DOI: 10.66069/ojspub.1137260709

A Digital Cost Management Competency Framework for Quantity Surveying Education: Integrating BIM 5D with Project-Based Learning

Jiaqi Song

School of Architectural Engineering, Jiangxi Vocational College of Water Resources, Nanchang 330013, Jiangxi, China

Abstract: ***The digital transformation of the construction industry has created growing demand for quantity surveyors with competencies in Building Information Modelling (BIM) and digital cost management. However, traditional quantity surveying education remains largely focused on theoretical instruction and software-oriented training, limiting students' ability to apply digital technologies in authentic engineering practice. This study proposes the Digital Cost Management Competency Framework (DCMCF), which integrates BIM 5D, Project-Based Learning (PBL), and competency-oriented assessment into quantity surveying education. A mixed-methods case study was conducted using two cohorts of students enrolled in an Engineering Quantity Measurement and Valuation course at a public higher vocational institution in China. Quantitative data were collected from students' academic performance, while qualitative evidence was obtained through classroom observations, project deliverables, and teaching reflections. Evaluation results indicated that students demonstrated a more comprehensive grasp of BIM operations and digital literacy. The PBL approach also led to more active peer discussions and tactical problem-solving when students were confronted with discrepant quantity take-offs. Compared with the previous cohort, students demonstrated improved performance, particularly in competency-oriented assessment and practical learning activities. The study offers a practical framework and empirical evidence for competency-oriented reform in quantity surveying education.***

Keywords: BIM 5D, Quantity surveying education, Digital cost management, Project-based learning, Competency-oriented education.

1. Introduction

Today's construction sector expects quantity surveyors to handle much more than static spreadsheets; they must interact with live BIM models and cloud data [1, 2]. These technologies require construction professionals to combine digital capability with engineering expertise across the project lifecycle [3, 4].

Among construction-related professions, quantity surveyors have experienced particularly significant changes. Their roles have expanded from traditional quantity measurement and cost estimation to BIM-based quantity take-off, digital cost management, lifecycle cost analysis, and collaborative decision-making. Employers therefore increasingly expect graduates to possess integrated competencies in technical knowledge, digital literacy, collaboration, and professional problem-solving, creating new challenges for quantity surveying education.

Higher education institutions have therefore incorporated BIM and related technologies into construction programs [5] [6]. BIM-supported teaching can improve spatial visualization, interdisciplinary collaboration, and understanding of engineering information [8], while Project-Based Learning (PBL) promotes active learning through authentic engineering projects [9, 10].

Despite these advances, several limitations remain. First, existing BIM education largely emphasizes software operation rather than the systematic development of professional competencies required in digital construction practice [11]. Second, BIM is often delivered as a standalone technical course instead of being fully integrated into quantity surveying curricula, limiting students' ability to connect digital technologies with quantity measurement, cost estimation, and engineering decision-making. Third, previous studies have primarily evaluated learning effectiveness through examination performance or learning satisfaction, while competency-oriented curriculum design and digital cost management competency development remain underexplored.

To address this gap, this work develops the Digital Cost Management Competency Framework (DCMCF), which integrates BIM 5D, Project-Based Learning, and competency-oriented assessment in quantity surveying education. The framework embeds authentic engineering projects to develop digital literacy, BIM operational skills, quantity surveying competency, collaborative communication, and problem-solving ability.

The study contributes by proposing the DCMCF, demonstrating how BIM 5D can be embedded in authentic engineering projects, and providing mixed-methods evidence for competency-oriented curriculum reform in quantity surveying education.

2. Literature Review

2.1 Digital Transformation in Construction Education

Previous studies indicate that BIM-supported teaching enhances collaboration and engineering communication. Recent research has therefore shifted towards digital competency development, which integrates BIM, engineering knowledge and collaborative problem-solving.

These changes are particularly significant for quantity surveying education. Contemporary quantity surveyors are expected to perform BIM-based quantity take-off, digital cost planning, and collaborative project coordination in addition to traditional measurement and cost estimation tasks [13]. Consequently, quantity surveying education must move beyond knowledge-oriented instruction towards competency-oriented learning that prepares students for digital construction practice.

However, much of this work discusses digital transformation at a general level or emphasizes technology adoption without linking industry needs, curriculum design, instructional strategies, and competency-oriented assessment in quantity surveying education [8, 11].

2.2 BIM 5D and Quantity Surveying Education

Building Information Modelling (BIM) is now a core technology in the AEC industry and an established component of construction education [1, 7]. By integrating geometric models with engineering information, BIM supports collaboration, project planning, construction management, cost estimation, and facility operation [3, 12].

Previous studies have shown that BIM-supported teaching enhances students' spatial visualization, engineering communication, interdisciplinary collaboration, and understanding of construction information [8, 14]. However, BIM education remains largely software-oriented, with many courses emphasizing modelling techniques while paying insufficient attention to engineering judgement, professional problem-solving, and authentic project application [11, 15]. In addition, BIM is often delivered as an independent technical subject rather than being integrated into quantity surveying and other professional courses, limiting students' understanding of BIM-supported engineering workflows.

These limitations are particularly evident in quantity surveying education, where the educational value of BIM is best realized through BIM 5D, which integrates three-dimensional models with quantity take-off and cost information. Compared with conventional BIM modelling, BIM 5D enables automatic quantity extraction, dynamic cost estimation, and real-time cost control, allowing students to connect digital models with engineering measurement, pricing, and cost management [16]. Consequently, recent studies advocate embedding BIM 5D within integrated digital workflows rather than teaching measurement and costing as isolated tasks [11, 18].

Despite growing interest in BIM 5D education, existing research remains fragmented. Most studies focus on students' perceptions, software proficiency, or individual classroom practices, with limited attention to curriculum-wide instructional frameworks that integrate competency development, authentic projects, and assessment strategies [8] [15]. Moreover, educational outcomes are commonly assessed through software skills or academic performance, whereas competencies such as collaborative communication, engineering judgement, and digital cost management receive comparatively less attention [16, 18].

2.3 Digital Cost Management Competencies

Digital construction has expanded the professional role of quantity surveyors beyond quantity measurement, cost estimation, and contract administration to include BIM, digital information, cloud collaboration, and data-driven decision-making [13]. Quantity surveying education therefore needs stronger competency-oriented learning.

Competency-based education emphasizes the application of knowledge, skills, and professional judgement in authentic workplace contexts rather than the acquisition of theoretical knowledge alone [17]. Within engineering education, competency development integrates technical expertise, communication, teamwork, problem-solving, and lifelong learning, making competency-oriented curricula increasingly important for meeting evolving industry demands.

In quantity surveying education, digital competency extends far beyond software operation. Digitally competent graduates should be able to integrate BIM models, engineering information, quantity measurement, pricing standards, and project management data to support engineering decision-making within collaborative digital workflows [1, 3] Existing studies consistently identify five core competency dimensions: digital literacy, BIM operational competency, quantity surveying competency, collaborative communication, and problem-solving ability [6]. Together, these competencies enable graduates to interpret engineering information, perform digital cost management, collaborate effectively with multidisciplinary teams, and make informed professional decisions.

However, existing studies remain largely conceptual and provide limited guidance on how these competencies can be developed through curriculum design or assessed through authentic engineering tasks [11, 15].

Accordingly, this study conceptualizes Digital Cost Management Competency as a multidimensional construct comprising digital literacy, BIM operational competency, quantity surveying competency, collaborative communication, and problem-solving ability. These five dimensions provide the theoretical foundation for the proposed Digital Cost Management Competency Framework (DCMCF) and guide the design of the teaching intervention and evaluation framework.

2.4 Project-Based Learning in Engineering Education

Project-Based Learning (PBL) has become a widely adopted pedagogical approach in engineering and vocational education because it promotes active learning, authentic problem-solving, and competency development through real-world project experiences [10, 19]. Unlike traditional teacher-centered instruction, PBL engages students in collaborative, inquiry-based learning that integrates theoretical knowledge with practical application, thereby enhancing motivation, communication, teamwork, and professional decision-making [20, 21]. These characteristics make PBL particularly suitable for engineering education, where professional competence depends on the integration of knowledge and practice.

Within construction education, PBL has been increasingly adopted to simulate authentic engineering projects and improve students' readiness for industry practice [22]. When combined with BIM, PBL provides students with digital project environments in which they can complete tasks such as model development, quantity take-off, cost estimation, construction planning, and project communication [7]. Instead of serving solely as modelling software, BIM functions as a collaborative learning platform that supports interdisciplinary teamwork and integrated project delivery [14]. Consequently, recent studies advocate integrating BIM with PBL to cultivate competencies that better reflect contemporary construction practice [11].

However, existing research often evaluates learning satisfaction or software proficiency rather than competency development [15], and tends to examine individual classroom activities rather than curriculum-wide frameworks [8]. Few studies focus on BIM-supported PBL in quantity surveying education, particularly digital quantity measurement, BIM-based cost estimation, and cost management decision-making [7].

2.5 Research Gap

The preceding review shows that BIM and Project-Based Learning (PBL) can strengthen visualization, collaboration, and practical learning in construction education [1, 6]. However, several gaps remain.

First, BIM education still focuses mainly on software operation, with limited attention to BIM 5D for digital cost management and competency development in quantity surveying curricula [11, 15]. Second, most studies evaluate isolated teaching activities instead of comprehensive instructional frameworks that align industry competency requirements, curriculum design, digital technologies, and assessment [8]. Third, outcomes are commonly assessed through software proficiency, examination performance, or satisfaction, while digital literacy, collaborative communication, engineering judgement, and problem-solving remain underexplored.

To address these gaps, this study proposes the Digital Cost Management Competency Framework (DCMCF), which integrates BIM 5D, Project-Based Learning, competency-oriented assessment, and authentic engineering projects within a unified curriculum model. Through a mixed-methods case study, the research evaluates the effectiveness of the framework in developing digital cost management competencies and provides empirical evidence to support competency-oriented curriculum reform in quantity surveying education.

Based on these identified gaps, an integrated conceptual framework was developed to guide curriculum design, teaching implementation, and competency evaluation.

2.6 Conceptual Framework

As illustrated in Figure 1, the framework assumes that digital transformation has redefined the competency requirements of quantity surveyors. Accordingly, curriculum objectives are aligned with five core competencies: digital literacy, BIM operational competency, quantity surveying competency, collaborative communication, and problem-solving ability. These competencies are developed through the integration of BIM 5D, Project-Based Learning (PBL), and competency-oriented assessment, enabling students to complete authentic engineering tasks within realistic project environments.

The DCMCF links industry demand, curriculum design, instructional strategies, digital technology integration, and competency development. It positions BIM 5D as a pedagogical platform for authentic learning, interdisciplinary collaboration, and digital cost management.

3. Methodology

3.1 Research Design

This study adopted a mixed-methods case study to develop and evaluate the DCMCF in quantity surveying education. Quantitative evidence was obtained from students' academic performance, while qualitative evidence was collected through classroom observation, project assessment, and teaching reflection.

A case study design was appropriate because the research examined curriculum innovation in an authentic educational setting, where instructional design, student engagement, assessment, and institutional context interact.

Project-Based Learning (PBL) served as the primary instructional strategy. BIM 5D was embedded throughout the Engineering Quantity Measurement and Valuation course, and students progressively completed BIM modelling, model-based quantity take-off, bill of quantities preparation, cost estimation, project reporting, and collaborative presentation.

The research process comprised six stages: (1) curriculum analysis and framework development; (2) curriculum redesign based on the DCMCF; (3) implementation of BIM 5D-supported project-based learning; (4) collection of multiple data sources; (5) data analysis; and (6) evaluation of learning outcomes and competency development.

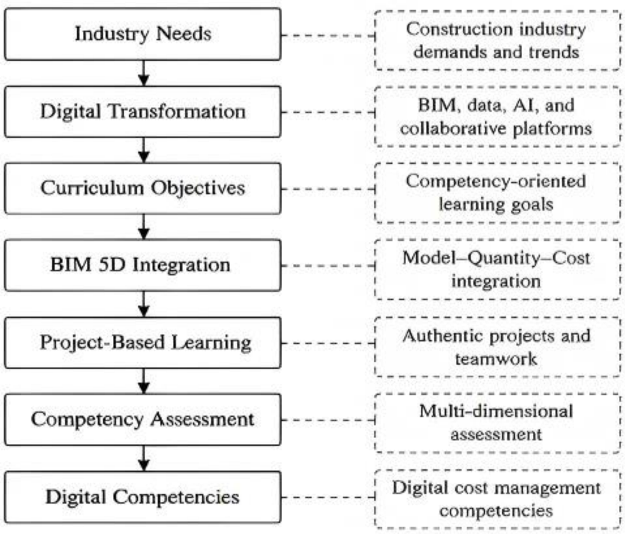

Figure 1: Conceptual framework of the DCMCF

3.2 Participants

The study was conducted at a public higher vocational college in China and involved students majoring in Engineering Cost

Management. Two independent student cohorts participated in the study.

The 2023 cohort consisted of 219 students, while the 2024 cohort comprised 281 students. Both cohorts completed the compulsory course Engineering Quantity Measurement and Valuation, one of the core professional courses within the Engineering Cost Management programme. The course covers engineering drawing interpretation, engineering quantity measurement, bill of quantities preparation, construction pricing, and cost estimation.

The two cohorts were instructed by the same lecturer following identical curriculum objectives, teaching schedule, and assessment standards. During the implementation of the curriculum reform, BIM 5D-supported Project-Based Learning was gradually incorporated into teaching activities. Consequently, both cohorts provided valuable evidence for evaluating the applicability and educational value of the proposed DCMCF under authentic teaching conditions rather than serving as traditional experimental and control groups.

Table 1: Participant characteristics

Variable	2023 Cohort	2024 Cohort
Academic Year	2023	2024
Number of Students	219	281
Major	Engineering Cost Management	Engineering Cost Management
Course	Engineering Quantity Measurement and Valuation	Engineering Quantity Measurement and Valuation
Institution	Public Higher Vocational College	Public Higher Vocational College
Assessment Approach	Competency-based Assessment	Competency-based Assessment

3.3 Development of the Digital Cost Management Competency Framework

The DCMCF was developed to align quantity surveying education with digital construction practice by integrating industry competency requirements, curriculum objectives, BIM 5D technologies, project-based learning, and competency-oriented assessment.

Curriculum objectives were reconstructed based on the competency requirements of digital construction enterprises. Besides engineering quantity calculation and pricing knowledge, the redesigned curriculum emphasized digital modelling, collaborative problem-solving, project management, and digital cost analysis.

BIM 5D was embedded throughout the entire teaching process rather than introduced as a separate software course. Students gradually completed professional tasks including BIM model development, engineering quantity extraction, bill of quantities preparation, cost estimation, cost analysis, and project reporting. Each learning activity reflected authentic professional responsibilities undertaken by quantity surveyors in practice.

Authentic engineering projects formed the main learning context. Students worked in groups on integrated project tasks, while instructors guided project implementation and reflection. Figure 2 presents the implementation process of the proposed DCMCF.

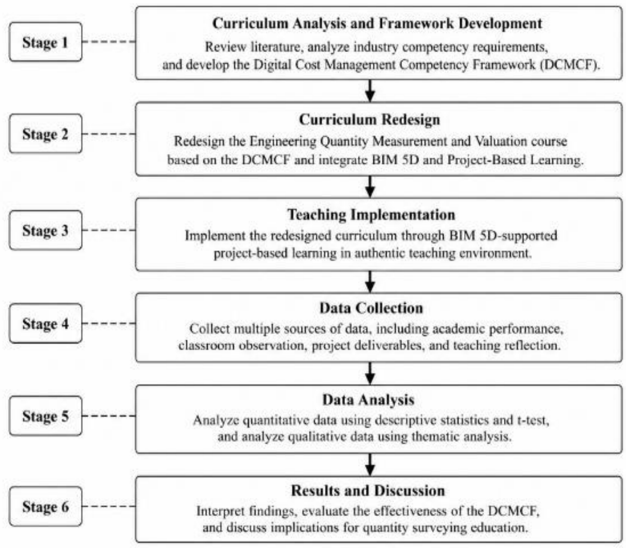

Figure 2: Instructional structure of the DCMCF

3.4 Teaching Intervention

The redesigned course was implemented through five consecutive instructional phases.

Phase 1. Fundamental Knowledge

Students first reviewed engineering drawing interpretation, engineering measurement specifications, quantity calculation rules, and pricing principles to establish a solid professional foundation.

Phase 2. BIM Modelling

Students constructed digital building models using Autodesk Revit based on authentic architectural drawings. Learning activities included structural modelling, architectural modelling, family creation, and model verification. This phase strengthened students' understanding of the relationship between engineering drawings and digital building information.

Phase 3. BIM 5D-Based Quantity Surveying

In this core stage, students transitioned from pure modelling to hands-on cost analysis. Students used the embedded BIM data to automate quantity extraction, followed by a verification process to ensure accuracy before preparing bills of quantities and performing digital cost calculations. This phase represented the core component of the DCMCF.

Phase 4. Integrated Engineering Project

Students completed comprehensive engineering projects in collaborative groups. Each project required students to establish BIM models, calculate engineering quantities, prepare cost reports, analyses project costs, and present project outcomes. Continuous formative feedback was provided throughout the project implementation process.

Phase 5. Reflection and Competency Assessment

Students reflected on their learning through project reports, classroom discussion, and peer evaluation. Competency assessment consisted of theoretical examination (30%), BIM modelling (20%), project report (25%), project presentation (15%), and classroom participation (10%), with greater emphasis on authentic engineering performance.

3.5 Data Collection

Multiple sources of evidence were collected for methodological triangulation.

First, academic performance data were obtained from students' continuous assessment, practical skills assessment, final examination, and overall course grades.

Second, classroom observations were conducted throughout the semester. Students' learning engagement, teamwork, BIM software operation, classroom participation, and problem-solving behaviors were systematically recorded by the instructor.

Third, project deliverables were collected, including BIM models, engineering quantity reports, bill of quantities documents, cost estimation reports, and project presentation materials. These artefacts provided direct evidence for evaluating students' digital cost management competencies.

Finally, teaching reflection records were maintained after each instructional module to document teaching implementation, student feedback, curriculum challenges, and opportunities for continuous improvement.

3.6 Data Analysis

Quantitative and qualitative data were analyzed using complementary analytical methods.

Descriptive statistical analysis was conducted to summarizes students' academic performance. Mean scores, standard deviations, pass rates, excellent rates, and score distributions were calculated for each cohort. In addition, independent-samples t-tests were performed to compare students' learning outcomes between the two cohorts where appropriate.

Qualitative data, including classroom observations, project reports, and teaching reflection records, were analyzed using thematic analysis. Students' competency development was coded according to five predefined dimensions:

1) Professional Knowledge;
2) BIM Operational Skills;
3) Digital Cost Management Competency;
4) Collaborative Competency;
5) Problem-Solving Competency.

4. Results

4.1 Descriptive Statistics of Student Performance

To provide an overview of students' academic performance, descriptive statistics were calculated for continuous assessment, final examination, practical skills, and overall course performance. The results are presented in Table 2.

Table 2: Descriptive statistics of student performance

Indicator	2023 Cohort (n = 219)	2024 Cohort (n = 281)
Continuous Assessment	**73.57 ± 14.49**	**81.65± 7.45**
Final Examination	**66.03 ± 17.82**	**69.83±20.49**
Practical Skills	**62.87 ± 21.27**	**73.47±16.14**
Overall Score	**67.14 ± 13.95**	**74.70±12.50**
Pass Rate (%)	86.76	92.88
Excellent Rate (≥85) (%)	12.33	22.06

Table 2 shows that both cohorts achieved satisfactory learning outcomes across all assessment components. Compared with the 2023 cohort, the 2024 cohort obtained higher mean scores in continuous assessment, practical skills, and overall course performance. The pass rate increased from 86.76% to 92.88%, while the excellent rate (≥85) increased from 12.33% to 22.06%. Greater variation was observed in practical skills and final examination scores, as reflected by their relatively larger standard deviations.

As shown in Figure 3, improvements were observed across all four assessment components. The largest difference occurred in practical skills assessment, followed by continuous assessment, whereas the difference in final examination scores was comparatively smaller.

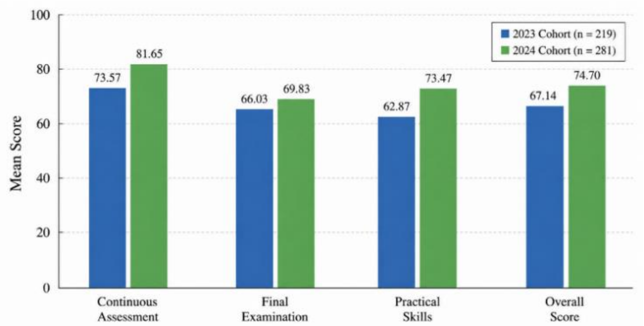

Figure 3: Comparison of mean scores between the two cohorts

4.2 Comparative Analysis of Learning Outcomes

To further examine differences in learning outcomes between the two cohorts, independent-samples t-tests were conducted for continuous assessment, final examination, practical skills assessment, and overall course performance. The results are presented in Table 3.

Table 3: Independent-samples t-test for learning outcomes

Variable	2023 Cohort (n = 219)	2024 Cohort (n = 281)	t	p	Cohen's d
Continuous Assessment	**73.57 ± 14.49**	**81.65 ± 7.45**	-7.520	<0.001	-0.729
Final Examination	**66.03 ± 17.82**	**69.83 ± 20.49**	-2.211	0.027	-0.196
Practical Skills	**62.87 ± 21.27**	**73.47 ± 16.14**	-6.122	<0.001	-0.571
Overall Score	**67.14 ± 13.95**	**74.70 ± 12.50**	-6.295	<0.001	-0.575

The results indicate statistically significant differences between the two cohorts across all four assessment components. The 2024 cohort achieved significantly higher scores in continuous assessment ($t = -7.520$, $p < 0.001$), practical skills assessment ($t = -6.122$, $p < 0.001$), and overall course performance ($t = -6.295$, $p < 0.001$), with moderate effect sizes (Cohen's $d = -0.571$ to -0.729). Although the difference in final examination scores was statistically significant ($p = 0.027$), the corresponding effect size was relatively small ($d = -0.196$).

4.3 Development of Digital Cost Management Competencies

Beyond academic performance, qualitative evidence from classroom observations, project deliverables, project assessment, and teaching reflections indicated that the implementation of the Digital Cost Management Competency Framework (DCMCF) supported students' competency development across multiple dimensions.

Digital Literacy and BIM Operational Competency

Students demonstrated substantial improvement in digital literacy and BIM operational skills throughout the course. Through BIM 5D-supported learning activities, students showed fewer conceptual errors when translating 2D blueprints into 3D Revit models, and they could independently map cost codes to model elements by the semester's end. Classroom observations further showed growing confidence in using BIM technologies to solve practical engineering problems.

Quantity Surveying and Digital Cost Management Competency

The project-based curriculum strengthened students' competency in quantity surveying by integrating BIM-supported quantity take-off, bill preparation, cost estimation, and cost analysis into authentic engineering tasks. Project reports demonstrated that students were able to establish clear links between engineering information, quantity measurement, pricing standards, and cost management, reflecting the competencies required in contemporary digital construction practice. Digital cost management competency emerged through the integration of BIM operational skills and quantity surveying competency.

Collaborative Communication and Problem-Solving Competency

Project-Based Learning promoted teamwork, communication, and problem-solving through collaborative engineering projects. Students coordinated modelling tasks, verified engineering quantities, discussed cost solutions, and jointly completed project reports. Teaching reflections indicated that students gradually shifted from passive learning towards active problem-solving and independent decision-making, while project reports revealed improvements in critical thinking and engineering judgement. Figure 4 summarizes the progressive development of students' digital cost management competencies. Overall, the qualitative findings show progressive development in digital literacy, BIM application, quantity surveying competency, collaborative communication, and problem-solving ability.

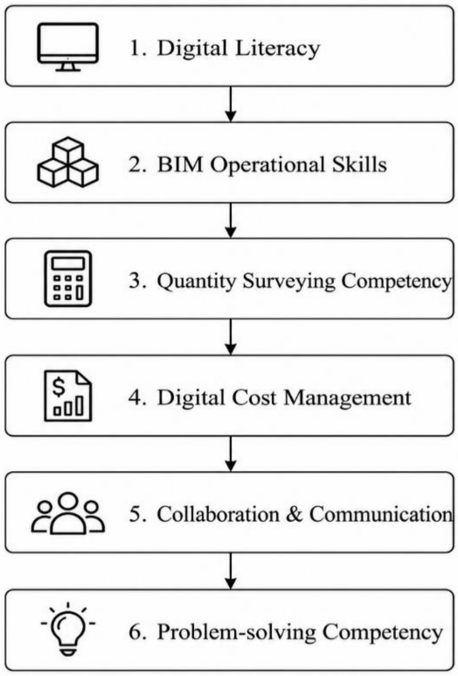

Figure 4: Development pathway of digital cost management competencies

5. Discussion

5.1 Validation of the Digital Cost Management Competency Framework

Taken together, these results suggest the effectiveness of the DCMCF in promoting competency-oriented learning within quantity surveying education. The framework integrates BIM 5D, Project-Based Learning (PBL), and competency-oriented assessment to align curriculum design with digital construction competencies.

A notable finding is that improvements were more pronounced in continuous assessment and practical skills than in traditional written examinations. This suggests that competency-oriented learning is more effectively demonstrated through authentic engineering tasks than through knowledge-based tests. Because students repeatedly applied BIM technologies, engineering measurement, and cost management skills in project activities, competency development was reflected primarily in practical performance rather than examination scores. These findings echo the long-standing argument in engineering education that examination scores alone rarely reflect students' readiness for professional practice [9, 10].

The qualitative findings further indicate that BIM 5D functions not only as a digital technology but also as a collaborative learning environment. By embedding BIM within authentic engineering projects, students developed stronger connections between engineering drawings, digital models, quantity measurement, and cost management. This supports previous research suggesting that BIM is most effective when integrated with project-based pedagogy rather than delivered as an isolated software course [1]. Unlike many existing studies that focus primarily on BIM modelling skills, our findings suggest how BIM 5D can facilitate the systematic development of digital cost management competencies.

Another important implication concerns competency-oriented assessment. Rather than relying primarily on written examinations, the proposed assessment strategy evaluated students' performance through project implementation, collaboration, communication, and reflective learning. Such assessment better reflects the professional expectations of contemporary quantity surveyors and supports the transition from knowledge-oriented instruction to competency-oriented engineering education.

5.2 Comparison with Previous Studies

The findings are consistent with studies showing that BIM enhances students' understanding of engineering information and that PBL promotes active learning, collaboration, and practical problem-solving [10]. They also address the limited guidance in prior work on systematic competency development.

This study extends previous research by showing how BIM 5D can operate as a pedagogical platform integrating engineering knowledge, quantity surveying, cost management, and collaborative learning.

Another important contribution is the adoption of an integrated competency-oriented approach. Unlike previous studies that evaluate individual technologies or teaching methods, the DCMCF combines curriculum objectives, BIM 5D, Project-Based Learning, and competency-oriented assessment within a unified instructional framework. This integration provides a clearer pathway for curriculum reform and better reflects the interdisciplinary competency requirements of the contemporary construction industry.

Furthermore, this study adopts a mixed-methods design that combines quantitative learning outcomes with qualitative evidence from classroom observations, project deliverables, and teaching reflections. Compared with studies relying solely on examination results or student satisfaction, this approach provides a more comprehensive understanding of competency development in authentic educational settings.

5.3 Theoretical Contributions

First, it proposes the Digital Cost Management Competency Framework (DCMCF) as an integrated pedagogical framework for quantity surveying education. Unlike previous studies that primarily focus on BIM implementation or technology adoption, the DCMCF systematically links industry competency requirements, curriculum objectives, BIM 5D, Project-Based Learning (PBL), and competency-oriented assessment, thereby extending existing research from technology application to curriculum design and competency development.

Second, this study reconceptualizes BIM 5D as a pedagogical platform rather than merely a digital technology. By embedding BIM 5D within authentic engineering projects, the framework demonstrates how digital technologies can support the systematic development of professional competencies instead of software proficiency alone.

Third, the study contributes to the application of Project-Based Learning in quantity surveying education. The findings provide empirical evidence that integrating BIM 5D with authentic engineering projects promotes competency development through continuous engagement in realistic professional tasks.

Finally, the DCMCF offers a transferable instructional model for digital engineering education. Although developed for quantity surveying, its principles of curriculum alignment, digital technology integration, project-based learning, and competency-oriented assessment may also inform curriculum reform in related disciplines such as construction management, civil engineering, and architectural engineering.

5.4 Practical Implications

First, the proposed Digital Cost Management Competency Framework (DCMCF) provides a systematic approach to curriculum reform. Rather than treating BIM as an isolated software course, digital technologies should be integrated throughout the curriculum to support the progressive development of professional competencies aligned with industry requirements.

Second, educators should adopt competency-oriented teaching strategies by embedding authentic engineering projects, collaborative learning, and BIM 5D technologies into classroom instruction. In this approach, teachers act as learning facilitators who guide students in applying engineering knowledge, solving practical problems, and reflecting on project experiences rather than simply delivering theoretical content.

Third, assessment methods should move beyond traditional written examinations to evaluate students' professional competencies more comprehensively. Competency-oriented assessment should combine project deliverables, BIM models, quantity reports, presentations, peer assessment, and reflective learning to better reflect students' readiness for professional practice.

Finally, the framework highlights the importance of closer collaboration between higher education institutions and the construction industry. Industry participation in curriculum development, project design, internships, and competency assessment can help ensure that educational programs remain aligned with the rapidly evolving competency requirements of the digital construction industry.

Although developed in a higher vocational education context, the framework may also inform curriculum reform in construction management, civil engineering, architectural engineering, and related disciplines.

5.5 Limitations and Future Research

A clear boundary of this study lies in its localized context—the data stems entirely from a single vocational college in Jiangxi. As institutional contexts, curriculum structures, and student characteristics vary across regions, the generalizability of the findings should be interpreted with caution.

Second, the study examined two student cohorts within one academic programme. Future research involving multiple institutions, larger samples, and diverse educational contexts would strengthen the external validity of the proposed framework.

Third, this study focused on students' learning outcomes during course implementation. Longitudinal research is needed to investigate whether the competencies developed through the Digital Cost Management Competency Framework (DCMCF) are sustained in professional practice and contribute to graduates' career development.

Finally, although this study center on BIM 5D, future research should explore how emerging technologies, such as artificial intelligence (AI), digital twins, cloud collaboration, and extended reality (XR), can be integrated into the DCMCF to further support competency-oriented construction education. Comparative studies across different countries, institutional types, and engineering disciplines would also help validate and refine the framework.

6. Conclusion

In this research, we developed and evaluated the Digital Cost Management Competency Framework (DCMCF) to support competency-oriented curriculum reform in quantity surveying education. By integrating BIM 5D, Project-Based Learning (PBL), and competency-oriented assessment, the framework aligns curriculum design with digital construction competencies.

Using a mixed-methods case study, the research demonstrated that the DCMCF effectively supported students' development of digital literacy, BIM operational skills, quantity surveying competency, collaborative communication, and problem-solving ability. Both quantitative and qualitative findings indicate that embedding digital technologies within authentic engineering projects is more effective than treating BIM as an isolated software application.

The study contributes an integrated pedagogical framework, demonstrates the use of BIM 5D in authentic engineering projects, and provides mixed-methods evidence for competency-oriented curriculum reform.

Although developed within the context of quantity surveying education, the DCMCF offers a transferable framework for curriculum innovation in other construction-related disciplines. Future research should further validate the framework across different educational contexts and explore the integration of emerging technologies, such as artificial intelligence, digital twins, and extended reality, to enhance competency-oriented engineering education.

References

[1] R. Sacks, C. Eastman, G. Lee, and P. Teicholz, BIM Handbook: A Guide to Building Information Modeling for Owners, Designers, Engineers, Contractors, and Facility Managers. John Wiley & Sons, 2018.

[2] D. Bassir, H. Lodge, H. Chang, J. Majak, and G. Chen, 'Application of artificial intelligence and machine learning for BIM: review', Int. J. Simul. Multidisci. Des. Optim., vol. 14, p. 5, 2023, doi: 10.1051/smdo/2023005.

[3] B. Succar and M. Kassem, 'Macro-BIM adoption: Conceptual structures', Automation in Construction, vol. 57, pp. 64–79, Sep. 2015, doi: 10.1016/j.autcon.2015.04.018.

[4] T. D. Oesterreich and F. Teuteberg, 'Understanding the implications of digitisation and automation in the context of Industry 4.0: A triangulation approach and elements of a research agenda for the construction industry', Computers in industry, vol. 83, pp. 121–139, 2016.

[5] M. B. Barison and E. T. Santos, "BIM teaching strategies: An overview of the current approaches," in Proc. ICCCBE 2010 Int. Conf. Comput. Civil Building Eng., 2010.

[6] E. Pikas, R. Sacks, and O. Hazzan, 'Building Information Modeling Education for Construction Engineering and Management. II: Procedures and Implementation Case Study', Journal of Construction Engineering and Management, vol. 139, no. 11, p. 05013002, Nov. 2013, doi: 10.1061/(ASCE)CO.1943-7862.0000765.

[7] R. Sacks and E. Pikas, 'Building Information Modeling Education for Construction Engineering and Management. I: Industry Requirements, State of the Art, and Gap Analysis', Journal of Construction Engineering and Management, vol. 139, no. 11, p. 04013016, Nov. 2013, doi: 10.1061/(ASCE)CO.1943-7862.0000759.

[8] H. Abdirad, C. S. Dossick, B. R. Johnson, and G. Migliaccio, 'Disruptive information exchange requirements in construction projects: perception and response patterns', Building Research & Information, vol. 49, no. 2, pp. 161–178, Feb. 2021, doi: 10.1080/09613218.2020.1750939.

[9] M. J. Prince and R. M. Felder, 'Inductive Teaching and Learning Methods: Definitions, Comparisons, and Research Bases', Journal of Engineering Education, vol. 95, no. 2, pp. 123–138, Apr. 2006, doi: 10.1002/j.2168-9830.2006.tb00884.x.

[10] A. Kolmos, R. G. Hadgraft, and J. E. Holgaard, 'Response strategies for curriculum change in engineering', Int J Technol Des Educ, vol. 26, no. 3, pp. 391–411, Aug. 2016, doi: 10.1007/s10798-015-9319-y.

[11] M. M. Rahman and Y. Watanobe, 'ChatGPT for Education and Research: Opportunities, Threats, and Strategies', Applied Sciences, vol. 13, no. 9, p. 5783, Jan. 2023, doi: 10.3390/app13095783.

[12] B. Becerik-Gerber et al., 'The field of human building interaction for convergent research and innovation for intelligent built environments', Sci Rep, vol. 12, no. 1, p. 22092, Dec. 2022, doi: 10.1038/s41598-022-25047-y.

[13] P. Smith, 'BIM & the 5D Project Cost Manager', Procedia - Social and Behavioral Sciences, vol. 119, pp. 475–484, Mar. 2014, doi: 10.1016/j.sbspro.2014.03.053.

[14] W. Wu and R. R. A. Issa, 'BIM Education and Recruiting: Survey-Based Comparative Analysis of Issues, Perceptions, and Collaboration Opportunities', Journal of Professional Issues in Engineering Education

and Practice, vol. 140, no. 2, p. 04013014, Apr. 2014, doi: 10.1061/(ASCE)EI.1943-5541.0000186.
[15] A. Abbas, S. Hosseini, J. L. M. Núñez, and S. Sastre-Merino, ‘Emerging technologies in education for innovative pedagogies and competency development’, Australasian Journal of Educational Technology, vol. 37, no. 5, pp. 1–5, 2021.
[16] RICS, ‘NRM 2 New Rules of Measurement Detailed Measurement for Building Works’. Royal Institution of Chartered Surveyors, 2021.
[17] C. Day, ‘Competence-based Education and Teacher Professional Development’, in Competence-based Vocational and Professional Education: Bridging the Worlds of Work and Education, M. Mulder, Ed., Cham: Springer International Publishing, 2017, pp. 165–182. doi: 10.1007/978-3-319-41713-4_8.
[18] O. I. Olanrewaju, A. F. Kineber, N. Chileshe, and D. J. Edwards, ‘Modelling the relationship between Building Information Modelling (BIM) implementation barriers, usage and awareness on building project lifecycle’, Building and Environment, vol. 207, p. 108556, Jan. 2022, doi: 10.1016/j.buildenv.2021.108556.
[19] J. W. Thomas, "A review of research on project-based learning," 2000. [Online]. Available: https://tecfa.unige.ch/proj/eteach-net/Thomas_researchreview_PBL.pdf.
[20] P. C. Blumenfeld, E. Soloway, R. W. Marx, J. S. Krajcik, M. Guzdial, and A. Palincsar, ‘Motivating Project-Based Learning: Sustaining the Doing, Supporting the Learning’, Educational Psychologist, vol. 26, no. 3–4, pp. 369–398, Jun. 1991, doi: 10.1080/00461520.1991.9653139
[21] J. R. Savery, ‘Overview of problem-based learning: Definitions and distinctions’, Essential readings in problem-based learning: Exploring and extending the legacy of Howard S. Barrows, vol. 9, no. 2, pp. 5–15, 2015
[22] J. E. Mills and D. F. Treagust, "Engineering education—Is problem-based or project-based learning the answer," Australas. J. Eng. Educ., vol. 3, no. 2, pp. 2-16, 2003.’

Author Profile

Jiaqi Songreceived the Bachelor of Engineering degree from Jiangxi Normal University in 2009 and the Master of Management degree from Nanchang University in 2024. She is currently with the School of Architectural Engineering, Jiangxi Vocational College of Water Resources, Nanchang, China. Her current research focuses on BIM, quantity surveying education, digital cost management, and engineering education.