional force problems and build spatial truss models[2].

Based on the theory of information integration, the order of the course content can also be arranged in a non-linear manner. The main database of BIM textbooks is no longer organised in a linear manner by chapters; now, it can be displayed horizontally to obtain holographic data flow information on the geometry, materials, loads, construction details and construction processes of specific structural systems or typical joints. According to the penetration capacity of the above data, modular deconstruction and a project-oriented approach can be employed in the teaching content, and thus the closed-loop process of "structural selection - analysis and verification - joint design - drawing expression" can be realised in the same digital environment. The theoretical foundation of curriculum reconstruction is that it should be in line with the unavoidable trend of engineering information change from discrete file delivery to continuous data flow in current construction work, and ensure that there is synchronous correspondence between the teaching supply side and the industry demand side at the level of information exchange standards.

2. Systematic Construction of the Teaching Mode for the Building Structure Course Based on BIM Technology

2.1 Hierarchical Resetting of Teaching Objectives for Structural Cognition and Collaborative Analysis

The teaching goals of the traditional structure course are based on the three relatively closed stages of cross-section strength verification, serviceability limit state checks and selection of construction details, and they have a linear progressive logic from single-component mechanical analysis to overall structural design. According to the individual indices above, BIM technology has been used to construct a three-dimensional, progressive system of structural performance in the reconstruction of the teaching goal. First, it is necessary to build a reasonable parametric component information model and establish an object-oriented association cognition of cross-sectional mechanical properties. The first goal is to learn how to observe the general shape of the structure under all kinds of loads and choose the most suitable one. The high-level modules are collision detection, joint deepening coordination and continuous transmission control of change data, etc., and all of them make up an integrated system of many disciplines. Therefore, it has gone from checking the individual parts to joint decision-making by everyone[3].

The hierarchy of the resetting logic for teaching objectives is clear, and it is graded according to the demand for collaborative analysis ability. With the help of the BIM workflow, the teaching goals for the structure course are no longer limited to the accuracy of internal force calculation and the rationality of reinforcement in structural engineering. Learners should be aware of the clearance requirements for the building and know that after running equipment pipelines, the structural capacity of the shared-parameter area will be reduced. In light of the new goals, we need to add the function of interpreting collision reports, optimisation strategies for structural cross-sections based on clear-height analysis, and construction feasibility prediction via process simulation to the scope of the evaluation system for the teaching objective. Therefore, the form of the teaching results will change from that of a technical executor with only calculation skills to that of a system constructor proficient in the digital collaborative analysis paradigm.

2.2 Modular Reorganisation and Ordering of Teaching Content Based on BIM Data Integration

BIM data environments can be used as teaching materials, and the old system of mandatory chapters does not need to be followed. First, extract, decompose and organise the existing knowledge units according to the whole-life cycle data flow of the structural system. The four relatively independent but progressively advanced logical units of the teaching content modules are in line with the level of information development of the BIM model: the conceptual massing exploration module, the physical model analysis module, the detailed design data generation module, and the construction simulation and visualisation module. The Concept Massing Exploration Module can be used to quickly obtain the structure system and general geometry topology. The parameters of the Physical Model Analysis Module are as follows: Material Non-linearity, Load-path Demonstration and Verification of the overall index output. The Design Data Generation Module has some rules for the arrangement of rebar joints, library invocation of connection details, and plan drawing customisation. The Construction Simulation and Visualization Module shows the construction time of the temporary structure and the lifting path simulation of the prefabricated parts.

The sequence rule of the organised teaching content modules is based on the natural timing of BIM data flow and the progressive logic of structural design decisions, rather than dividing them according to the traditional categories of materials or force types. All the modules have a simple logic connection, and they can be controlled by changing a parameter in the central model. The geometric position information and cross-section definition data outputted by the previous module are directly used as the boundary input for the analysis and calculation in the next module, so there will be no global propagation of perception changes in the sequence of teaching content. At the same time, in the sequencing of teaching content, training elements for data management can also be added, such as model version comparison, dynamic clearance detection, quantity difference tracking, etc., so that learners can learn the structure of collaborative Design Thinking based on a single data source naturally and be aware of data asset management at each module[4].

2.3 Integrated Design of Visualization-Based Interactive Methods and a Multi-dimensional Evaluation Mechanism

The Goal of Visualisation-based Interactive Methods is to change how people learn by showing the results of BIM models in an animated way. The three parts of the interaction logic are Sectional View Observation, Parameter-Driven Deformation and Time-Dimension Unfolding. Observation Areas can be divided and selected freely, and they can be used to show the spatial arrangement of the rebar cage in components, the layout of stirrup densification at joint core areas, and the internal interface relationship of composite sections. Parameter-driven deformation takes general indices, such as the ratio of inter-story drift and the order of plastic hinge formation, to create animated physical responses of the structure under lateral load by colouring the mesh and overlaying displacement cloud maps based on the results of finite element analysis. Unfolding in the time dimension is the layer-by-layer construction simulation of the main structure, linked with construction schedule data, and at the same time, changes in the mechanical state during the erection of the support system and the closing time of post-casting strips are shown.

All-weather operation, interactivity and a good visual style will be added to improve the visibility of the three assessments: verification of the compliance of model data, generation and selection of quantitative indicator output for scheme comparison, and traceability analysis in the collaborative process. Model Data Compliance Check will be carried out to ensure that the component names are uniform, the cross-section library is used correctly, and there is logical consistency in the node degree-of-freedom constraints. Automatically calculate the statistics and extractions of converted concrete thickness, distribution of steel consumption, and ranges of component stress ratio from the BIM schedule, obtain a quantitative index for scheme comparison and selection, etc. Collaborative Process Traceability Analysis can determine how quickly a problem has been solved by recording which department reported the problem, how long it took to respond, and how it was corrected. All the design will be checked, and based on pictures, we can quickly get feedback and adjust the teaching on the spot for immediate correction instead of finding problems later.

3. Implementation Path and Application Framework of the BIM Teaching Mode for the Building Structure Course

3.1 Division of the Teaching Process and BIM Task-driven Organisational Procedures

With the increase in the amount of information in the BIM model, the three stages of the teaching process are now: the basic modelling cognition period, the structural analysis and optimisation period, and the collaborative deepening and integration period. The first kind of model cognition is to define families of parametric components, set up the spatial anchoring for the level and axis network system, assign semantic associations to material properties, etc., so that learners can build a digital mapping logic between the geometric information of components and non-geometric attributes. The Structure Analysis and Optimisation stage is to transfer the lossless geometry of the BIM model to the analysis software, obtain indicator data such as inter-story drift ratios and component stress ratios by calculating the mode-superposition response spectrum, and then iteratively adjust the cross-section dimensions based on the results of inversion. In recent years, collaboration and integration have been deepening, and now both hard collision and soft clearance collision detection are being carried out in an integrated way across all fields; based on the results of conflict resolution, hole positioning drawings and detailed rebar arrangement drawings for joints have been produced[5].

The Organisation Process of BIM in task-oriented teaching takes all the deliverables of a typical structural system as the longitudinal guide, converts the stage teaching objectives into a series of engineering sub-tasks, and specifies the input conditions and output standards for each node. Each sub-task has a list of corresponding deliverables that match the model depth at that time, and the main results are file merges of the component library, cyclic mode analysis reports, coordinated hole positioning plans, etc. StageTransitionNodes have added an automatic data compliance check rule set to find model overlap interference, missing material definitions and cross-section type invocation errors. Models that cannot be verified will not be used in the next stage and will therefore be excluded from the progressive control closed-loop system according to the data-quality gate.

3.2 Preset Architecture of the Digital Teaching Resource Cluster and Collaborative Work Platform

The cluster of digital teaching resources has a bottom-up layered structure, and the three layers are, in order, the basic component-level resource library, the typical case-level resource library, and the standard code-level resource library. The three kinds of parametric component family in the basic component-level resource library are concrete, steel and composite structures, and each family type has been pre-set with a common parameter set according to the rules for plane drawing expression. Generally speaking, the four types of systems in the case-level resource library are frame, shear wall, frame-core tube and large-span space grid; full data evolution snapshots from the scheme comparison model to the detailed design solid reinforcement model are collected, and the parameter change trajectories of the key design nodes in a version chain are saved. The standard code-level resource library has organised the normative data in a table of normative data, such as seismic design parameters, minimum reinforcement ratio limits and construction detail drawing indices, and has set up a real-time invocation channel to the BIM modelling environment via an interface.

The first Design of the collaborative work platform will be a cloud-based central database, and there will be hierarchical permission control. The three parts are the model storage server, the mini-browser engine and the annotation tracking system. The Model Storage Server divides the independent workspace area according to teaching groups and reduces bandwidth by sending only the necessary part when many people are using it at the same time. A small browser can show the entire model and the section view on a mobile phone. The annotation tracking system will record all the stages of the issue report, responsibility assignment and status closure, and save them in the model metadata. Only one data exchange interface will be provided that meets the requirements of the main analysis software, and the semantic consistency of the geometric topological information and load-case combination information will be guaranteed in the round trip.

3.3 Evolution Trend of Teaching Interaction Behaviors and Planning of Adaptive Guidance Strategies

There has been a change in the pattern of interaction behaviour in the BIM teaching environment; that is to say, it has moved from model-creation-oriented operational interaction to data-analysis and collaborative decision-making-oriented analytical interaction. At the beginning of the teaching process, most of the interaction is in the form of modelling operations to select components, arrange them in space, set parameters, etc. Gradually, they will start to debug the boundary conditions, observe how the analysis results change, and also monitor the parameter sensitivity of all schemes. The problem of cooperation at present is also very serious. Learners need to find the origin of the conflict among the many levels of superimposed views, determine how far the consequences will spread for adjustment plans, and complete the closed-loop transmission of coordination instructions via the platform annotation system. At this time, the form of interaction has been changed to all-round training in the control logic of engineering information flow.

The adaptive guidance strategy will change according to the changes in the identified pattern of behaviour among young children during play. At the beginning of construction, there will be many demonstrations and playback sessions of the operation process to reduce the initial cognitive load of 3D parametric modelling. At the stage of structural analysis, the main direction of guidance is to present problems for diagnosis caused by computational divergence or indicator exceedance, but the students' sense of exploration has not been eliminated yet. In the stage of collaborative integration, the direction of guidance will be process control at the metacognitive level, and the first frameworks for hierarchical conflict resolution and training in identifying the propagation delays of information changes will be established. The first is that the upper bound of the adaptation range has been altered. Based on how often there are all kinds of errors and how frequently students correct them in their homework, the system will adjust the details of prompts and the time for intervention to keep students in a good state for cognitive development.

Conclusion

Teaching Mode for the Building Structure Course Based on BIM Technology: Only the parametric 3D model is used as the source of teaching information flow to achieve a dimensional leap in the structural cognitive path from individual verification to systematic collaborative decision-making. The first way is to construct a hierarchical resetting of teaching objectives that is oriented towards structural cognition and collaborative analysis; then, use the BIM data integration mechanism to carry out modular deconstruction and progressive ordering of teaching content; finally, build a closed-loop system for cognitive construction and efficacy diagnosis by integrating the design of visualization-based interactive methods and a multi-dimensional evaluation mechanism. At the level of implementation, the division stage of the teaching process and the task-oriented organisation procedure are supportive factors for the new mode, and in addition, there is a preset architecture for the digital resource cluster and dynamic configuration of adaptive guidance strategies. The following two directions will be taken for future research: First, quantify the matching gradient of the matching gradient between the information depth of the BIM model and the learner's cognitive development curve. Second, improve the integration of artificial intelligence-assisted model compliance verification and an adaptive feedback mechanism to achieve high-precision personalisation of learning-path navigation and intervention in the field of structural teaching.

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