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Teaching Collaborative BIM in Higher Education: A New Pedagogical Framework

Dhia Eddine Chenah[1], Conrad Boton[2]

[1] Graduate Student, LaRTIC – Research Laboratory on Information Technology in Construction, Department of Construction Engineering, École de technologie supérieure, Montreal, 1100 Notre-Dame Street West, Montreal, QC H3C 1K3, Canada,

[2] Full Professor, LaRTIC – Research Laboratory on Information Technology in Construction, Department of Construction Engineering, École de technologie supérieure, Montreal, 1100 Notre-Dame Street West, Montreal, QC H3C 1K3, Canada

Corresponding author: conrad.boton@etsmtl.ca

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Teaching Collaborative BIM in Higher Education: A New Pedagogical Framework

Collaborative Building Information Modeling (BIM) plays a critical role in the architecture, engineering, and construction (AEC) industry, yet BIM education still predominantly focuses on technical software skills, often neglecting the collaborative competencies required for interdisciplinary teamwork. This study proposes and validates a pedagogical framework for collaborative BIM education grounded in the Functional Trefoil model, which emphasizes communication, coordination, and production. A hands-on BIM clash detection assignment was designed to replicate professional workflows using industry-standard tools, including Newforma Konekt, Navisworks, Revit, and Tekla Structures, allowing students to engage in model federation, conflict resolution, and structured team collaboration. The assignment was implemented in the BIM830 course at École de technologie supérieure (ÉTS) and evaluated through student surveys. Responses from 42 participants revealed increased engagement, satisfaction, and confidence in collaborative BIM practices, with over 85% reporting clear instructions, 90% valuing the collaborative effectiveness of the tools, and more than 80% indicating improved confidence in team-based BIM environments. The results demonstrate that integrating collaborative technologies and structured workflows into BIM education can effectively bridge the gap between theory and practice. The proposed approach offers a scalable and adaptable model for institutions seeking to modernize BIM curricula while highlighting the importance of equipping educators with digital and active learning competencies aligned with industry needs.

Keywords: building information modeling; BIM education; functional trefoil; collaborative work.

1. Introduction

The construction industry, often defined by its complexity, uncertainty, and inherent risks, relies fundamentally on collaboration among a wide range of stakeholders. Architects, engineers, contractors, subcontractors, suppliers, and clients—each contributing unique expertise and perspectives—must coordinate their efforts to achieve project objectives. Seminal research by the Construction Industry Institute (University of Texas at Austin. Construction Industry Institute 1991) showed that effective collaboration improves project performance, reduces costs, and enhances safety outcomes. More recent studies confirm that collaboration fosters trust, innovation, and more efficient decision-making across multidisciplinary teams (Forgues and Koskela 2009; Ibrahim et al. 2013) Despite these benefits, achieving effective collaboration in construction remains challenging. The industry's fragmented structure, characterized by multiple stakeholders with divergent interests, often undermines team cohesion and shared responsibility (Eriksson 2010; Mignone et al. 2016). Traditional contractual arrangements such as design–bid–build tend to exacerbate these issues by prioritizing individual gains and risk transfer over collective success (Lahdenperä 2012). Moreover, the inherent complexity of construction projects, with numerous interdependencies and evolving requirements, calls for advanced collaboration mechanisms and communication frameworks (Ghassemi and Becerik-Gerber 2011). To overcome these challenges, relational contracting approaches such as alliances, partnerships, and Integrated Project Delivery (IPD) have been introduced to promote risk- and reward-sharing, joint decision-making, and trust-based collaboration (El Asmar et al. 2013; Kent and Becerik-gerber 2010). However, while these contractual models encourage cooperation, their success depends heavily on the availability of effective digital tools capable of supporting real-time information exchange and multidisciplinary coordination. In this context, collaborative Building Information Modeling (BIM) has emerged as a critical enabler, providing shared digital environments where stakeholders can integrate models, detect conflicts, and manage information transparently throughout the project lifecycle. By combining contractual innovation with BIM-enabled collaboration, the construction industry can move toward more efficient, integrated, and resilient project delivery.

BIM represents a process of creating and managing a digital representation of the building. This representation encompasses not only its physical attributes, but also its functional and performance characteristics. This digital model contains data on materials, systems and spatial relationships, serves as a central repository of information accessible to all project stakeholders (Sacks et al. 2018). Unlike traditional 2D drawings, BIM models are interactive, making it possible to visualize and analyze real-time data from different design scenarios. A characteristic of BIM is its object-oriented nature. Each element of the model, from walls and doors to mechanical systems and equipment, is represented as a separate object with its own properties and attributes. Building Information Modeling (BIM) has become a cornerstone of digital trans-formation in the architecture, engineering, and construction (AEC) industry. By centralizing project data and enabling real-time collaboration, BIM enhances efficiency, reduces errors, and improves decision-making throughout a project’s lifecycle. Indeed, while BIM facilitates collaboration by allowing stakeholders to access and share project information in a centralized and integrated manner (Succar 2009), collaborative BIM is an iterative and multi-party process which aims to establish synergy between stakeholders around a centralized and interoperable digital model (Sacks et al. 2018). One of the foundations of collaborative BIM is the adoption of open file formats and common standards, such as the Industry Foundation Classes (IFC) and the BIM Collaboration Format (BCF). These standards allow interoperability between software and platforms used by the different project stakeholders (Sacks et al. 2018). Thus, data can be exchanged independently of the specific tools used by each actor. This collaborative approach creates an integrated work environment where information is shared in real time. Conflicts, whether spatial, temporal or functional, are identified and resolved proactively, with the aim of limiting the risk of project errors (Sacks et al. 2018). The teaching of collaborative BIM (Building Information Modeling) presents several key challenges and opportunities (Boton 2020; Boton et al. 2018). As BIM increasingly becomes the standard in the construction and architecture industries, it is crucial to equip students with the skills necessary to work in integrated, multidisciplinary teams.

However, traditional BIM education often prioritizes technical software skills over essential collaborative competencies, limiting students' ability to engage effectively in interdisciplinary teamwork. To address this gap, educational institutions have explored active learning strategies, such as the flipped classroom model, which has already been implemented at École de Technologie Supérieure (ÉTS) (Boton 2020). The teaching of BIM at ÉTS has evolved through a structured three-step approach closely aligned with industry needs and the institution's applied engineering mission. The first step took place between 2009 and 2011 with a "design lab" experiment jointly conducted with McGill University. This initiative introduced undergraduate students, practitioners, and administrators to BIM through multidisciplinary design charrettes, emphasizing emerging technological competencies and showcasing BIM's potential for problem-solving, without being tied to a specific academic level (Forgues and Staub-French 2011). The second step was the creation of a standalone master's-level BIM course, the first of its kind in Québec. This intensive course aimed to provide students with a solid introduction to BIM processes, practical modeling skills, and interoperability issues. The third step was the establishment in 2017 of a dedicated graduate short program in BIM and a Diploma of Specialized Studies (DESS) in BIM and Digital Innovation, designed in response to growing industry demand for highly skilled professionals. These programs are organized around a set of 10 courses, with BIM830 functioning as the foundational introduction to BIM. While these initiatives contributed to raising awareness and improving technical competencies, they also revealed challenges such as limited integration of collaborative frameworks and insufficient emphasis on interdisciplinary teamwork. Thus, despite considerable efforts made over the past few years, the teaching of BIM-based collaboration remains a major area for improvement.

We sought to improve collaborative BIM education at ETS by: (1) Developing a theoretically-grounded pedagogical framework; (2) Re-designing the clash detection assignment to align with the new framework; and (3) Gathering student feedback on the effectiveness of the new clash detection assignment. The framework is based on theories from computer-supported collaborative work scientific domain, and organizes BIM collaboration into three key dimensions: communication, coordination, and production.

This study adopted a design science research (DSR) approach (Hevner and Chatterjee 2004; Johannesson and Perjons 2021) to iteratively improve collaborative BIM instruction in a classroom setting. The research process included a literature review to establish a theoretical foundation for BIM collaboration, an analysis of existing BIM-based practical sessions to identify challenges and learning practices, the development of revised instructional activities informed by these findings, and the pilot implementation and exploratory assessment of these activities within an academic course.

The steps of the methodology are presented in Figure 1.

2. Literature Review and Theoretical Framework

Research on BIM education consistently points to a misalignment between the skills emphasized in academic programs and those demanded by industry. While many curricula prioritize technical proficiency in software such as Revit, Navisworks, or Tekla, employers increasingly highlight the importance of interdisciplinary collaboration, communication, and coordination as essential competencies for BIM-enabled practice (Abdirad and Dossick 2016; Barison and Santos 2010; Sacks and Pikas 2013). Studies show that this software-centric approach leaves graduates underprepared to address the teamwork, decision-making, and conflict-resolution challenges inherent in collaborative

BIM projects (Bozoglu 2016; Peterson et al. 2011). Zhao et al. (Zhao et al. 2015) further argue that without structured opportunities for joint problem-solving, students risk perceiving BIM as an individual rather than a collective activity. More recent works confirm these gaps, pointing to the persistent mismatch between employer expectations and graduate capabilities, and stressing the need for pedagogical strategies that explicitly cultivate collaborative competencies alongside technical skills (Dotta Correa et al. 2025). Addressing this misalignment is critical not only for improving graduate employability but also for supporting the construction industry's ongoing digital transformation.

2.1 Conceptual analysis

The first step of this study was a detailed review of the scientific literature on Computer-Supported Cooperative Work (CSCW), which provided the theoretical foundations for analyzing collaboration in digital environments. CSCW research has produced several influential models that conceptualize collaboration as the interplay between communication, coordination, and production, often referred to in francophone literature as the "trèfle fonctionnel" (Béguin and Darses 1998; Salber et al. 1995). These models highlight that effective collaboration is not limited to information exchange but also involves aligning tasks and resources, managing interdependencies, and producing shared outputs. Such frameworks were essential in identifying which theories could support the design of a coherent pedagogical approach to collaborative BIM.

The theoretical foundations of the *Functional Trefoil* model proposed in this paper are rooted in these well-established models. This model highlights the three main dimensions of collaboration: communication, coordination, and production.

Communication facilitates the exchange of information among team members and encompasses multiple layers, including verbal and non-verbal exchanges, formal and informal channels, and synchronous as well as asynchronous interactions. Shannon and Weaver's (Shannon and Weaver 1949) seminal work laid the foundation for communication theory, emphasizing the transmission of signals and the disruptive role of noise in the communication process. Expanding on this, Daft and Lengel (Daft and Lengel 1986) introduced media richness theory, which posits that the effectiveness of communication depends on the fit between the communication medium and the complexity of the information being conveyed. In collaborative settings, rich media such as face-to-face meetings or video conferencing are more effective for complex and ambiguous tasks, whereas lean media such as emails or memos are adequate for routine exchanges. Furthermore, communication dynamics are shaped by social and cultural factors. For example, Tannen's (Tannen 1990) work on gender and discourse illustrates how differences in communication styles may influence collaborative interactions, underscoring the need for adaptability in diverse teamwork environments.

Coordination refers to the alignment of tasks, resources, and activities to achieve collective goals. Malone and Crowston (Malone and Crowston 1994) define coordination as the management of dependencies between activities, identifying mechanisms such as standardization, mutual adjustment, and direct supervision, each suited to specific organizational contexts. In project management, coordination is often facilitated through methodologies such as Agile and Scrum, which emphasize iterative planning, continuous feedback, and adaptive workflows (Schwaber and Beedle 2002). Effective coordination also relies on shared mental models, suggesting that team members must develop a common understanding of tasks, roles, and processes to collaborate effectively. Such shared cognition improves efficiency, reduces misunderstandings, and enhances collective problem-solving (Cannon-Bowers et al. 1993).

Production, the third dimension of the Functional Trefoil, concerns the creation and delivery of collaborative outputs. It involves both the technical execution of tasks and the strategic achievement of objectives. In collaborative contexts, production is inherently interdependent: one team member’s output frequently becomes the input for another, reinforcing the need for integration across tasks. Insights from work design theories, particularly Hackman and Oldham’s (Hackman and Oldham 1976) Job Characteristics Model, explain how task structuring through dimensions such as variety, identity, significance, autonomy, and feedback can improve motivation and performance at both the individual and team levels.

To ensure a comprehensive understanding, the literature review also encompassed BIM pedagogy and collaborative learning research. Systematic reviews and empirical studies confirm that BIM education has often prioritized technical software skills while paying insufficient attention to collaborative competencies (Abdirad and Dossick 2016; Sacks and Pikas 2013). At the same time, recent works show that project-based and interdisciplinary approaches significantly enhance students' teamwork and problem-solving abilities, better reflecting real-world professional contexts (Monson et al. 2015; Peterson et al. 2011). By combining insights from CSCW and BIM education literature, this phase established a coherent and rigorous theoretical foundation for developing our pedagogical framework.

2.2 Development of a theoretical framework

This phase focuses on developing a theoretical framework to guide educators in enhancing collaborative BIM teaching. The framework provides a structured approach to fostering interdisciplinary collaboration and serves as a foundation for integrating these principles into practical coursework.

Building on insights from the literature review, key concepts are systematically organized into a coherent framework. The development process involves identifying fundamental principles and components of collaborative BIM teaching, structuring these elements into a logical and practical framework, and validating the framework through its application in a real course setting. To facilitate this process, concept mapping tools such as Microsoft PowerPoint and Lucidchart are used to visually structure and refine the framework.

The proposed framework, based on the "Functional Trefoil" model of collaboration, which encompasses the communication space, the coordination space and the production space, provides a structured approach to strengthen and improve BIM collaboration in student projects (Figure 2).

2.2.1 The communication space

The literature review highlights the need to use digital communication platforms and a common data environment (CDE) to streamline communication (Bedoiseau et al. 2022; Hochscheid et al. 2022). Tools such as Microsoft Teams, Slack and Zoom provide platforms for synchronous and asynchronous interactions, while a CDE like Autodesk Construction Cloud (ACC) or Newforma Konekt centralizes BIM models and associated documents. Establishing structured communication protocols, including guidelines regarding frequency, channels and etiquette, is important. Regular meetings and updates should be scheduled to ensure ongoing dialogue and problem resolution. Transparency of information flow can be maintained by documenting all changes, updates and comments in the CDE.

To assess the effectiveness of the communication space, various metrics can be used, such as frequency and quality of interactions, effectiveness of the feedback loop, and student engagement levels. Surveys and communication logs can help track these metrics, providing insight into the communication dynamics within the project. The feedback loop can be measured by evaluating how students respond to feedback through improvements in performance, engagement, and the quality of subsequent work (Jellicoe and Forsythe 2019).

2.2.2 The coordination space

It is important to clearly define roles and responsibilities within the project team, as this helps distribute the workload evenly and leverage individual strengths. A BIM Execution Plan (BEP) in the form of a map, which describes the processes and standards for BIM implementation, serves as a guiding document for coordination efforts.

Phased planning divides the project into key deliverables with specific deadlines, while role-based coordination assigns tasks based on students' strengths and learning goals. Implementing standardized processes for mock-up creation, data sharing and version control ensures quality throughout the project.

Coordination effectiveness can be assessed using measures such as task completion rates, clarity and execution of defined roles, and adherence to the BEP. Peer and instructor reviews, as well as project tracking tools, can provide valuable data on these aspects.

2.2.3 The production space

Standard BIM software such as Autodesk Revit, ArchiCAD or Tekla Structures are essential for creating models. Model integration tools facilitate conflict detection and coordination between different disciplinary models. Quality control mechanisms, such as scheduled review sessions for mock-up verification and clash detection, are intended to support the alignment of student work with defined instructional and industry standards. These standards include model accuracy, adherence to project specifications, coordination efficiency, and conformance to modeling protocols defined in the BIM Execution Plan (BEP). Regular review cycles also promote early detection of modeling errors and allow for the iterative improvement of coordination practices (Paik et al. 2022).

Collaborative modeling sessions, in which students work together on the BIM model, promote collaboration and real-time learning. Implementing version control systems and documentation procedures makes it possible to manage changes and maintain the integrity of the model. Production space efficiency can be evaluated based on the clarity, consistency, and spatial accuracy of the coordinated outputs produced by the students, as well as the effectiveness of their proposed conflict resolution strategies.

3. Analysis of a current practical work

3.1 Documentation analysis

The objective of this analysis is to evaluate existing assignments to identify areas for improvement in BIM collaborative learning. The practical sessions analyzed are part of the BIM courses taught at École de Technologie Supérieure (ÉTS), and the selected assignment must be directly related to BIM collaboration. To achieve this, a comparative analysis was conducted on the deliverables of the compulsory BIM courses in the master's program in project management, specifically BIM810, BIM820, BIM830, and BIM840.

The selection criteria for identifying relevant practical sessions include BIM collaboration, Project-based learning, Software-based learning, Interoperability between

BIM software, Federation of multidisciplinary models. All mandatory BIM course assignments are reviewed and classified based on their relevance to collaborative BIM. One assignment is then selected for in-depth analysis. The selected practical session is examined across four key dimensions:

- Processes – Workflow structure and student interactions.
- Software – Tools and technologies used.
- Educational materials – Resources provided for learning.
- Educational objectives – Alignment with learning outcomes.

To gain student perspectives, a survey is conducted among those who have completed the assignment. The survey, administered via Microsoft Forms, collects feedback on their learning experience, challenges faced, and areas needing improvement. Data analysis is carried out using Excel for quantitative insights, while document analysis tools are employed to assess teaching materials and assignments.

The expected outcomes of this phase include a comprehensive evaluation of the existing assignment, the identification of specific areas for improvement, based on both theoretical frameworks and student feedback, a structured plan for developing an improved version of the assignment.

3.2 The survey of the old deliverables

The survey was administered to the students registered in the BIM830 course in the sessions before the winter 2024 session. The questionnaire included several questions aimed at assessing different aspects of deliverable 3 (Navisworks) and the associated learning experience. Deliverable 3 was selected as the focus of this case study because it is the first major team-based assignment in the course that requires students to integrate BIM concepts in a collaborative manner. Unlike earlier assignments, which are mainly introductory and individual, Deliverable 3 emphasizes teamwork, role distribution, and the use of collaborative tools—making it a critical component for assessing communication, coordination, and production, as conceptualized in the Functional Trefoil model.

The student survey was designed to capture both quantitative and qualitative feedback on the redesigned assignment. It combined closed-ended Likert-scale items and a limited number of open-ended questions. The closed-ended questions focused on clarity of instructions, workflow efficiency, task distribution, relevance of learning resources, and the extent to which the assignment supported the learning objectives. The open-ended items invited students to provide feedback on challenges encountered and suggestions for improvement. To ensure content validity, the survey questions were adapted from prior studies on BIM education and collaborative learning (Abdirad and Dossick 2016; Peterson et al. 2011) and reviewed by two faculty members with expertise in BIM pedagogy. A pilot test was conducted with a small group of graduate students not involved in the course to refine clarity and wording.

Here are some sample questions:

- "How clear and understandable did you find the instructions for deliverable 3?"

- "How do you evaluate the effectiveness of the software used for deliverable 3?"
- "Have you encountered any difficulties in distributing tasks within your team?"

Participants were asked to rate each question on a satisfaction scale ranging from "Not at all" to "Very well". This evaluation measures students' perceptions of the quality of instructions, the effectiveness of software tools, collaboration within teams and the relevance of learning resources. The main objective was to collect feedback from students regarding deliverable 3. Survey results can also be used to adjust teaching methods and identify areas where improvement is needed.

4. Development of Revised BIM Sessions

This phase focuses on developing a revised version of the BIM course practical sessions based on the proposed framework, integrating key improvements to enhance collaboration. The main objectives are to develop a new version of the assignment with clearly defined elements, ensure that the revised assignment aligns with the theoretical framework, strengthen the collaborative aspects of the learning experience. The revised practical sessions are structured around four key elements:

- Processes: Establishing clear workflows and structured collaborative procedures.
- Software: Integrating appropriate BIM tools to facilitate teamwork and coordination.
- Instructional materials: Developing comprehensive educational resources.

- Learning objectives: Refining outcomes to better align with collaborative competencies.

This structured approach is intended to promote student engagement in realistic, industry-relevant collaboration, potentially reinforcing both technical proficiency and teamwork skills.

4.1 Developing a new process map

A new process map has been developed based on the principles of the proposed theoretical framework. This revision addresses the challenges identified in the analysis of the original practical sessions. The new process is represented both visually, using Lucidchart, and textually, with detailed explanations.

The following methodology was used to create the process mapping, including the meaning of key graphic elements and the roles of participants:

- Green circles indicate the starting point, marking the beginning of activities.
- Red circles represent the end of the process, signaling task completion.
- Green tasks correspond to communication activities between team members, such as meetings, information sharing, and task status updates.
- Black tasks are dedicated to modeling activities, focusing on BIM software for model creation and modification.

- Red iteration points highlight critical decision-making stages, typically formulated as yes/no questions that dictate whether tasks proceed or require adjustments.
- Files in the last row represent the models and documents produced or utilized throughout the process.
- Role-specific tracks define team responsibilities, including the manager, architect, and engineer, providing a clear visualization of assigned tasks and collaborative workflows.

This structured representation enhances clarity, ensuring that all participants understand their roles, interactions, and decision points within the BIM collaboration framework.

This section presents the new process for carrying out the new proposed practical sessions in detail. This process is presented in Figure 3b while the old process is presented in Figure 3a, for comparison purposes. These processes are related to the deliverable 3. During the third week's practical work, students use Navisworks Manage to integrate the two models created in the previous weeks, perform multidisciplinary coordination, detect and resolve clashes and other coordination issues, and provide recommendations to the professionals involved.

4.2 Collaborative platform

The new process mapping integrates the use of a collaborative platform to enhance communication, tracking, and traceability in managing conflicts between different disciplines. The selected platform, Newforma Konekt (formerly known as BIMTrack), serves as a centralized hub for information exchange, ensuring that all project stakeholders have access to up-to-date data and structured workflows.

To assess its potential integration, a detailed analysis of Newforma Konekt's functionalities was conducted. The objective was to clearly identify the key features that can be leveraged in the new deliverable and evaluate how they can enhance student collaboration. The analysis focused on several critical aspects:

- Centralized communication: Integrated messaging and issue-tracking tools streamline interactions, ensuring that discussions and decisions are documented and easily accessible.
- Version control and document management: Students can upload, share, and review BIM models, reducing inconsistencies and miscommunication related to outdated files.
- Task assignment and workflow automation: The ability to assign tasks, set deadlines, and track progress ensures a structured approach to collaborative work.
- Commenting and annotation Features: Students can annotate BIM models, providing clear visual feedback on issues and proposed solutions.

By incorporating Newforma Konekt (formerly known as BIMTrack) into the practical sessions, students are expected to gain hands-on experience with real-world collaboration tools, reinforcing industry-standard practices. The platform supports a more structured, transparent, and potentially more efficient approach to BIM conflict management and coordination, which may help students begin to bridge the gap between theoretical knowledge and practical application.

4.3 The educational material part of the improved deliverable

To address the issues identified, the teaching materials have been updated, particularly the video modules developed to help learners complete the practical work, while adapting our teaching approach to better meet students' needs. A total of 30 video modules, each averaging 3 minutes in length, were developed on the use of Autodesk Revit, Tekla Structures, Navisworks Manage, and Newformat Konek software to support the completion of practical assignments. We used OBS Studio, a free and open-source software for video capture and live streaming, configured to record in Full HD (1920x1080) at 60 frames per second. This setup ensures smooth playback and clear visuals. For video compression, we selected the H.264 codec, known for its efficiency and compatibility with most devices. The compression profile was set to "High" with a bitrate of 5000-10,000 kbps to maintain optimal visual quality.

For video editing, we opted for DaVinci Resolve, a professional-grade software offering advanced editing, color correction, and audio enhancement tools. This choice allowed us to adjust brightness and contrast for improved readability, perform color corrections for consistent visuals, cut unnecessary segments to maintain focus, and add smooth transitions and animations to explain complex concepts. The tutorials were structured logically, guiding students step by step through the learning process. Once finalized, the videos were exported in optimized formats for various platforms, including YouTube and Moodle, ensuring consistent quality and seamless accessibility.

To reduce cognitive overload and maintain student engagement, we restructured the videos into short, focused segments. Each tutorial now lasts between five and fifteen minutes, concentrating on a single task or software feature. Videos are indexed with chapters, allowing students to quickly access relevant sections. High-quality AVC (H.264) compression settings were used to maximize clarity, and all recordings are available in Full HD (1080p) resolution for crisp, detailed visuals. Clear and well-articulated subtitles were added, displayed over a black background to improve readability.

All tutorials have been updated to align with the latest software versions, including Autodesk Revit 2024 and Navisworks 2024. These updates introduce students to new features, interface modifications, and industry best practices, ensuring they develop skills that are directly applicable in professional BIM environments. By integrating modern video production techniques and industry-aligned content, this revamped approach provides students with high-quality, interactive, and accessible learning resources, reinforcing both technical proficiency and practical application in BIM software.

5. Pilot of Revised BIM Sessions

The final phase consisted of the pilot implementation of the enhanced lab in an authentic educational setting, accompanied by an exploratory evaluation based on student feedback. In line with the Trefoil model, the primary objectives of this phase were to integrate the revised lab into the BIM830 course on a trial basis, to collect and analyze student feedback, and to conduct a preliminary comparison with the original assignment in order to identify potential areas of improvement.

Under the supervision of the instructor, students completed the revised assignment as part of this pilot, with the implementation process being closely monitored to document its application and to ensure alignment with the proposed guidelines. Upon completion, students participated in a final survey aimed at gathering indicative feedback on instruction clarity, collaboration effectiveness, and overall satisfaction, rather than establishing conclusive measures of effectiveness.

Survey responses and student performance data were analyzed to compare the revised assignment with the original version. Student performance data referred specifically to the quality of the submitted assignments, as assessed by the course instructor within the standard evaluation framework of BIM830. The grading criteria emphasized model completeness, accuracy, coordination outcomes, and adherence to assignment requirements. Key indicators included student engagement, quality of collaborative work, and achievement of learning objectives. Data collection were conducted via Microsoft Forms, while analysis is performed using Excel.

The expected outcomes included validating the effectiveness of the revised practical sessions in improving collaboration and identifying strengths and areas for further enhancement. The survey was administered to 42 students enrolled in the Winter 2024 session of BIM830, using the same questionnaire as in the initial analysis phase.

5.1 Context of the pilot

During the Winter 2024 session, students in the BIM830 course were introduced to the revised deliverable as part of a pilot implementation. The study involved the full cohort of 32 students enrolled in the course during this implementation semester. While this sample corresponds to the total course enrolment, it is treated as a convenience cohort intended to capture the range of perspectives available within the pilot context, rather than to support statistical generalization.

The students are divided into different roles, such as architect, engineer, and BIM manager, to collaboratively work on a project using various software tools. The process begins with a kickoff meeting where the team defines the project objectives and assigns roles. The manager sets up the project in the Newforma Konekt platform, adding team members and their respective responsibilities. The architect and engineer then check the compatibility of their models in Revit and Tekla, exporting them in formats (NWC for Revit and IFC for Tekla) for sharing through Newforma Konekt. The manager uses Navisworks to check the models, identify conflicts between the architectural and structural models, and communicate necessary corrections to the team. These conflicts are resolved by adjusting the models in Revit and Tekla, followed by re-exporting and re-checking until all issues are resolved. The final versions of the models and conflict reports are archived in Newforma Konekt for future reference.

The educational goal of this practical is to enhance students' understanding and skills in BIM project management. Students learn to use industry-standard software like

Revit, Tekla, Navisworks, and Newforma Konekt for model creation, validation, and coordination. They develop communication and collaboration skills through the centralized platform, Newforma Konekt, and practice conflict detection and resolution using Navisworks' Clash Detective tool. Additionally, students gain experience in managing a BIM project, organizing roles, and ensuring that the models are accurately exported and documented. The course is supplemented by a series of instructional videos, which provide detailed explanations and visual aids, helping students better grasp the concepts and tools involved in BIM project management. These resources aim to equip students with the practical knowledge needed to succeed in the industry.

To assess the impact of the revised assignment, both collaborative skills and technical proficiency were evaluated through complementary instruments. Collaborative skills were measured using survey items designed to capture students' perceptions of teamwork, role distribution, and communication effectiveness, supported by self-assessments of group dynamics. Technical proficiency was assessed through instructor rubrics applied to the submitted BIM models, focusing on criteria such as accuracy of geometry, completeness of information, interoperability between disciplines, and the ability to resolve model clashes. Although peer evaluations and external benchmarks were not employed in this pilot, these limitations are acknowledged and identified as areas for future refinement.

5.2 Survey results

Figure 4 to Figure 10 presents how the results of the second survey on the new practical sessions compare to the results of the first survey.

Overall, students perceived the collaborative tools as more effective after the introduction of the new platform. Prior to its use, most respondents rated the software as only “somewhat effective” (86%), with a small minority describing it as “effective” (14%). Following the pilot implementation, perceptions improved substantially: 71% of students rated the tools as “effective” and 21% as “highly effective” (Figure 4). Beyond percentages, open-ended feedback revealed that students particularly valued the platform’s ability to centralize communication and track design conflicts, which they perceived as reducing misunderstandings and delays within teams. This directly aligns with the communication and coordination dimensions of the Functional Trefoil model, as students felt that the platform provided clearer channels for exchanging information and better mechanisms for managing interdependencies. At the same time, some respondents reported difficulties in mastering the interface and integrating it seamlessly into their workflow, pointing to a learning curve that limited its immediate impact on the production dimension. These results suggest that while the platform enhanced collaboration, complementary training and ongoing support are necessary to fully realize its benefits. Moreover, the experience highlights the potential of integrating similar platforms into other BIM-related courses or programs, offering a transferable model for improving collaborative competencies across curricula.

Students’ perceptions of the clarity of the instructions and workflow also improved following the pilot implementation (Figure 5). In the initial survey, only 43% of respondents considered the instructions “clear,” while 29% rated them as “somewhat clear” and 14% as “not clear.” After revisions, 79% of students rated the instructions as “clear,” and no respondent selected “not clear.” The proportion of students identifying the instructions as “very clear” remained constant at 14% across both surveys. Beyond percentages, student comments suggested that the revised instructions provided more explicit guidance on sequencing tasks and using the platform, thereby reducing ambiguity during group work. This improvement reflects stronger coordination, as clarified instructions enabled students to better align roles, responsibilities, and task dependencies. At the same time, the absence of growth in the “very clear” category signals a need to refine the pedagogical design further, for instance by incorporating step-by-step exemplars or interactive tutorials that support both communication and production dimensions of the Trefoil. More broadly, these findings illustrate how refining instructional clarity can directly enhance collaboration, and they suggest that similar improvements could be extended to other BIM assignments or integrated into curricula at different institutions to foster more effective teamwork and project-based learning.

Students generally perceived the workflow as supportive of efficient time management and task completion (Figure 6). In the first survey, more than 80% of respondents rated the workflow as “effective,” while around 14% considered it “somewhat effective.” In the follow-up survey, responses became more distributed: although a small proportion of students now rated the workflow as “highly effective,” the percentage selecting “effective” decreased, and more respondents identified it as “somewhat effective.” Importantly, no students in either survey considered the workflow to be “not effective.” Beyond these numbers, student feedback suggested that the revised workflow provided greater structure and accountability but also introduced additional steps that some found time-consuming. This ambivalence reflects a tension between coordination (ensuring systematic task alignment) and production (completing deliverables efficiently). While the structured workflow improved transparency in team interactions, it sometimes constrained flexibility, leading certain groups to perceive it as less efficient. These findings underscore the importance of balancing rigor with adaptability when designing collaborative processes. For future iterations, scaffolding the workflow with optional shortcuts or adaptive pathways could help reconcile these two dimensions. More broadly, these results provide valuable lessons for other BIM courses: workflows must be designed not only for consistency but also with room for customization to better reflect the realities of interdisciplinary collaboration in professional contexts.

The distribution of tasks and roles was generally perceived as satisfactory, with the majority of students reporting positive experiences and only one participant expressing dissatisfaction (Figure 7). In the first survey, more than 60% of respondents reported being “satisfied” or “very satisfied,” while 29% indicated being “somewhat dissatisfied.” In the second survey, perceptions improved: 71% of students rated the distribution as “satisfied,” and the proportion of “somewhat dissatisfied” responses decreased to 7%. Beyond these numbers, student comments suggested that clearer role definitions and structured guidance in the revised framework contributed to reducing ambiguity in team responsibilities, strengthening the **coordination** dimension of the Functional Trefoil model. At the same time, lingering dissatisfaction appears to stem from unequal workloads or a mismatch between assigned roles and individual competencies, highlighting the complexity of achieving fairness in collaborative settings. These results suggest that while structured frameworks improve clarity, additional strategies—such as peer-negotiated role assignments or rotating responsibilities—could enhance both **communication** and **production** by ensuring more equitable engagement. From a broader perspective, this insight underscores the importance of role management in collaborative BIM education and offers a transferable lesson for other courses and institutions seeking to foster stronger team dynamics.

Regarding the learning resources, most participants rated them as relevant or very relevant to the tasks associated with Deliverable 3 (Figure 8). In the first survey, however, perceptions were less positive: over 40% of students considered the resources only "somewhat relevant," with relatively fewer identifying them as "relevant" or "highly relevant." Following the pilot implementation of the collaborative platform, evaluations shifted markedly, with 79% of respondents rating the resources as either "relevant" (43%) or "highly relevant" (36%). Importantly, no students in either survey rated the resources as "not relevant." Beyond percentages, student feedback indicated that the revised materials were perceived as more practical, better tailored to the new workflow, and easier to integrate into team-based activities. This alignment illustrates stronger support for both communication (clearer references and shared understanding) and production (direct applicability to modeling tasks) within the Functional Trefoil model. However, the persistence of "somewhat relevant" ratings highlights that certain resources may still lack depth or contextual examples, suggesting a need for further refinement, such as adding case-based tutorials or interactive guides. From a curricular perspective, these findings emphasize the importance of continuously updating and contextualizing learning resources, not only to meet evolving software requirements but also to reinforce collaborative competencies across BIM education programs.

Additionally, the resources were perceived as effective or very effective in supporting the understanding of key concepts and techniques, thereby fulfilling their educational purpose (Figure 9). In the first survey, the majority of students (around 70%) rated the resources as "effective," while smaller proportions considered them either "highly effective" or "somewhat effective." After the pilot implementation of the collaborative platform, the distribution of responses became more balanced: the share of "effective" responses decreased to 43%, but this was offset by an increase in students rating the resources as "highly effective" (36%). The proportion of "somewhat effective" responses remained stable across both surveys. Beyond percentages, students highlighted that the revised resources provided more concrete examples of conflict detection and resolution, which made abstract concepts easier to apply in practice. This improvement directly reinforced the production dimension of the Functional Trefoil model, as resources were perceived not only as informative but as enabling tools for completing tasks more effectively. At the same time, the persistence of "somewhat effective" ratings suggests that some materials still lacked sufficient scaffolding to fully support diverse learning preferences, particularly for students less confident in technical modeling. For future iterations, layering resources with both introductory and advanced materials could strengthen inclusivity and adaptability. From a broader perspective, this result underlines the critical role of high-quality, practice-oriented resources in bridging theoretical understanding with applied collaborative BIM skills—an insight transferable to other courses and institutions seeking to balance technical and teamwork competencies.

Most students reported that Deliverable 3 contributed either moderately or significantly to achieving the intended learning objectives (Figure 10). In the first survey, prior to the introduction of the collaborative platform, the vast majority of students (86%) perceived its contribution as "moderate," with only a small proportion (14%) rating it as "significant." Following the pilot implementation, perceptions shifted noticeably: half of the students (50%) rated the deliverable's contribution as "significant," while "moderate" responses dropped to 43%. A small minority (7%) considered the impact to be only "light," and no students selected "not at all" in either survey. Beyond the percentages, student feedback indicated that the new assignment design better supported collaboration through clearer workflows and improved communication channels, which reinforced both the communication and coordination dimensions of the Functional Trefoil model. At the same time, the deliverable’s technical complexity provided more authentic opportunities for students to engage in production, linking conceptual learning with practical application. Nonetheless, the persistence of “moderate” and “light” ratings suggests that not all students benefitted equally, likely reflecting variations in prior experience or comfort with the new tools. This highlights the need for additional scaffolding and adaptive support to ensure more consistent learning gains. More broadly, the findings point to the potential of structured, collaborative assignments to strengthen the integration of technical and teamwork skills in BIM education, offering valuable insights for the design of curricula in other institutions.

In sum, the survey results provide valuable insights into participants' experiences and perceptions regarding Deliverable 3 and the tools used in the BIM830 course. Overall, feedback was positive, with most students highlighting improvements in the software, instructions, workflow, task distribution, and learning resources. These findings suggest that the revised assignment better supported collaboration by clarifying communication processes, streamlining coordination, and reinforcing the production of deliverables—three interdependent dimensions emphasized by the Functional Trefoil model. At the same time, some variability in responses indicates that certain students still experienced challenges, particularly related to workload balance and the efficient use of the platform. Addressing these areas for improvement could further enrich the collaborative learning experience and ensure more consistent engagement across the cohort. Beyond this course, the lessons learned highlight how a theoretically grounded framework can inform the design of BIM curricula, offering guidance for future adaptations in related courses and across institutions seeking to strengthen collaborative competencies alongside technical proficiency.

6. Discussion and lessons learned

6.1 Discussion

The primary objective of this study was to improve collaborative BIM education at ÉTS through the development and pilot implementation of a theoretically grounded pedagogical framework based on the Functional Trefoil model. The results indicate that this objective was effectively achieved. By explicitly structuring the learning activities around communication, coordination, and production, the proposed framework translated abstract collaborative principles into concrete, assessable practices within a BIM learning environment. Student feedback demonstrates not only increased engagement and satisfaction but also improved confidence in collaborative BIM workflows, suggesting that the framework successfully supported the development of non-technical competencies that are often underemphasized in traditional BIM education.

Most respondents found the software effective or very effective in supporting the collaborative aspects of the deliverable, indicating an overall positive perception of the collaborative capabilities of the tools used. Additionally, most participants rated the instructions and workflow as clear, with only one respondent finding them somewhat clear and another finding them very clear, suggesting a good general understanding of the instructions. Students also felt that the workflow was efficient, facilitating optimal time management and task completion. The distribution of tasks and roles was considered satisfactory or very satisfactory by the majority, although one participant expressed some dissatisfaction. This indicates an overall positive team dynamic but highlights the need to address individual concerns to further improve this dynamic. Regarding the learning resources, most participants found them relevant or very relevant to the tasks of deliverable 3. Additionally, they were considered effective or very effective in helping to understand the necessary concepts and techniques, achieving thus their educational objective. Most students felt that the deliverable helped them achieve the learning objectives moderately or significantly, with only one participant rating it slightly.

In sum, the survey results provide insight into participants' experiences and perceptions regarding deliverable 3 and the tools used in the BIM830 course. Feedback was generally positive, with a majority liking the software, instructions, workflow, task distribution and learning resources. Considering the identified areas for improvement could further enrich the collaborative learning experience and ensure better student engagement with the course teaching materials.

This study highlights the importance of integrating collaborative workflows into BIM education and demonstrates how structured, project-based learning can enhance students' technical and teamwork skills. By analyzing the limitations of traditional BIM teaching methods, this research addressed key challenges such as the lack of standardized collaborative processes, fragmented communication, and inconsistent student engagement in interdisciplinary work.

These findings confirm that grounding BIM pedagogy in a clear theoretical model can enhance both the learning experience and the acquisition of collaborative skills aligned with professional practice. The results confirm that adopting a structured, collaborative framework—centered on communication, coordination, and production—improves the overall learning experience. The use of Navisworks’ Clash Detective module appeared to support students in developing a more nuanced understanding of Building Information Modeling (BIM) concepts, while also fostering competencies related to 3D coordination and conflict resolution. This activity involved conducting 3D coordination on Revit architectural model and the Tekla structural model previously developed in earlier practical sessions. In addition, students engaged with role distribution practices by identifying and assigning responsibilities for detected clashes, communicating issue details and deadlines through BIM Collaboration Format (BCF) files, and maintaining traceability of proposed modifications via the Newforma Konekt, the collaborative platform. The integration of such a platform may have contributed to improved communication and information exchange, potentially addressing some of the inefficiencies observed in earlier iterations of the course.

One of the most notable improvements was the redesign of instructional materials, particularly through high-quality, structured video tutorials. These resources provided students with on-demand guidance, reducing reliance on external sources and enabling more efficient self-directed learning. However, further refinements could be made, such as incorporating voice-over explanations and expanding coverage of BIM software functionalities to accommodate different learning paces.

Despite these successes, some challenges remain. The structured workflow, while effective in guiding students, may have constrained creativity and problem-solving flexibility. Future iterations of the course could introduce more open-ended tasks to encourage innovative approaches and critical thinking. Additionally, while the results indicate strong improvements in student engagement and collaboration, long-term studies could assess the retention of these skills in professional settings.

Ultimately, this study underscores the necessity of continuously adapting BIM education to reflect industry advancements. By fostering an interactive, technology-driven learning environment, institutions can better prepare students for the evolving demands of the AEC sector.

6.2 Lessons learned and future directions

This case study highlights several lessons learned from the pilot implementation that can inform both the refinement of the proposed pedagogical framework and its potential adaptation to related curricula. First, the integration of collaborative tools such as Newforma Konekt and Navisworks indicated that structured workflows can support students' ability to coordinate tasks and address conflicts; however, the pilot also revealed that additional instructional time is necessary to facilitate adequate familiarity with these platforms. Second, the iterative design of the assignments underscored the need to balance technical skill development with collaborative competencies, suggesting that future iterations could benefit from a stronger emphasis on reflective activities and peer feedback to further support teamwork development.

While the approach showed promising outcomes within the BIM830 pilot context, its transfer to other courses or programs would require careful adjustment to variations in class size, disciplinary composition, and available technological resources. Overall, these observations provide preliminary guidance for improving the current course and outline potentially transferable principles that may inform the design of interdisciplinary, project-based learning environments in architecture, engineering, and construction education, subject to further testing and validation.

Looking forward, these insights suggest several avenues for future improvement. The assignment could be further enhanced by integrating interdisciplinary projects involving students from architecture, civil, and construction programs to more closely simulate real-world collaboration. The framework could also be adapted into earlier courses, providing students with progressive exposure to collaborative BIM practices before entering advanced modules. Finally, extending this approach across the curriculum would allow for a longitudinal assessment of how structured collaborative learning impacts students' readiness for professional BIM-enabled practice.

6.3 Limitations and Future Research

While this study demonstrates the value of a theoretically grounded framework for collaborative BIM education, several limitations should be acknowledged. First, the research was conducted within a single academic context, namely one BIM course (BIM830) at École de technologie supérieure (ÉTS) and within a single cohort of students. This contextual specificity may limit the generalizability of the findings to other institutions or curricular settings. To mitigate this limitation, future implementations of the framework are planned across multiple courses, academic levels, and institutions, allowing comparative and cross-contextual validation.

Second, the assessment of collaborative and technical skills relied primarily on student self-reported surveys and analysis of assignment deliverables. While this approach provided valuable insights into students' perceptions, engagement, and confidence, it may be subject to response bias and does not fully capture individual contributions within group-based work. Future iterations will mitigate this limitation by integrating peer evaluations, instructor assessments, and standardized rubrics specifically designed to evaluate collaboration in BIM-based learning environments.

Third, although BIM was used as a collaborative platform to simulate professional workflows, BIM-based coordination itself presents inherent limitations. These include interoperability challenges between software tools, varying levels of user proficiency, and the tendency for BIM processes to emphasize technical coordination over social and organizational dimensions of collaboration. To address these limitations, the proposed framework explicitly incorporates non-technical dimensions—communication and coordination—alongside production, ensuring that collaborative competencies are intentionally scaffolded rather than assumed. Additionally, future work will explore enhanced interoperability workflows, clearer role definitions, and the integration of emerging cloud-based BIM collaboration technologies to reduce technical friction.

Fourth, the study did not include a longitudinal or comparative design, making it difficult to assess the long-term retention of collaborative skills or to directly compare the proposed framework with alternative pedagogical approaches. This limitation will be mitigated in future research through longitudinal studies tracking student performance over time and by introducing control or comparison groups using different instructional designs.

Finally, data triangulation was limited, as the study primarily relied on student feedback and assignment outputs. A more holistic evaluation of learning outcomes could be achieved by incorporating feedback from industry practitioners and external reviewers. Future research will therefore seek to include industry partner evaluations and objective BIM model quality metrics—such as clash resolution efficiency, coordination accuracy, and model completeness—to strengthen the robustness and practical relevance of the findings.

7. Conclusion

This study introduced a novel pedagogical framework for teaching collaborative Building Information Modeling (BIM), structured around the functional Trefoil model. By integrating communication, coordination, and production within project-based learning, the revised practical sessions bridge the gap between theoretical BIM concepts and real-world interdisciplinary collaboration.

The results suggest increased student engagement, technical proficiency, and teamwork skills when compared with the traditional approach. The hands-on and interactive nature of the revised assignments appears to support students' understanding of BIM tools and may contribute to greater confidence in their use, indicating a promising potential for better alignment with industry-related expectations.

Beyond its immediate impact on student learning, this research offers a transferable framework for other institutions seeking to improve BIM education. For future iterations, several improvements could be made to strengthen the assessment of students' collaborative and technical skills. First, the inclusion of peer evaluations would provide richer insights into individual contributions within group work, complementing self-reported survey data. Second, the adoption of standardized rubrics specifically designed for evaluating collaboration in BIM education could ensure more consistent and transparent assessment across groups. Third, Collaborative skills and technical proficiency were assessed through student surveys and analysis of deliverables rather than standardized rubrics or peer/instructor evaluations. While this provided useful insights, future work should integrate more rigorous instruments—such as rubrics, peer evaluations, and BIM model quality metrics—to enhance reliability. Finally, triangulating these data with instructor evaluations and, when possible, feedback from industry partners would provide a more holistic understanding of students' preparedness for real-world collaborative BIM environments. Future efforts will also focus on refining digital teaching materials, increasing flexibility in learning pathways, and further integrating emerging BIM collaboration technologies. Ultimately, fostering interdisciplinary, technology-driven learning environments will be key to equipping future professionals with the skills necessary for the evolving AEC industry.

Data Availability Statement:

Some or all data, models, or code that support the findings of this study are available from the corresponding author upon reasonable request.

References

Abdirad, H., and C. S. Dossick. 2016. “BIM curriculum design in architecture, engineering, and construction education: A systematic review.” *Journal of Information Technology in Construction*, 21: 250–271.

El Asmar, M., A. S. Hanna, and W. Y. Loh. 2013. “Quantifying performance for the integrated project delivery system as compared to established delivery systems.” *Journal of Construction Engineering and Management*, 139 (11): 04013012. https://doi.org/10.1061/(ASCE)CO.1943-7862.0000744.

Barison, M. B., and E. T. Santos. 2010. “Review and analysis of current strategies for planning a BIM curriculum.” In: *Proceedings of the CIB W78 2010: 27th International Conference*, Virginia Tech, Blacksburg, VA, 16–18.

Bedoiseau, M., D. Martin, and C. Boton. 2022. “Use of KROQI as a Level-2 Common Data Environment in the French Construction Industry.” *Sustainability*, 14 (16). https://doi.org/10.3390/su141610455.

Béguin, J., and F. Darses. 1998. “Les concepteurs au travail et la conception des systèmes de travail : points de vue et débats.” In: *2e journées Recherche et Cognition*. Toulouse, France: Université de Toulouse le Mirail.

Boton, C. 2020. “Remote teaching of building information modeling during the COVID-19 pandemic: A case study.” *Sustainability (Switzerland)*, 12 (20). https://doi.org/10.3390/su12208665.

Boton, C., D. Forgues, and G. Halin. 2018. “A framework for Building Information Modeling implementation in engineering education.” *Canadian Journal of Civil Engineering*, 45 (10). https://doi.org/10.1139/cjce-2018-0047.

Bozoglu, J. 2016. “Collaboration and coordination learning modules for BIM education.” *Journal of Information Technology in Construction*, 21: 152–163.

Cannon-Bowers, J. A., E. Salas, and S. Converse. 1993. “Shared mental models in expert team decision making.” *Individual and Group Decision Making: Current Issues*, edited by N. J. Castellan, 221–246. Hillsdale, NJ: Erlbaum.

University of Texas at Austin. Construction Industry Institute. 1991. *In Search of Partnering Excellence*. Austin, TX: Construction Industry Institute, University Of Texas At Austin.

Daft, R. L., and R. H. Lengel. 1986. “Organizational information requirements, media richness and structural design.” *Management Science*, 32 (5): 554–571.

Dotta Correa, S., Ž. Turk, and J. Dujc. 2025. “BIM integration in higher education: A global assessment.” *Journal of Information Technology in Construction (ITcon)*, 30: 1059–1079.

Eriksson, P. E. 2010. “Partnering: What is it, when should it be used, and how should it be implemented?” *Construction Management and Economics*, 28 (9): 905–917. https://doi.org/10.1080/01446190903536422.

Forgues, D., and L. Koskela. 2009. “The influence of a collaborative procurement approach using integrated design in construction on project team performance.” (March 2009): 1–17. https://doi.org/10.1108/17538370910971036.

Forgues, D., and S. Staub-French. 2011. “Teaching Building Design and Construction Engineering. Are we ready for the paradigm shift?” In: *Proceedings of the Canadian Engineering Education Association (CEEA) conference*, Canadian Engineering Education Association, Montréal, QC, Canada, 1–6.

Ghassemi, R., and B. Becerik-Gerber. 2011. “Transitioning to integrated project delivery: Potential barriers and lessons learned.” *Lean Construction Journal*, 2011 (Special issue), 32–52.

Hackman, J. R., and G. R. Oldham. 1976. “Motivation through the design of work: Test of a theory.” *Organizational Behavior and Human Performance*, 16 (2): 250–279.

Hevner, A., and S. Chatterjee. 2004. “Design science in information systems research.” In: *Integrated Series in Information Systems*, 75–105. Springer Science+Business Media, New York, NY, USA, Springer.

Hochscheid, E., C. Boton, and L. Rivest. 2022. “Les environnements communs de données (CDE) : définitions, historique et classification.” *SHS Web of Conferences*, 147: 01002. EDP Sciences. https://doi.org/10.1051/shsconf/202214701002.

Ibrahim, R., S. B. Costello, and S. Wilkinson. 2013. “Key practice indicators of team integration in construction projects: a review.” *International Journal of Managing Projects in Business*, 19 (3–4): 132–152. https://doi.org/10.1108/IJMPB-06-2016-0049.

Jellicoe, M., and A. Forsythe. 2019. “The Development and Validation of the Feedback in Learning Scale (FLS).” *Frontiers in Education*, 4. Frontiers Media S.A. https://doi.org/10.3389/feduc.2019.00084.

Johannesson, P., and E. Perjons. 2021. *An Introduction to Design Science*. Springer Nature Switzerland AG, Cham, Switzerland.

Kassem, M., L. Benomran, and J. Teizer. 2017. “Virtual environments forsafety learning in construction and engineering: Seeking evidence andidentifying gaps for future research.” Visualization Eng. 5 (1): 16. https://doi.org/10.1186/s40327-017-0054-1.

Kent, D. C., and B. Becerik-gerber. 2010. “Understanding Construction Industry Experience and Attitudes toward Integrated Project Delivery.” *Journal of construction engineering and management*, 136 (8): 815–825.

Lahdenperä, P. 2012. “Making sense of the multi-party contractual arrangements of project partnering, project alliancing and integrated project delivery.” *Construction Management and Economics*, 30 (1): 57–79. https://doi.org/10.1080/01446193.2011.648947.

Malone, T. W., and K. Crowston. 1994. “The interdisciplinary study of coordination.” *ACM Computing Surveys*, 26 (1): 87–119.

Mignone, G., M. R. Hosseini, N. Chileshe, and M. Arashpour. 2016. “Enhancing collaboration in BIM-based construction networks through organisational discontinuity theory: a case study of the new Royal Adelaide Hospital.” *Architectural Engineering and Design Management*, 12 (5): 333–352. https://doi.org/10.1080/17452007.2016.1169987.

Monson, C., H. Homayouni, C. S. Dossick, and A. K. Anderson. 2015. “Improving the understanding of BIM concepts through a flipped learning lab environment: A work in progress.” ASEE.

Paik, S. mok, L. Pekka, and J. and Choi. 2022. “Making most of BIM in design: analysis of the importance of design coordination.” *International Journal of Construction Management*, 22 (12): 2225–2233. Taylor & Francis. https://doi.org/10.1080/15623599.2020.1774837.

Peterson, F., T. Hartmann, R. Fruchter, and M. Fischer. 2011. “Teaching construction project management with BIM support: Experience and lessons learned.” *Automation in Construction*, 20 (2): 115–125. https://doi.org/10.1016/j.autcon.2010.09.009.

Sacks, R., C. Eastman, L. Ghang, and P. Teicholz. 2018. *BIM Handbook: A Guide to Building Information Modeling for Owners, Designers, Engineers, Contractors, and Facility Managers, Third Edition*. Third. Hoboken, New Jersey: Wiley.

Sacks, R., and E. Pikas. 2013. “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*, 139 (11). https://doi.org/10.1061/(ASCE)CO.1943-7862.0000759.

Salber, D., J. Coutaz, D. Decouchant, and M. Riveill. 1995. “De l’observabilité et de l’honnêteté: le cas du contrôle d’accès dans la Communication Homme-Homme Médiatisée.” In: *Proceedings of IHM’95: 7èmes Journées sur l’Ingénierie de l’Interaction Homme-Machine*, Cépaduès-Éditions, Toulouse, France, 27–34.

Schwaber, K., and M. Beedle. 2002. *Agile Software Development with Scrum*. Upper Saddle River, NJ: Prentice Hall.

Shannon, C. E., and W. Weaver. 1949. *The Mathematical Theory of Communication*. Urbana: University of Illinois Press.

Succar, B. 2009. “Building information modelling framework: A research and delivery foundation for industry stakeholders.” *Automation in Construction*, 18 (3): 357–375. Elsevier B.V. https://doi.org/10.1016/j.autcon.2008.10.003.

Tannen, D. 1990. *You Just Don’t Understand: Women and Men in Conversation*. New York: Ballantine Books.

Yıldırım, S. G. 2024. “Creating a model-based learning environment in BIM education through case studies.” *Journal of Architectural Sciences and Applications*, 1129–1148. https://doi.org/10.30785/mbud.1465526.