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Constructing a Cultivation Model for Interdisciplinary Collaboration Competence of BIM Professionals within the Emerging Engineering Education

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Abstract: To address the demand for interdisciplinary BIM professionals under the Emerging Engineering Education (EEE) initiative and mitigate the prevalent deficiency in interdisciplinary collaboration competence (ICC) within current university BIM training programs, this study, using Nanyang Normal University as a case study, constructs an ICC cultivation model for BIM professionals within the EEE framework. Employing methodologies including literature review, questionnaire surveys, and practical case analysis, the research demonstrates that this model effectively enhances students' interdisciplinary knowledge integration, teamwork, and engineering practice capabilities through optimizing the curriculum system, strengthening interdisciplinary practice, and introducing industry-academia collaboration mechanisms. Empirical data reveal that students in the pilot cohort significantly outperformed their peers trained under traditional models in BIM project collaboration, with corporate feedback satisfaction increasing by approximately 25%. This research provides a replicable reform pathway for cultivating BIM talent at regional universities and offers practical evidence for deepening engineering education reform within the EEE context.

1. Introduction

The field of engineering education is undergoing profound transformations driven by the accelerating pace of a new technological revolution and industrial transformation. Emerging Engineering Education (EEE), a pivotal strategic initiative in China's higher education reform, imposes heightened demands on engineering talent development, emphasizing disciplinary convergence, innovation cultivation, and practical capability enhancement [1]. Building Information Modeling (BIM) technology not only revolutionizes traditional construction methodologies but also imposes entirely new requirements on the knowledge structures and competencies of relevant practitioners [2].

Currently, the construction industry exhibits an urgent demand for BIM professionals proficient in interdisciplinary collaboration. Research indicates that modern engineering projects frequently involve multiple specialized domains such as architecture, structure, and MEP (Mechanical, Electrical, and Plumbing), necessitating practitioners to possess not only domain-specific expertise but also the ability to collaborate effectively across disciplines [3]. Talent cultivated under traditional engineering education models often remains confined within singular disciplinary boundaries, struggling to meet the industry's demand for interdisciplinary professionals [4]. This supply-demand mismatch is particularly pronounced in regional universities, necessitating the exploration of novel BIM talent cultivation models aligned with EEE requirements.

This study aims to construct an ICC cultivation model for BIM professionals within the EEE framework. By systematically integrating multidisciplinary knowledge, innovating pedagogical approaches, and establishing practical platforms, it seeks to provide theoretical guidance and practical references for cultivating interdisciplinary talent that meets industry needs. The model's construction focuses not only on imparting specialized knowledge but also on cultivating students' teamwork awareness, communication and coordination skills, and interdisciplinary thinking [5], enabling them to function effectively within complex engineering environments.

From an educational practice perspective, this research holds significant implications for advancing engineering education reform in regional universities. Firstly, it contributes to optimizing the BIM talent cultivation system and enhancing training quality. Secondly, the findings offer transferable experiences for peer institutions, fostering the overall improvement of engineering education standards [6]. From an industry development standpoint, cultivating BIM professionals with ICC will effectively alleviate structural talent shortages and provide crucial human resource support for the digital transformation of the construction industry [7]. Furthermore, this research offers new insights and pathways for deepening industry-education integration and university-enterprise collaboration [8].

2. Overview of EEE and BIM Talent Cultivation

2.1. The Connotation and Development of EEE

As a strategic response to the new technological revolution and industrial transformation, EEE's essence lies in the innovative restructuring of traditional engineering education. Its core characteristics encompass three fundamental elements: interdisciplinary convergence, technology-driven innovation, and industry-need orientation [1]. Compared to traditional engineering education, EEE places greater emphasis on cultivating students' innovative thinking, transboundary integration capabilities, and engineering practice skills. This shift stems from the practical need for multidisciplinary collaboration to address increasingly complex systemic challenges in contemporary engineering [3].

Analyzing its developmental trajectory, EEE construction exhibits three key trends: Firstly, disciplinary boundaries are increasingly blurred, with deepening convergence between civil engineering and emerging fields like information technology and artificial intelligence [9]. Secondly, talent cultivation models increasingly prioritize practical innovation, with novel pedagogical approaches such as project-based learning (PBL) and industry-academia collaborative education gaining widespread adoption [8]. Thirdly, the educational evaluation system increasingly emphasizes competency orientation, where students' comprehensive qualities and ability to solve complex engineering problems become key metrics for assessing training quality [6].

EEE exerts a profound influence on engineering education reform. Philosophically, it drives a transition from single-discipline training towards cultivating interdisciplinary professionals. Methodologically, it promotes a shift from traditional lecture-based teaching towards project-based collaborative learning. Content-wise, it necessitates a restructuring of the curriculum system from a discipline-centric to a problem-oriented approach [10]. This evolution demands that engineering education dismantle disciplinary silos and establish more open and flexible cultivation systems.

Research demonstrates that modern engineering professionals require four core competencies: technological innovation capability, interdisciplinary integration capability, teamwork competence, and international competitiveness [3]. Among these, interdisciplinary collaboration competence (ICC) is particularly critical, as over 75% of complex engineering projects necessitate collaborative efforts from multidisciplinary teams [11]. This competence encompasses not only the cross-application of specialized knowledge but also emphasizes soft skills such as communication, coordination, resource integration, and team leadership [5].

ICC holds an irreplaceable position in EEE talent cultivation. It is an essential skill for solving complex engineering problems, as modern projects often require collaboration across architecture, structure, MEP, and other specialized domains [7]. It is a crucial element for achieving technological innovation, where diverse disciplinary perspectives foster creative solutions [4]. It is a foundational capability for adapting to industrial transformation, as the construction industry's digital transformation demands practitioners capable of collaborating effectively with IT professionals [2]. Consequently, within the EEE talent cultivation process, ICC must be prioritized as a core objective [12].

2.2. Application of BIM Technology in Engineering

BIM (Building Information Modeling) technology, as an integrated digital tool, operates on the core principle of consolidating geometric and non-geometric information throughout a building's lifecycle via a 3D model, enabling collaborative sharing and dynamic updating of multi-disciplinary data [7]. Based on parametric modeling, intelligent associations between components ensure global linkage of design changes, while reliance on the IFC (Industry Foundation Classes) standard facilitates cross-platform data exchange, establishing a unified information collaboration environment for all project stakeholders [2]. Compared to traditional CAD, BIM offers superior visualization, stronger information integration, and enhanced collaboration efficiency. Its data-driven nature enables precise transmission of design intent to construction and operation phases, effectively resolving information silo issues in construction [1].

During the design phase, BIM's clash detection function automatically identifies spatial interferences between models from different disciplines. Relevant studies indicate that BIM application can reduce design errors by approximately 40%, enhancing design quality [13]. Its parametric design capability supports rapid generation of multiple design alternatives for comparison. Integrated with energy consumption analysis and structural calculation plugins, it facilitates performance-driven optimized design. In construction management, integrating BIM with schedule management (4D) and cost management (5D) enables automatic generation of construction simulation animations and resource consumption curves, improving schedule plan rationality by over 30%. Real-time synchronization between mobile terminals and cloud-based models can control deviation rates between on-site construction and the design model within 2%, significantly reducing rework risks [9].

BIM's long-term value manifests in the operation and maintenance phase. Facility management systems interfacing with the as-built model enable visual querying of equipment information, improving maintenance response times by 50% [8]. Predictive maintenance algorithms trained on historical operational data can reduce equipment failure rates by 15%-20%, extending the building's service life [5]. Notably, BIM also demonstrates strong adaptability in infrastructure domains like transportation and utilities. The integration of linear modeling with Geographic Information Systems (GIS) provides novel solutions for engineering design under complex terrain conditions [12].

BIM's collaborative value is particularly evident in large-scale complex projects. Establishing a Common Data Environment (CDE) enables parallel design and real-time coordination of models from architecture, structure, MEP, and other disciplines. Practice shows that projects using BIM collaboration platforms can improve communication efficiency by 60% and reduce design cycles by 25% [11]. This integrated workflow not only overcomes the limitations of traditional sequential processes but also, through functionalities like clash detection and automatic quantity take-off, confines engineering change costs to within 3% of total project value, far below the industry average of 8%-10% [4]. With the integration of technologies like the Internet of Things (IoT) and artificial intelligence (AI), BIM is evolving towards digital twin applications, continuously expanding its value creation dimensions in engineering [6].

2.3. Analysis of BIM Talent Requirements within the EEE Paradigm

Within the EEE framework, BIM technology, as the core driver of the construction industry's digital transformation, imposes novel demands on talent competency structures. From a market demand perspective, BIM professionals require not only specialized technical knowledge but also ICC. This interdisciplinary competency has become a critical indicator in industry talent evaluation. Research indicates that work scenarios involving collaboration between architecture, structure, MEP, and other disciplines constitute over 70% of modern engineering projects, thereby increasing the weight of ICC within the BIM talent competency structure [11].

Analyzing the competency composition, BIM professionals' ICC manifests primarily across three dimensions: technical multi-disciplinary model integration capability, managerial project coordination capability, and communicative teamwork competence. Technical integration capability demands the ability to understand and coordinate BIM models from diverse disciplines (architecture, structure, MEP, etc.), ensuring accurate transmission and seamless integration of design information. Project management capability is reflected in the planning and control of multi-disciplinary workflows and schedules. Teamwork competence emphasizes effective communication and conflict resolution skills within interdisciplinary teams. The organic integration of these three facets constitutes the comprehensive framework of ICC for BIM professionals.

Considering industry trends, the importance of ICC will become increasingly prominent as BIM penetrates the entire engineering lifecycle. In emerging fields like smart construction and digital twins, the characteristic of multi-disciplinary convergence renders single-disciplinary expertise insufficient. Relevant survey data shows that the proportion of BIM-related job postings in the construction industry explicitly requiring ICC has risen from 35% in 2018 to 62% in 2022. This trend underscores the centrality of ICC in BIM talent cultivation.

Examining the educational supply side, current BIM training often suffers from disciplinary silos and insufficient collaborative training. The traditional single-discipline cultivation model struggles to meet the demand for interdisciplinary BIM professionals under EEE. Therefore, constructing an

ICC-centric BIM talent cultivation model is not only a proactive response to industry needs but also a crucial breakthrough point for advancing engineering education reform. By dismantling disciplinary boundaries and innovating cultivation approaches, it can effectively enhance the comprehensive quality of BIM professionals, providing robust human resource support for the construction industry's digital transformation [9].

3. Current State of BIM Talent Cultivation at Nanyang Normal University

3.1. Existing Curriculum Structure

The current BIM-related curriculum within the School of Civil Engineering and Architecture at Nanyang Normal University primarily comprises three components: core professional courses, professional elective courses, and foundational theoretical courses. Core courses, such as Fundamentals of BIM Technology and Building Information Modeling Applications, focus on developing students' operational skills in mainstream software like Revit and Navisworks. Professional electives, like BIM Construction Organization Design and BIM Cost Management, emphasize specialized applications in particular domains. Foundational theoretical courses cover traditional civil engineering subjects such as Architectural Drafting and Building Architecture. While this "foundation + core + specialization" three-tiered structure offers systematic delivery of subject-specific knowledge, it exhibits significant shortcomings in interdisciplinary knowledge integration.

Regarding course articulation, the current system demonstrates a characteristic of "excessive vertical depth and insufficient horizontal integration." While progression exists between individual BIM courses, there is a severe lack of courses fostering cross-disciplinary interaction with associated fields. For instance, in related disciplines like MEP installation or engineering cost management, BIM technology is only sporadically mentioned as an auxiliary tool, lacking systematic cross-disciplinary course design. This fragmented curriculum impedes students' ability to develop a comprehensive understanding of BIM collaborative workflows, creating a gap with the industry's demand for "whole-lifecycle BIM application" competence.

The cross-disciplinary coverage of course content also requires enhancement. Current courses predominantly concentrate on 3D modeling of single buildings, with limited coverage of BIM application stages like construction simulation, cost control, and facility management. There is a lack of specialized courses integrating BIM technology with emerging areas such as project management or green building. Research indicates that modern projects require BIM engineers to collaborate with teams from at least 5 different disciplines [13], a demand that the existing curriculum clearly struggles to meet.

The limited interdisciplinary synergy within practical components constitutes another flaw. Although the school has established a BIM training center, practical projects are often confined to single disciplines, lacking simulations of real-world multi-disciplinary collaborative scenarios. This "siloed" practical approach prevents students from experiencing the core value of BIM technology in interdisciplinary coordination. Compared to the talent standards of leading industry firms, graduates from this model exhibit a competency gap exceeding 30% in cross-disciplinary communication and coordination skills.

The course evaluation system also fails to reflect an ICC orientation. Current assessment methods rely primarily on individual assignments and theoretical examinations, lacking systematic evaluation of team collaboration outcomes. This evaluation mechanism inadvertently reinforces an "individualistic" learning mode, contradicting the collaborative ethos central to BIM technology. Research shows that students assessed through interdisciplinary project-based evaluations can achieve twice the improvement in teamwork skills compared to those under traditional assessment models [14].

3.2. Teaching Methods and Practical Components

The selection of teaching methods significantly impacts the quality of BIM talent cultivation. The prevalent approach typically combines theoretical lectures with practical software operation. Theoretical lectures focus on BIM software principles, operational procedures, and industry standards, while practical sessions emphasize hands-on application skills. Although this dual approach ensures foundational skill acquisition, it remains inadequate for fostering systemic thinking and ICC. Within the theoretical component, the perspective is often limited to a single discipline, failing to fully demonstrate BIM's core value in multi-disciplinary collaboration.

The implementation of practical teaching directly relates to cultivating students' practical abilities. Regarding laboratory infrastructure, most institutions have established dedicated BIM labs equipped with mainstream software platforms, providing a basic practice environment. However, these labs often serve only single-discipline teaching needs, lacking mechanisms for cross-disciplinary sharing. Concerning industry-academia collaboration, while practice bases have been established and a number of practical projects undertaken, these projects are frequently centered on single-discipline tasks, failing to adequately simulate the multi-disciplinary collaborative scenarios of real projects. This limitation hinders students' ability to effectively apply cross-disciplinary knowledge in authentic work environments.

Several critical issues impede the practical component's effectiveness in cultivating ICC. The primary issue is the lack of interdisciplinary synergy in project design. Most practical tasks require students only to complete BIM modeling within their own discipline, neglecting coordination with other specialties. Secondly, instructors guiding these practices often possess a singular disciplinary background, proficient only in their own domain, limiting their ability to effectively mentor interdisciplinary collaboration. Thirdly, the practical evaluation system is flawed. Current assessment criteria primarily focus on the quality of an individual student's modeling output, overlooking the evaluation of key competencies developed during teamwork, such as communication, coordination, and knowledge integration [14]. Collectively, these issues constrain the development of students' ICC.

From a resource allocation perspective, the distribution of practical teaching resources is hindered by disciplinary barriers. Disciplines often independently establish BIM labs, purchasing duplicate hardware and software, resulting in resource wastage and hindering the construction of cross-disciplinary practice platforms. Regarding practical project development, the absence of effective cross-departmental collaboration mechanisms makes it difficult to create projects that integrate the knowledge and skill requirements of multiple disciplines [12]. This fragmented resource allocation prevents students from gaining a systematic cross-disciplinary practical experience, consequently impacting their collaborative skill development.

Addressing these issues requires multi-dimensional improvements. Pedagogically, Project-Based Learning (PBL) should be introduced, utilizing authentic interdisciplinary engineering projects to foster comprehensive abilities through teamwork. In platform development, disciplinary barriers must be dismantled to create shared BIM practice centers providing essential hardware support for cross-disciplinary activities. Concurrently, interdisciplinary teaching teams need to be established to co-guide student projects, ensuring multi-perspective mentorship. Furthermore, the practical evaluation system must be enhanced by incorporating ICC metrics, guiding students to value teamwork skill development [10]. Implementing these improvements will significantly enhance the role of practical components in cultivating students' ICC.

3.3. Current Status of Students' Interdisciplinary Collaboration Competence

When assessing students' current ICC levels, questionnaire surveys and project artifact analysis are two effective research methods. Well-designed surveys systematically gather data on students' performance in teamwork, communication, and knowledge fusion. Survey content typically encompasses students' awareness of interdisciplinary collaboration, frequency of participation in collaborative projects, and typical obstacles encountered during collaboration. Project analysis evaluates students' completed interdisciplinary work, objectively assessing their practical ability to integrate and apply knowledge from different fields. These complementary methods provide a comprehensive picture of students' actual ICC levels.

Regarding teamwork, students often exhibit unclear role definitions and weak accountability during collaboration. Some students prefer working independently, lacking the initiative to communicate and coordinate with peers from other disciplines. This tendency constrains overall team effectiveness. Communication issues primarily manifest as inconsistent use of professional terminology and unclear cross-disciplinary expression. Due to differing knowledge structures among students from various backgrounds, information distortion frequently occurs during project discussions.

Deficiencies in knowledge integration ability are particularly pronounced. Many students struggle to organically synthesize knowledge from different fields when tackling complex interdisciplinary problems. They often resort to mechanically assembling technical points from various disciplines, lacking systemic thinking and holistic optimization awareness. This situation reflects limitations in the current curriculum's capacity to cultivate knowledge transfer skills. Survey data indicates that approximately 65% of students report insufficient knowledge when participating in interdisciplinary projects, hindering their ability to grasp technical points from other specialties.

The causes of these problems are multifaceted. Pedagogically, traditional siloed teaching results in narrow knowledge structures and a lack of cross-disciplinary perspective. The absence of authentic interdisciplinary collaborative projects in practical components deprives students of essential collaborative experience. Evaluation systems that overemphasize individual achievement while neglecting team contribution further dampen students' motivation to collaborate. These factors collectively impede the development of students' ICC.

Based on the identified issues, the subsequent cultivation model construction should prioritize strengthening several areas: First, establishing interdisciplinary knowledge-sharing platforms to broaden students' multi-disciplinary perspectives. Second, designing authentic collaborative practice projects, enabling students to enhance communication and coordination skills through solving complex engineering problems [14]. Third, refining the evaluation mechanism by incorporating teamwork performance into the assessment system, guiding students to value collaborative skill development [10]. Only through systematic reforms can students' ICC be effectively enhanced.

4. Constructing the ICC Cultivation Model for BIM Professionals within the EEE Paradigm

4.1. Cultivation Objectives and Principles

Within the EEE framework, setting the objectives for cultivating BIM professionals' ICC must be grounded in the context of engineering education reform while addressing industry needs. The core objective is to cultivate interdisciplinary technical professionals proficient in multi-disciplinary knowledge integration and effective teamwork. Such professionals require not only specialized BIM operational skills but also comprehensive capabilities for effective communication, coordination, and decision-making within interdisciplinary teams. From the perspective of educational taxonomy, this objective encompasses cognitive domain requirements (technical mastery), affective domain cultivation (collaborative attitudes), and psychomotor domain development (practical application), forming a three-dimensional competency framework.

The formulation of cultivation principles should adhere to dual guidance from educational principles and industry demands. The Interdisciplinary Integration Principle necessitates breaking down traditional disciplinary barriers, achieving organic integration of knowledge from civil engineering, architecture, MEP, and other fields through modular curriculum design. This integration transcends mere knowledge accumulation; it constructs logical connections and synergistic mechanisms between disciplines based on the functional characteristics of the BIM platform. The Practice-Orientation Principle emphasizes the deep integration of theoretical instruction and practical training. Utilizing project-driven pedagogy, students experience the complete interdisciplinary collaboration workflow within authentic engineering contexts. Research indicates that collaborative practice based on BIM platforms enhances students' team collaboration self-efficacy, which correlates positively with future professional performance [13].

The Scientific Principle requires that model construction be based on empirical evidence from educational measurement and evaluation. By establishing quantifiable competency indicators and employing a combination of formative and summative assessments, dynamic monitoring and continuous improvement of the cultivation process can be achieved. The Rationality Principle is reflected in the alignment of the cultivation plan with the university's positioning and industry talent needs. Balancing theoretical depth and practical breadth is essential, tailored to the characteristics of applied talent cultivation. These two principles ensure the model conforms to fundamental higher education norms while meeting the specific requirements of EEE construction.

Guided by these objectives and principles, the cultivation model should establish a three-tiered structure encompassing knowledge modules, competency dimensions, and quality requirements. Knowledge modules focus on systematically mastering core BIM knowledge and relevant foundational theories from associated disciplines. Competency dimensions prioritize developing students' problem-solving and innovative thinking abilities within multi-disciplinary collaborative environments. Quality requirements emphasize the cultivation of non-technical elements like professional ethics and team spirit. This hierarchical design ensures comprehensiveness while highlighting the centrality of ICC, providing a clear logical framework for subsequent concrete cultivation measures. Crucially, the implementation effectiveness of this model significantly depends on the degree of interdisciplinary coordination in teaching organization, necessitating the establishment of corresponding interdisciplinary teaching teams and collaborative management mechanisms.

4.2. Model Architecture Design

The architecture design of the ICC cultivation model requires a systems thinking approach, constructing a multi-dimensional, hierarchical, modular structure. The model comprises four core elements: Curriculum System Module, Pedagogical Approach Module, Practice Platform Module, and Evaluation System Module. These modules are interconnected through information flows, competency pathways, and value networks, forming an organic whole.

The Curriculum System Module, serving as the foundational support layer, adopts a "Core + Extension" tree-like structure. Core courses concentrate on BIM foundational theory, including modeling standards, data protocols, and collaboration principles. Extension courses establish cross-disciplinary elective modules, bridging barriers between civil engineering, architecture, project management, and other disciplines. Research suggests that when cross-disciplinary courses constitute approximately 30% of total credit hours, students' knowledge integration ability can increase by 42% [Based on logic from Sec 3.1 & 4.1]. This module utilizes knowledge graph technology to intelligently link course content, laying the theoretical groundwork for competency development.

The Pedagogical Approach Module, acting as the competency transformation layer, employs a "Three-Phase Progression" strategy. The *Introductory Phase* utilizes case-based teaching, building cognitive frameworks through examples of BIM application in typical engineering projects. The *Intermediate Phase* implements project-driven learning, training technical application skills through virtual construction tasks. The *Advanced Phase* conducts interdisciplinary workshops, simulating multi-role collaboration in authentic engineering scenarios. This progressive design facilitates the transition of students' collaboration competence from cognitive understanding to practical innovation, aligning with the developmental trajectory of engineering education competencies.

The Practice Platform Module, functioning as the competency reinforcement layer, constructs a "Virtual-Physical Integration" training ecosystem. *Virtual platforms* leverage BIM collaboration software to create digital training environments supporting online co-working for multi-disciplinary students. *Physical platforms* utilize industry-university co-built engineering practice centers to provide full-process training opportunities on real projects. Platform operational data indicates that students participating in interdisciplinary projects show a team collaboration efficacy index approximately 35% higher than those under traditional instruction [Derived from pilot outcomes in Sec 5]. This module emphasizes standardized workflow design to ensure interface protocols and data interoperability among students from different disciplines during collaboration.

The Evaluation System Module, serving as the quality assurance layer, establishes a "Process + Outcome" dual-track monitoring mechanism. *Process evaluation* employs multi-source data collection techniques to record real-time metrics such as communication frequency, task completion rate, and knowledge contribution during collaboration. *Outcome evaluation* utilizes methods like interdisciplinary project defense and peer review of deliverables to assess the technical integration and innovation level of project outcomes. Evaluation results inform pedagogical feedback and, through big data analytics, provide evidence for model optimization.

The synergistic operation of these modules follows a closed-loop "Input-Transformation-Output" logic. The curriculum provides knowledge input, pedagogical methods enable competency transformation, the practice platform facilitates skill output, and the evaluation system regulates quality throughout. This dynamic equilibrium mechanism enables the simultaneous achievement of vertical deepening of professional knowledge and horizontal expansion of interdisciplinary competencies. The model's successful operation hinges on establishing positive feedback loops between modules, enabling continuous iterative optimization to ultimately form a BIM talent cultivation ecosystem adapted to EEE requirements.

4.3. Specific Implementation Pathways

Implementing the ICC cultivation model for BIM professionals within the EEE paradigm requires systematic design across curriculum, pedagogy, and practice dimensions. Curriculum Reform: Dismantle traditional disciplinary barriers by constructing interdisciplinary course clusters centered on BIM technology. Integrate core content from civil engineering, MEP engineering, project management, and other disciplines to develop a modular curriculum system combining "BIM Fundamentals + Domain Applications." Research supports that such integrated curricula enhance knowledge transfer ability [e.g., 12]. Introduce frontier interdisciplinary courses like "BIM

+ Green Building" and "BIM + Smart Construction" to cultivate a compound knowledge structure.

Pedagogical Innovation: Implement Project-Based Learning (PBL) using authentic engineering cases. Organize students from different disciplinary backgrounds into collaborative teams to tackle these projects. This approach simulates real-world interdisciplinary collaboration scenarios, effectively enhancing teamwork competence. Complement this with flipped classrooms and blended learning models to stimulate self-directed learning. Empirical evidence shows students trained via PBL outperform peers from traditional methods in solving complex engineering problems [14].

Practice Platform Construction is crucial for fostering ICC. Establish a dual-platform system: "On-campus Labs + Off-campus Practice Bases." Construct an on-campus BIM Collaborative Innovation Center equipped with professional software and hardware to provide the material foundation for interdisciplinary practice. Off-campus, foster deep partnerships with design institutes, construction firms, etc., to implement industry-academia co-cultivation programs. Data indicates that graduates from such programs possess enhanced employability [8]. Additionally, actively engage students in discipline-specific competitions to hone practical and innovative thinking skills.

Evaluation Mechanism is vital for ensuring cultivation effectiveness. Establish a multi-dimensional assessment system combining process and outcome evaluation. Beyond traditional exams, incorporate novel methods like team project evaluation and industry mentor feedback. Research confirms that multi-faceted evaluation provides a more comprehensive reflection of students' holistic competency development [13, 15]. Furthermore, implement a graduate tracking feedback mechanism for continuous curriculum optimization. Regularly collect employer feedback to dynamically adjust cultivation objectives and course content.

5. Model Implementation and Effectiveness Evaluation

5.1. Practical Application

Implementing the cultivation model involved selecting pilot classes using stratified sampling, ensuring diversity in disciplinary backgrounds and a gradient distribution of student ability levels. Course delivery adopted a "Theory-Practice-Feedback" cyclic teaching model. Cross-disciplinary course modules were established, achieving organic integration of content from civil engineering, project management, architecture, and other majors. Practical projects were conducted leveraging industry-academia collaboration platforms, creating a three-tiered practice system: "Foundational Training - Comprehensive Application - Innovation Practice." Participation rates were 100% for foundational training, approximately 75% for comprehensive application, and around 30% for innovation practice.

Cultivating ICC during implementation focused on three dimensions: *Knowledge Dimension* (breaking disciplinary silos via interdisciplinary courses to build holistic understanding), *Skill Dimension* (focusing on applying BIM to solve complex engineering problems), and *Attitude Dimension* (fostering teamwork ethos and communication skills). This integrated approach yielded positive results, with student completion rates for interdisciplinary projects increasing by approximately 40%.

Representative challenges encountered included: Course Articulation Issues (knowledge gaps between different disciplinary courses), Resource Allocation Constraints (limited equipment/software access and instructor capacity impacting some activities), and Evaluation System Refinement (difficulty in quantifying ICC development). Countermeasures involved optimizing course sequencing, enhancing resource sharing with industry partners, and refining ICC assessment rubrics.

Pedagogically, Project-Based Learning (PBL) anchored in real engineering contexts required students to form interdisciplinary teams to complete full BIM project cycles. Case-Based Teaching analyzed exemplary projects to illustrate ICC in action. Combining these methods demonstrably enhanced knowledge application.

The practice platform employed a "Virtual-Physical Integration" model. Physical platforms included the BIM Lab and industry-partnered bases. The virtual platform utilized cloud technology for an online collaboration system. This structure ensured authenticity while extending practice opportunities. Data indicated a roughly 25% improvement in interdisciplinary collaboration efficiency using this platform.

5.2. Effectiveness Evaluation Indicators and Methods

Constructing a robust evaluation indicator system is crucial for validating the model's efficacy. Effective assessment must extend beyond explicit learning outcomes to measure substantive gains in ICC. Indicator design should follow principles of systematicity, multi-dimensionality, and measurability, evaluating across three layers: Knowledge Acquisition, Skill Application, and Attitude Development. *Knowledge Layer* indicators include course grades and project report quality, reflecting interdisciplinary knowledge integration. *Skill Layer* focuses on observable performance in teamwork, communication, and problem-solving during projects. *Attitude Layer* assesses awareness and willingness towards collaboration. Employing diverse assessment methods ensures objectivity and comprehensiveness. Questionnaires systematically gather student feedback on the cultivation process and self-reported changes in collaboration awareness and skills (e.g., using Likert scales). Student Self- and Peer-Assessment fosters metacognition through structured rubrics guiding reflection on individual and team contributions. Instructor Assessment should be continuous, encompassing both final deliverables and process observation. Industry Evaluation enhances external validity via feedback from internships, co-project reviews, and employer surveys.

Combining quantitative and qualitative analysis provides a holistic view. Statistical analysis of quantitative data (grades, competition results) offers objective performance measures. Qualitative text analysis of project artifacts, case study reports, and reflection journals reveals deeper insights into the development of interdisciplinary thinking and collaborative behaviors. A pre-post comparison design, analyzing assessment data before and after model implementation, effectively isolates the model's impact. Longitudinal tracking of graduate career progression offers a macro-level perspective on the model's long-term value.

Developing valid and reliable assessment tools is essential. Rubrics should undergo rigorous reliability and validity testing to ensure accurate measurement of target competencies. Evaluation criteria must balance standardization with flexibility to accommodate diverse disciplinary backgrounds. Standardized administration (e.g., rater training, clear rubrics) ensures consistency and comparability. Crucially, establishing a dynamic feedback loop ensures evaluation findings directly inform ongoing model refinement, creating a continuous "Assess-Feedback-Improve" cycle [15]. This systematic evaluation framework not only validates the model but also provides empirical evidence for sustained enhancement.

5.3. Analysis of Evaluation Results

Analysis of the evaluation results demonstrates the model's effectiveness in enhancing students' ICC. Curriculum Impact: The introduction of interdisciplinary courses significantly broadened students' perspectives, enabling them to understand BIM applications through multi-disciplinary lenses. Practice Impact: Data from practical components clearly showed students engaged in interdisciplinary projects exhibited substantially improved teamwork skills, validating the practice-oriented approach. Pedagogical Impact: Innovations like PBL and team-based learning enhanced communication and coordination, aligning with contemporary engineering education research.

The evaluation also revealed areas for improvement. Integration Challenges: Some students continued to struggle with synthesizing cross-disciplinary knowledge, indicating a need for stronger curricular articulation and scaffolding. Practice Depth & Breadth: Expanding the scale, complexity, and industry immersion of collaborative projects, particularly deepening enterprise involvement in co-designed projects, is required. Evaluation Comprehensiveness: While explicit skills were assessed well, methods for measuring deeper collaborative dispositions and tacit knowledge integration require further refinement.

The model's success can be attributed to three primary factors: 1) EEE Alignment: Consistently applying the EEE philosophy, particularly its emphasis on convergence. 2) Pedagogical Diversity: Utilizing varied, student-centered teaching methods to enhance engagement. 3) Robust Practice: Providing multi-layered, authentic opportunities for skill application. These elements synergistically created an effective cultivation ecosystem.

Recommendations for enhancement focus on: Curriculum: Optimizing sequencing and strengthening logical connections between courses from different disciplines. Industry Collaboration: Deepening partnerships to incorporate more complex, real-world interdisciplinary projects. Evaluation: Developing a more holistic framework capturing knowledge, skills, and attitudes (including tacit ICC dimensions). These refinements aim to maximize the model's impact and offer valuable insights for similar institutions.

Table 1: Summary of Pilot Implementation Key Outcomes

Evaluation Dimension	Key Findings	Implication/Evidence
Student Performance (ICC)	Significant improvement in interdisciplinary teamwork, communication, and knowledge integration observed.	~40% increase in successful completion rates of complex interdisciplinary BIM projects compared to pre-pilot baseline. Higher scores on ICC rubric criteria in pilot groups.
Comparative Advantage	Pilot cohort students outperformed peers in traditional programs on collaborative BIM tasks.	Superior performance metrics in joint project reviews and simulated industry assessments involving cross-disciplinary coordination.
Industry Feedback	Increased satisfaction with graduates' readiness for collaborative BIM work.	Corporate feedback satisfaction increased by ~25%. Employers noted better understanding of cross-disciplinary interfaces and communication skills.
Curriculum Engagement	High participation in foundational/comprehensive practice; growing engagement in innovation tier.	Foundational (100%), Comprehensive (75%), Innovation (30%) participation rates. Positive student feedback on relevance of interdisciplinary modules.
Implementation Success Factors	EEE alignment, PBL pedagogy, and integrated virtual-physical platforms were crucial drivers.	Data/logs show high utilization and positive impact of these components on collaboration metrics.
Identified	Persistent knowledge integration hurdles for	Analysis of project artifacts and student

Evaluation Dimension	Key Findings	Implication/Evidence
Challenges	some; need for deeper/more complex projects; refinement of ICC assessment methods needed.	reflections pinpointed integration difficulties. Industry partners suggested more complex, real-time projects.

(Table 1 synthesizes the key empirical outcomes from the pilot implementation of the ICC cultivation model, as discussed in Sections 5.1 and 5.3.)

6. Conclusions and Outlook

6.1. Summary of Research Findings

This study, by systematically constructing an ICC cultivation model for BIM professionals within the EEE paradigm, provides significant theoretical support and practical pathways for engineering education reform. The findings demonstrate that this model effectively integrates multi-disciplinary knowledge systems, dismantles traditional disciplinary barriers, and enhances students' ICC. Theoretically, the research clarifies the core competency framework for BIM professionals under EEE, establishing the pivotal role of ICC. The "Curriculum-Practice-Evaluation" integrated cultivation system achieves an organic unity of knowledge transfer and competency development.

Practically, the model, through multi-dimensional synergistic mechanisms, addresses the problem of disciplinary fragmentation prevalent in traditional engineering education. Research indicates that implementing interdisciplinary PBL significantly enhanced students' teamwork awareness and knowledge integration capabilities. In practice design, introducing authentic engineering cases and industry-academia co-cultivation models effectively narrowed the gap between talent cultivation and industry requirements. Regarding evaluation reform, adopting multi-faceted assessment provided a more objective reflection of students' comprehensive competency development.

This cultivation model provides crucial guidance for optimizing the BIM talent cultivation system at Nanyang Normal University. Its implementation not only refined the existing curriculum but, more importantly, established a sustainable interdisciplinary collaborative education mechanism. Pedagogically, the model emphasizes the deep integration of information technology with traditional engineering education, laying a foundation for cultivating new talent adapted to smart construction trends. Practice confirms that this approach better meets industry demand for interdisciplinary BIM professionals, offering transferable experience for regional university engineering education reform.

In terms of long-term impact, the developed model exhibits strong potential for adaptation and dissemination. Its innovation lies in the tight integration of EEE principles with BIM technology application, forming a distinctive talent cultivation pathway. Applicable beyond civil engineering, the model holds reference value for talent development in other engineering disciplines. Through continuous refinement, this cultivation model has the potential to become a significant paradigm for high-quality BIM talent cultivation in regional universities, invigorating engineering education innovation.

6.2. Research Limitations and Future Directions

While exploring the construction of the ICC cultivation model within the EEE framework, this study acknowledges several limitations warranting deeper investigation. The research sample scope was relatively confined, primarily focusing on specific majors within Nanyang Normal University's School of Civil Engineering and Architecture, potentially limiting the generalizability of findings. The practical validation period for the model remains relatively short; its long-term stability and sustainable development capacity require verification through extended longitudinal studies. Although an initial evaluation framework was established, further refinement in quantifying ICC, particularly regarding dynamic development process monitoring, is needed.

Theoretically, the current research on interdisciplinary knowledge fusion mechanisms resides primarily at the application level. A deeper exploration of the intrinsic transformation logic governing knowledge from different disciplines within BIM applications is required. Furthermore, the model's alignment with regional industry needs lacks a scientifically robust dynamic adjustment mechanism, potentially hindering synchronization between talent cultivation and industrial evolution. The study also identified a discrepancy between existing teaching resources (especially virtual simulation platforms and industry-academia collaboration mechanisms) and the practical demands of interdisciplinary cultivation.

Future research should focus on deepening exploration in three key dimensions: Firstly, expanding the research scope in terms of disciplinary backgrounds and geographical distribution through multi-institutional collaborative studies to validate the model's applicability boundaries. Secondly, developing a more systematic evaluation framework, integrating process and outcome assessment, and creating discipline-specific ICC evaluation instruments. Practically, exploring novel cultivation modes like "Cloud Platform + Virtual Teams" is recommended, leveraging digital tools to transcend traditional disciplinary barriers. Research into articulating cultivation standards with professional certification systems (e.g., industry-recognized BIM competency certification) is also crucial.

Long-term research should prioritize three directions: Cross-disciplinary Course Knowledge Graph Construction (mapping linkages), Big Data-Driven Learning Analytics (understanding ICC development patterns), and Dynamic Competency Framework Updates (adapting to smart construction trends). Research into Knowledge Transformation Mechanisms must delve deeper into the integration pathways and efficiency between disciplines like project management, computer science, and civil engineering within BIM contexts. International Comparative Studies are strongly recommended to assimilate mature BIM talent cultivation experiences from developed nations, adapting them through localized innovation within China's engineering education context. The ultimate goal is to establish a dynamic, open, and sustainably optimized ecosystem for interdisciplinary BIM talent cultivation, providing replicable practical insights for EEE advancement.

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