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Development of a simulation-based learning model for building information modeling course in vocational civil engineering education

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ABSTRACT

The rapid adoption of Building Information Modeling (BIM) in the construction industry requires vocational civil engineering graduates to develop competencies beyond technical modeling skills, including interdisciplinary coordination and collaborative project workflows. However, BIM instruction in vocational higher education remains predominantly software-oriented and lacks structured integration of authentic industry practices within formal coursework. This study aimed to develop and validate a semester-integrated simulation-based learning model embedded in a compulsory BIM course. Using a Research and Development approach based on the ADDIE framework, the study involved competency gap analysis, model design, expert validation, and classroom implementation. Five experts—two BIM academics, one instructional design specialist, and two industry practitioners—evaluated the model, resulting in an overall mean feasibility score of 4.48 (SD = 0.18), categorized as Highly Valid. The model was implemented over one semester with 32 fourth-semester students. CLO-aligned performance assessment showed average scores of 82.6 in modeling accuracy, 79.4 in coordination quality, 84.1 in clash detection effectiveness, and 86.3 in teamwork, while 81% of students reported improved understanding of interdisciplinary BIM workflows. The findings demonstrate that structured simulation supports industry-aligned competency development in vocational BIM education.

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Introduction

The integration of Building Information Modeling (BIM) into vocational civil engineering education requires instructional strategies that extend beyond procedural software training toward structured, industry-aligned learning embedded within formal coursework (Besné et al., 2021; Forcael et al., 2025; Hagan, Aryanti, & Saleh, 2025). In Indonesia, BIM adoption in mid- to large-scale building and infrastructure projects increasingly demands competencies in interdisciplinary coordination, clash detection, digital collaboration, and model-based decision-making. These competencies must be systematically developed within vocational curricula rather than delivered through short-term, stand-alone training(Aryanti et al., 2020; Border et al., 2024; Rani et al., 2023).

Despite this demand, BIM instruction in many Diploma-level civil engineering programs remains software-oriented and fragmented(Besné et al., 2021; Luo & Xi, 2020). Teaching commonly emphasizes step-by-step modeling procedures using Autodesk Revit without embedding students in collaborative project workflows(Li, 2021; Telaga, 2022). Preliminary curriculum review and classroom observations in a Diploma III Civil Engineering Program indicated that students were capable of producing individual 3D models but showed limited ability in model coordination, clash detection using Navisworks, interdisciplinary communication, and integrated project reporting. This gap suggests misalignment between industry competency requirements and course-level instructional design(Rahmadona et al., 2022; Telaga, 2022).

From a theoretical perspective, vocational education should replicate authentic occupational environments. Prosser's vocational education principles emphasize that effective vocational instruction must mirror real workplace conditions, tools, and processes(Oroh, 2023; Suyitno et al., 2022). Conventional BIM instruction, when limited to demonstration and procedural replication, constrains this experiential cycle and reduces opportunities for collaborative problem-solving(Borkowski, 2023).

Furthermore, under the Indonesian National Qualification Framework (KKNI) and Outcome-Based Education (OBE) principles, Course Learning Outcomes (CLOs) must explicitly align with learning activities and assessment strategies(Aminah et al., 2025; Shallal, 2018). In vocational civil engineering education, BIM-related CLOs should encompass cognitive competencies at levels C3–C6 (analysis, evaluation, and problem-solving), psychomotor skills in modeling and coordination, and affective competencies such as teamwork, communication, and professional responsibility(Forcael et al., 2025; Succar et al., 2013). However, many BIM courses emphasize technical modeling skills while insufficiently addressing higher-order cognitive and collaborative dimensions.

To address this misalignment, a needs analysis was conducted through curriculum review and Focus Group Discussions involving three construction industry practitioners and three vocational education experts. Industry participants highlighted recurring competency gaps among graduates, particularly in: (1) interdisciplinary model coordination (architectural, structural, and MEP); (2) clash detection and conflict resolution; (3) interpretation of BIM outputs for decision-making; and (4) digital teamwork within project environments. These findings informed the instructional design of a structured simulation-based learning model integrated into a BIM course.

In this study, simulation-based learning is defined not merely as the use of BIM software but as a semester-based collaborative project environment that reflects authentic construction workflows. Unlike conventional lecture-based BIM instruction, the developed model positions BIM as a coordinated project simulation platform. Students are organized into interdisciplinary teams and assigned professional roles such as modeler, coordinator, and reviewer. Using Autodesk Revit for modeling and Navisworks for coordination, they develop discipline models, conduct clash detection, generate coordination reports, and present integrated outputs. Structured discussion and reflective evaluation stages are incorporated to strengthen conceptual understanding and professional reasoning.

The instructional model was developed using a Research and Development (R&D) approach based on the ADDIE framework (Analysis, Design, Development, Implementation, and Evaluation). ADDIE was selected due to its systematic alignment between needs analysis, instructional design, iterative validation, classroom implementation, and measurable evaluation within curriculum-integrated contexts(Isya et al., 2023; Mdodana-Zide, 2024; Sun & Khamcharoen, 2025). Following the analysis phase, the model was validated by five experts in BIM and instructional design. Implementation was conducted over one full semester in two parallel classes involving 32 fourth-semester students with varied levels of digital proficiency.

To accommodate differences in student readiness, scaffolding strategies, guided demonstrations, structured teamwork protocols, and formative feedback mechanisms were incorporated. Evaluation of the model included expert validation scores, rubric-based assessment aligned with CLOs, observation of collaborative performance, analysis of coordinated BIM outputs, and structured feedback from students and instructors. These evaluation mechanisms ensure that learning effectiveness is measured not only in technical modeling accuracy but also in cognitive analysis, collaborative coordination, and professional communication.

Although previous studies have discussed BIM education and software-based training, limited research has developed and empirically validated a semester-integrated, simulation-based learning model specifically designed for vocational civil engineering programs under KKNI and OBE frameworks(Hagan et al., 2025; Telaga, 2022). Many existing approaches focus on short-term workshops or isolated technical modules without embedding collaborative workflows into formal course structures(Barakat et al., 2024; Ekundayo et al., 2020; Patching et al., 2023).

Therefore, this study aims to develop and validate a simulation-based learning model integrated into a compulsory BIM course in vocational civil engineering education. By aligning industry competency needs, experiential learning principles, and outcome-based curriculum frameworks, the research contributes a structured and empirically validated instructional model that strengthens collaborative BIM competencies within semester-based vocational learning environments. The model is designed to be adaptable for similar vocational institutions seeking to enhance industry relevance while maintaining formal curriculum alignment

Method

This study employed a Research and Development (R&D) approach to develop and validate a simulation-based learning model embedded within a compulsory fourth-semester Building Information Modeling (BIM) course (3 credits) in a Diploma III Civil Engineering program. The development process followed the ADDIE framework (Analysis, Design, Development, Implementation, and Evaluation) to ensure systematic alignment between competency needs, instructional design, validation procedures, and classroom implementation within a formal curriculum context. The study was conducted in one vocational higher education institution, and the model was designed based on Outcome-Based Education (OBE) principles aligned with KKNI descriptors to enable contextual adaptation in similar vocational programs.

Model validation involved five experts selected purposively to ensure representativeness of academic and industry perspectives, consisting of two BIM academics (minimum Master's degree with at least five years of teaching experience), one instructional design expert specializing in curriculum and learning model development, and two BIM industry practitioners with a minimum of five years of professional experience in BIM implementation. Limited implementation involved 32 fourth-semester students enrolled in the compulsory BIM course (two parallel classes, 16 students each). All participants had completed a prerequisite CAD course and possessed basic familiarity with Autodesk Revit, but had no prior interdisciplinary BIM coordination experience. The students demonstrated heterogeneous levels of digital proficiency.

The Analysis phase aimed to identify competency gaps between existing BIM course delivery and industry requirements. Data were collected through curriculum document analysis (course learning outcomes, syllabus, and assessment rubrics aligned with OBE and KKNI), classroom observations of prior course implementation, and Focus Group Discussions involving three industry practitioners and three vocational education experts. Competencies were mapped into cognitive (C4–C6: analysis, evaluation, and problem-solving), psychomotor (modeling accuracy, coordination execution, clash detection), and affective (team collaboration and professional responsibility) domains. A competency mapping matrix was used to compare expected CLO indicators with observed student performance and industry standards.

During the Design phase, identified competencies were translated into a structured semester-based instructional syntax integrated into the BIM course. The learning model consisted of five stages: orientation and problem framing, guided demonstration, structured discussion and case analysis,

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Vol. 12, No. 1, 2026, pp. 65-72

collaborative BIM project simulation, and reflective evaluation. Students were organized into interdisciplinary teams of four to five members and assigned rotating professional roles (modeler, coordinator, reviewer) to simulate authentic BIM workflows. Each weekly session (150 minutes) was structured into approximately 60 minutes (40%) of structured lecture, demonstration, and guided discussion, followed by 90 minutes (60%) of supervised laboratory-based BIM simulation. In addition, students completed independent team-based project tasks outside scheduled class hours to ensure continuous development of the semester-long simulation project. This proportional structure was intentionally designed to balance conceptual understanding with procedural mastery, reflecting the collaborative and technical nature of BIM practice.

In the Development phase, the research produced a simulation-based learning model handbook, instructor guide, semester lesson plan, BIM project simulation scenarios based on a mid-scale building case, CLO-aligned assessment rubrics, and validation instruments. Validation instruments employed a five-point Likert scale (1 = very inappropriate; 5 = very appropriate), with items constructed based on CLO alignment, instructional design quality, feasibility, and industry relevance indicators. Content validity was ensured through preliminary expert review prior to formal validation. Quality control procedures included CLO–activity alignment checking, peer review of instructional materials, and formative revisions based on expert feedback.

The model was implemented over one full semester (16 meetings) within the regular BIM course schedule. Students developed architectural and structural models, performed interdisciplinary integration, conducted clash detection using Navisworks, and produced coordination reports as part of a continuous semester project. Formative evaluation was conducted through weekly progress monitoring, interim project reviews, and structured instructor feedback sessions. Mitigation strategies included additional scaffolding sessions for students with lower modeling proficiency, structured role rotation to ensure equitable participation, and milestone checkpoints to maintain project pacing.

Quantitative validation data were analyzed using mean score calculations for each dimension, with feasibility categorized as ≥4.20 (Highly Valid), 3.40–4.19 (Valid), 2.60–3.39 (Moderately Valid), and <2.60 (Less Valid). Qualitative feedback was analyzed thematically and used for model refinement prior to full implementation. Student performance was assessed using CLO-aligned rubrics measuring modeling accuracy, coordination quality, clash detection effectiveness, and teamwork. Descriptive statistics were used to summarize performance outcomes. To enhance reliability, data triangulation was conducted by comparing expert validation results, student performance data, classroom observations, and student feedback questionnaires. The study focused on development and feasibility validation within one institution involving 32 students; therefore, broader multi-institutional implementation is recommended to examine generalizability and long-term effectiveness.

Results and Discussions

This study developed a simulation-based learning model for a BIM course and evaluated its effectiveness across three dimensions: competency gap identification, model feasibility validation, and limited classroom implementation.

The gap level categorization (High, Medium–High) was determined based on triangulated findings from curriculum document analysis, classroom observation records, and Focus Group Discussion (FGD) feedback. A gap was categorized as “High” when more than 70% of observed indicators showed misalignment between expected CLO standards and demonstrated student performance, while “Medium–High” indicated partial competency attainment with structured but inconsistent practice

The competency gap analysis revealed critical deficiencies in students’ BIM workflow comprehension and technical coordination skills, both categorized as High gaps, while professional collaboration and attitude were rated Medium–High. Traditional instruction emphasized software introduction and policy knowledge, but lacked structured practice in interdisciplinary coordination and teamwork.

Table 1. Competency Gap Levels of BIM Students

Competency	Gap Level	Description
BIM Knowledge	High	Students understand basic modeling commands but lack understanding of interdisciplinary coordination and information flow
Technical Skills	High	Limited practice in clash detection and model integration
Professional Attitude	Medium-High	Teamwork and digital communication are unstructured and incidental

The findings confirm that software-focused instruction alone is insufficient to develop industry-relevant competencies. Identifying priority gaps allowed redistribution of learning activities, with a 60% focus on simulation to enhance procedural mastery and collaborative performance.

Weekly sessions were structured with 40% orientation and 60% supervised BIM simulation (150 minutes per session). Early meetings focused on conceptual understanding, while simulation intensity increased over the semester. Students rotated roles as modelers, coordinators, and reviewers, while instructors acted as facilitators, technical coaches, and evaluators.

Table 2. Weekly Time Distribution

Week	Orientation (min, 40%)	Demonstration Discussion (min)	Simulation (min,60%)	Notes
1	60	90	0	Initial orientation & course introduction
2	60	90	0	Introduction to software & BIM concepts
3	60	30	60	Start of project simulation, role assignment
4-15	60	30	90	Intensive simulation and milestone reviews

Structured role rotation and proportional time allocation enhanced engagement, reduced passive learning, and aligned classroom activities with vocational practice. Five experts (two BIM academics, one instructional design expert, and two industry practitioners) validated the model. The overall mean score was 4.48/5 (SD = 0.18), categorized as Highly Valid. Industry relevance received the highest score (4.70), while clarity of syntax scored 4.40.

Table 3. Expert validation Scores (Likert 1-5)

Assessment aspect	Mean Score	SD	Category
Industry Relevance	4.70	0.12	Highly Valid
Clarity of Syntax	4.40	0.15	Highly Valid
Model Structure Consistency	4.50	0.20	Highly Valid
Rubric Appropriateness	4.45	0.18	Highly Valid
Overall Mean	4.48	0.18	Highly Valid

High validation scores confirm the model's relevance to industry standards. Expert recommendations on formative checkpoints and rubric clarity were incorporated, enhancing its effectiveness in classroom implementation. The model was applied to 32 fourth-semester students. Competency achievement was assessed using course learning outcome-aligned rubrics.

Results indicate that simulation-based learning effectively improves technical skills, teamwork, and workflow comprehension. Students reported better understanding of interdisciplinary coordination compared to conventional software-focused instruction. These scores indicate satisfactory achievement of the targeted CLO indicators within the semester-based implementation rather than comparative improvement against a control or baseline condition.

Table 4. Average Student Competency Scores

Competency Dimension	Mean Score (0 - 100)	Description
Modeling accuracy	82.6	Accuracy of models according to specifications
Coordination quality	79.4	Quality of coordination among models
Clash detection effectiveness	84.1	Effectiveness in detecting model conflicts
Team collaboration	86.3	Team collaboration performance

Table 5. Contribution of Each Learning Stage

Learning Stage	Competency Focus	Contribution to Outcomes
Orientation	Workflow comprehension	Strengthened conceptual alignment
Demonstration	Minimize procedural errors	Reduced early modeling mistakes
Structured Discussion	Problem solving	Improved response during clash detection
Simulation	Technical mastery	Largest improvement in technical skills
Reflection	Professional awareness	Increased professional awareness

The analysis of each learning stage highlights its role in developing cognitive, technical, and professional competencies in the BIM course. Orientation provided a conceptual understanding of workflow, while demonstration minimized procedural errors and reinforced correct modeling practices. Structured discussion enhanced problem-solving and decision-making, preparing students for complex coordination tasks. Simulation contributed most to technical mastery through iterative, hands-on application of BIM tasks, and reflection strengthened professional awareness, teamwork, and metacognitive skills. Overall, the sequential, scaffolded approach ensured balanced competency development aligned with academic outcomes and industry expectations.

Table 6. Challenges and Mitigation Strategies

Challenge	Impact	Mitigation Strategy	Outcome
Time management during clash coordination	Delayed tasks	Milestone checkpoints	Balanced participation, timely task completion
Uneven software proficiency	Modeling speed gap	Role rotation	Reduced the performance gap, and scaffolding is effective

Milestone checkpoints and role rotation effectively addressed participation inequity and proficiency disparities, demonstrating the importance of active scaffolding in simulation-based learning. The simulation-based BIM learning model successfully enhanced cognitive, technical, and collaborative competencies. Iterative simulation practice, structured role rotation, and alignment with industry workflow fostered both technical mastery and professional awareness. This approach demonstrates vocational authenticity, addressing limitations of conventional lecture-focused BIM courses.

The study was conducted at a single institution with one project scenario; longitudinal retention and multi-institutional generalizability remain untested. The model provides a replicable framework for BIM education, emphasizing practical skills, teamwork, and workflow comprehension, aligning with industry expectations for civil engineering graduates.

Conclusions

This study developed a simulation-based learning model integrated into a compulsory BIM course for vocational civil engineering education using the ADDIE framework. Expert validation by five specialists yielded a mean feasibility score of 4.48 (SD = 0.18), categorized as Highly Valid, confirming strong alignment with vocational learning principles and industry requirements. Implementation with 32 students over one semester demonstrated satisfactory competency achievement aligned with the defined Course Learning Outcomes (CLOs), with average scores of 82.6 in modeling accuracy, 79.4 in coordination quality, 84.1 in clash detection effectiveness, and 86.3 in teamwork, while 81% of students reported improved understanding of interdisciplinary BIM workflows compared to previous lecture-focused instruction. These results indicate that structured simulation enhances technical mastery, collaborative skills, and professional readiness. Although limited to one institution and project scenario, the model shows strong potential for broader adoption, and future research should investigate large-scale implementation and long-term competency retention.

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