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BIM AS EDUCATION PLATFORMS FOR TACKLING WICKED TRANSITIONS: POTENTIALS AND LIMITATIONS

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Abstract

Wicked challenges such as energy and material shortage have prompted educators in AECO disciplines to adopt CBL methods. This paper explores the potential and limitations of using BIM as an education platform to address these challenges within an inter-disciplinary setting. Through two cases at TU Delft, one re-design of a routine building information management course and a new demo-course with joint-interdisciplinary groups, the research evaluates BIM's role in preparing students for real-world energy and circular transitions. Findings highlight BIM's capacity to bridge academic learning and professional practice, while also identifying areas for improvement in its pedagogies.

Introduction

The Architecture, Engineering, Construction & Operations (AECO) industry faces mounting challenges, including climate change, energy shortages, and the need for more sustainable and circular economy approaches to buildings and infrastructure. These pressing issues have prompted educators in AECO disciplines to rethink traditional pedagogies and adopt Challenge-based Learning (CBL) approaches. By focusing on real-world challenges, the educational model aims to equip future professionals with the skills and knowledge necessary to devise innovative solutions for an ever-changing industry landscape.

In the current industrial discourses, BIM stands for two often interchangeable terms: "building information modelling" and "building information management" (McArthur, 2015; Sacks et al., 2018). BIM is traditionally more understood as a digital model and relevant tools that has revolutionized project workflows and decision-making in the built environment (Gupta et al., 2020.; Sacks et al., 2018). More recently, its scope expanded to include the management aspects, emphasizing its role in coordinating workflows, data sharing, and lifecycle asset management across all stages of projects or domains in the built environment (Koutamanis, 2022; Zhang et al., 2018). Beyond its established use as an engineering tool, BIM can serve as a platform for education with its extensive capabilities to model and manage data of the built environment and support workflows for problem-solving purposes (Obi et al., 2022; Yusof et al., 2018). Educational programs in recent years have seen a broadening set of applications to integrate BIM in CBL, context-based projects or other forms active pedagogy. For example, Palma & Morales Segura (2024) implemented in architecture and engineering education with the real-world challenge of sustainable material selection. McGinley & Krijnen (2021) leverage open BIM standards and promoted a "learning from BIM" approach for students to gain insights from analyzing data to simulate professional problem-solving conditions. Obi et al. (2022) designed semi-structured project using BIM for clash detection, data management, and reporting to effectively expose students to simulated industrial challenges. Although previous educational studies have made valuable contributions, relatively few have positioned BIM as a means of simulating and teaching the "twin-transition" challenge of sustainability and digitalization in the built environment (Bianchini et al., 2023). This gap is particularly evident in interdisciplinary settings involving both technical and management students, where "wicked" problems demand integrated approaches. We define the challenge in our CBL approach as such "wickedness" as addressed by Rittel (1984) and Buchanan (1992) in planning and design research.

This paper investigates the potential role of BIM as an education platform for innovation to tackle pressing challenges in the AECO sector that span between education institutions and practice. The study focuses on two master's-level course designs at the Dutch university of TU Delft. Course A, named "Building Information Management" is developed from a previous course as part of the "MSc management in the built environment" program. The course is transformed from a more traditional knowledge-based individual assignment to a CBL team education approach. The second course is a new experimental course developed as one group of the university wide "Joint Interdisciplinary Project", only three students were involved in this project, who are from distinct background outside of the AECO domains. The project also involved collaboration with an external company, from which more mentors are involved. By integrating insights from both students, educators and industry experts, the research evaluates BIM's potential in CBL and current limitations to prepare future professionals for an evolving industry landscape. The findings underscore BIM's capacity to bridge academic learning and professional practice, while also highlighting areas where its educational application can be further enhanced.

Theory on BIM and CBL

Educating wicked transitions for the built environment

Addressing grand challenges such as climate change, resource scarcity, and the transition towards sustainable and circular economy demands a paradigm shift in education for the built environment. These challenges, characterized by their complexity, scale, and urgency, require innovative approaches that equip future professionals with the tools and mindset necessary to navigate and tackle such issues (Hart et al., 2016; Nowell et al., 2020; Ding et al., 2023). Among these approaches, CBL has emerged as a particularly promising pedagogical framework (Leijon et al., 2022). The twin-transition of sustainability and digitalization are inherently interdisciplinary, requiring collaboration across disciplines and industrial fields， involving systemic problems that demand holistic, systematic thinking approaches rather than isolated, discipline-specific solutions (Kanda et al., 2020). For example, energy transition necessitates rethinking energy sources, construction materials, and new products, the circular economy calls for innovative design principles, product-service models, adaptive reuse strategies for built properties, etc. (Chen et al., 2022). Educating future AECO professionals must, therefore, focus on equipping them to tackle such multifaceted problems.

CBL builds on experiential and problem-based education frameworks but emphasizes engaging students directly with real-world, complex problems. It differs from the more traditional scenarios where learners are given pre-defined problems. In CBL, students first work collaboratively to identify a challenge, research its context, propose actionable solutions, and reflect on the outcomes of their efforts (Leijon et al., 2022; Palma & Morales Segura, 2024). This approach is particularly relevant to current AECO disciplines, as it aligns with the industry's demand for professionals who can integrate technical, managerial, and ethical considerations into decision-making. CBL also resonates with the constructivist learning theory, which posits that students learn best by actively constructing knowledge through experience and reflection (Dolmans et al., 2005; Savery & Duffy, 1995). Therefore, courses that incorporate live projects or simulate real-world conditions can encourage students to apply theoretical knowledge and learn from decision-making processes.

CBL also emphasizes the importance of stakeholder engagement and collaborative problem-solving, mirroring the collaborative nature of AECO projects. Studies have shown that collaborative learning environments promote critical thinking and innovation, essential for addressing dynamic and unpredictable challenges (Bereiter & Scardamalia, 2014). Many of the prior courses already implemented a team-based learning approach while integrating BIM, which has proven effective in boosting both the technical and interpersonal competencies required for BIM practice (Obi et al., 2022; Özener, 2023; Zhang et al., 2018) .

Several higher education initiatives in AECO illustrate the potential of CBL to prepare students for transitions. For example, multiple European universities engaged students in designing net-zero buildings within realistic constraints, leveraging digital platforms that enable students to visualize and manage complex data related to energy efficiency, lifecycle analyses, and resource usage (Christou et al., 2024). Similarly, Özener (2023) designed realistic, open-ended scenarios. introducing role-playing simulations that place students in different professional roles (e.g., project manager, architect, contractor) to solve complex BIM-related problems.

Nevertheless, implementing CBL in AECO education is not without challenges. It requires significant resources, including access to advanced tools, as well as faculty training to adopt new pedagogical roles (Bereiter & Scardamalia, 2014; Christou et al., 2024). Furthermore, the assessment of student outcomes in CBL contexts is more complex than traditional evaluation methods, requiring metrics that capture not only technical proficiency but also teamwork, creativity, and systems thinking (Leijon et al., 2022). In addition, teaching interdisciplinary groups spanning technical and managerial backgrounds in CBL intensifies these complexities, since education must bridge diverse skill sets and evaluate contributions grounded in distinct fields of expertise (T. P. McGinley & Krijnen, 2021; Zhang et al., 2018).

BIM as an education platform for transition challenges

BIM is increasingly recognized as a critical methodology for addressing the complex challenges of the built environment. Beyond its association with software tools, BIM's platform-based and intermediary role is gaining recognition as a transformative enabler in the AECO sector. In transition management literature, the concept of intermediaries helps understand the practice by actors who act as brokers or platforms between different actors and networks that play important roles in the transition process (Kanda et al., 2020; Ding et al., 2023). Instead focusing on the products and processes offered by individual actors, the lens of intermediaries is often incorporated to analyse the complex networks.

BIM's capabilities extend beyond representing real-world objects, materials, spaces, and the performance of the built environment. It also facilitates the creation of virtual digital twins that not only reflect real-world problems but also generate a digital data space for breeding suitable solutions (Demian & Walters, 2014). Additionally, BIM serves multiple functions, including regulatory compliance checking, technical knowledge dissemination, and resource planning for construction processes and organizations (Demian & Walters, 2014). As an information-centric platform, BIM can act as an effective transition intermediary, bridging gaps in practice that are difficult to address by individual actors.

The intermediary role of BIM has also opened new possibilities for pedagogical approaches in AECO education. As an education platform, BIM helps bridge gaps between academic institutions and real-world practice, creating opportunities for students to engage with integrated technical, managerial, and environmental considerations (Bilge & Yaman, 2021). This aligns closely with CBL, as BIM allows students to explore scenarios that simulate project workflows and decision-making processes. Prior studies highlight the importance of teaching BIM competencies within the broader context of these practical and collaborative workflows, instead of only training BIM competency as a skill (Huang, 2018; T. P. McGinley & Krijnen, 2021).

Recent pedagogical studies further underscore the interdependence of BIM and CBL in AECO education, demonstrating the value of integrating constructive approaches to enhance student learning outcomes. By leveraging BIM's platform-based capabilities, educational programs can better connect curriculum with the rapidly evolving industry. Obi et al. (2022) demonstrated through a network analysis in undergraduate courses that shifting from traditional lectures to CBL frameworks can significantly enhance how students internalize and apply BIM concepts. Özener (2023) used a context-based role-play approach that proved effective in helping students integrate lifecycle considerations, regulatory contexts, and collaborative workflows into their learning. Similarly, Zhang et al. (2018) demonstrates that team-based learning can be adapted to emulate real BIM workflows, improving both the technical and collaborative skills of civil engineering and management students. The study also highlighted the complexity in managing students with diverse backgrounds, ensuring sufficient faculty support, and maintaining effective collaboration practices.

In addition, as more attention is put on OpenBIM platforms, there has been growing interest in CBL explorations with more focus on the potentials of data interoperability and platforms. For example, in DTU of Denmark, curriculum introduces students to open data environments and ontologies, guiding them to develop their own tools using platforms (T. McGinley et al., 2023). In Dutch universities of TU Delft and TU Eindhoven, similar approaches are taken to support learning from BIM through frameworks that emphasize analysis embedding OpenBIM feedback loops to promote learning and knowledge sharing (Boeykens et al., 2013). In Australia, a few universities have also embraced open data not just for technical upskilling but as a way to overcome educational silos, addressing interoperability and industry-readiness gaps (Casasayas et al., 2021).

While BIM is both a tool and technique emphasized in the learning process in all of the above courses, what is often underexplored is how real-world problems are tackled with BIM education. The key characteristic of CBL is that it takes a broader approach by immersing students in challenges that lack clear solutions. In sustainability education, CBL may not only improve technical competencies but also enhance students' ability to address transitions more creatively, as demonstrated in the "flipped classroom model" to train students in selecting sustainable building materials by Palma and Morales Segura (2024). This methodology aligns closely with CBL approaches, as it encourages students to actively engage with BIM technology while identifying challenges and design solutions. *Figure 1* illustrates the framework for the proposed CBL curriculum, based on principles from Leijon et al. (2022) and Palma & Morales Segura (2024) and was adapted for the two course contexts. The framework sets the core pedagogical approach for course designing.

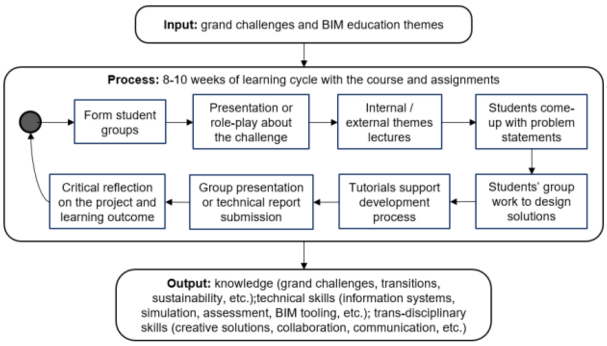

Figure 1: CBL education framework

Course design and review process

This research investigates how BIM could be used as an education platform for students to explore the specific context of energy and circular transitions and promote the development of solutions and practical skills to engage with real-world challenges. The study examines two distinct cases of course design conducted during separate periods: Course A titled "Building Information Management", which ran from April 2024 to July 2024, and Course B, held from September 2024 to November 2024. Course A is re-designed based on one routine course that have been running for a few semesters and adapted the previous problem-based model to CBL. The course is open to students from the "management in the built environment" tracks, involved 60 participants working in groups of 3–5 students for each group, resulting in 15 submissions. Students are assigned roles of construction managers, architects, circular economy managers, and BIM coordinators. The challenge for Course A was framed from the perspective of social housing organizations tasked with renovating large building stocks to enhance energy efficiency. Students were required to engage with complex project planning, evaluation, and execution processes while considering energy performance, circular economy principles, and compliance with the latest government regulations. The course focused exclusively on traditional BIM concepts, using BIM as the primary toolset.

In contrast, Course B, is a new experimental developed as part of the "joint-interdisciplinary project" initiated by TU Delft. The course involved a specially designed assignment titled: "Digital twining for circular construction supply chains" for an interdisciplinary group of three students without construction-related backgrounds (Mathematics, Mechanical Engineering and Management). This challenge cantered on the role of urban miners in managing the acquisition of secondary construction materials for reuse or recycling. Here, BIM was conceptualized more broadly, encompassing information management and digital-twinning within the industry. Students were encouraged to independently develop solutions to model real-world scenarios and simulate possible outcomes when different BIM systems are engaged.

Table 1: Key features course content and assignments

	Course A	Course B
Level of Education	MSc	MSc
Teaching period	Apr ~ Jul2024	Sept ~ Nov2024
Total students	60	3
No. of groups	15 (3-5 members each)	1
Challenge	mixed (energy & circular transition)	circular transition
Perspective	social housing associations (owners and developers)	urban miners (demolishers and resellers)
Form of teaching	lectures, hands-on training, workshops, role-play	Group tutorials, company visits, research sessions, simulation methods
Involved parties	only university	university and a company from ICT/ construction informatics
Student background	management track students with originally architecture or management background	multi-disciplinary, the 3 students are from mechanical, mathematics and management
Assignment	weekly-based quiz, Report & BIM models	Interim and final reports & simulation models

According to Yin (2009), case studies enable empirical investigation of contemporary phenomena within real-life settings, facilitating the development of analytical insights. This approach is based on the premise that BIM in the sense of an information management platform could enable the teaching and learning goals of CBL to tackle transitional challenges in the industry. The study examines this construct by analyzing the performances of students in the modules, student feedback and external reviews. Table 1 gives an overview of how the two courses are designed.

The reports of the student work are analysed using Atlas.Ti software, based on coding of key themes relevant to the topics addressed in CBL and the potential use of BIM to fulfil the education tasks and nuanced written content is analysed from the reports. Afterwards, the feedback by the students is also reviewed to give reflective perspectives to the course design as well as the outcomes. Finally, three evaluation conversations of around 1 hour were conducted with professionals from the AECO management positions to evaluate the content and results of the courses and give insights on whether the course designs would provide adequate skill sets that are needed in real-world practices. Table 2 outlines the review process took to gain insights into the pedagogical performance of the two courses.

Table 2: Review process of courses

	Student reviews	
	Course A	Course B
Technical report	Analysis of 15 reports	Analysis of 1 progress and 1 final report
Models reviewed	Observation of 15 Revit models and generated reports	Observation of two simulation models developed with Python packages
Course reviews received	anonymous feedback forms	1 face-to-face feedback session
	General review from external professionals	
	Professional role	Years of experience
Reviewer 1	BIM expert and developer	6-10
Reviewer 2	Data systems expert and COO	11-15
Reviewer 3	BIM Coordinator	6-10

Findings

Potential of BIM in educating challenges

The analysis of student work has shown the varying levels of skill application across the two courses and reveal BIM's different applications as an education aid. As listed in the *Table 3*, both Courses share several commonalities in their approach CBL that focused on addressing transition-related challenges in the AECO sector. Using BIM as a platform for manipulating data and information, the students' work demonstrates complex problem-solving processes through data informed approaches. Additionally, both courses have successfully engaged a resource-based reality for students to work on strategies such as waste reduction, energy retrofitting, and budget management. For instance, in course A, multiple group reports have considered the interplay between energy cost savings and embodied carbon emissions of new materials applied to renovation. As shown in *figure2*, students use BIM to simulate renovation circular performances for the decision-making process. In Course B, the cost of storing waste materials is modelled alongside the estimated selling price of the materials, using information available in BIM. The students' reflections and expert reviews partially aligned with the expectation of simulating real-world challenges in group work. The teaching process and quality of the reports suggest that students have developed a deeper understanding of the challenges and transition of the industry through the use of BIM.

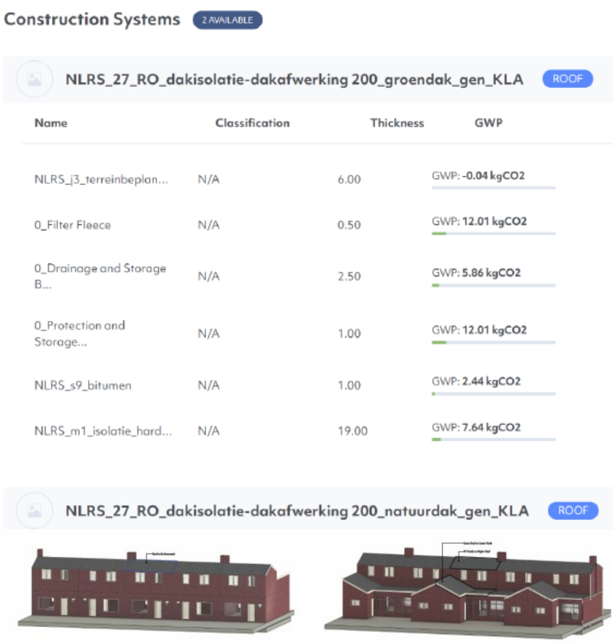

Figure 2: Example student work course A

Collaborative learning was another highlighted feature for the courses, as students worked in teams ranging from 3 to 5 members to develop practical solutions, demonstrating high levels of teamwork and collective decision making. Both courses showed evidence that building information could play a role in group decision-making processes in the course environment, particularly in project planning and optimization of solutions. For example, most groups of course A have compared more than one building retrofit options and involved BIM generated bill of materials supported by calculations of energy efficiency estimates and cost calculations. Course B students dived into how building data could be structured and delivered to support the workflow of managing reverse material flows in the circular supply chain. The reports and course review results indicate that most students prefer group work for tackling complex challenges. Groups tend to achieve more constructive solutions by leveraging the diverse skills and expertise that certain members bring from their prior education or practical experience.

Furthermore, the group reports reveal evidence of how BIM can act as an platform in disseminating knowledge about transitions in AECO applications. This is particularly sensible as students are required to engage in tasks such as researching on sustainability standards, calculating environmental impact, and addressing stakeholder interests. The multi-functional nature of BIM platforms is suitable for such learning needs..

The nature of CBL dictates that solutions must be derived from multi-level approaches, with students actively seeking new knowledge to understand the industrial landscape and emerging technologies, which they then apply to the design of systematic solutions. As *figure 3* shows, Course A students are given a rough context for the project, but are free to choose a project within the Netherlands as their case. Students created BIM model of the project and conducted research and design to tackle the energy retrofitting challenge. Course B students came up with their own problem definition for the practice of reverse logistics by urban miners. The students later developed a simulation model based on the problems defined in the background research phase. According to the student feedback of both courses and external experts, it is positive to engage students in problem definition, which adds to the capabilities in real project settings.

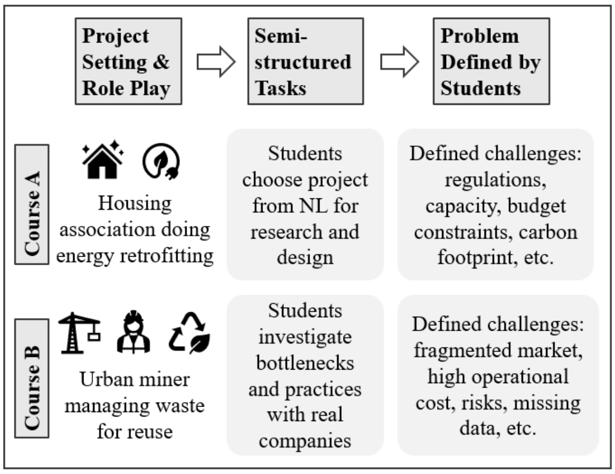

Figure 3: problem definition processes

Lastly, external reviewers provided valuable insights into how the course content aligns with the skills and qualities currently demanded in professional AECO practice. One BIM specialist reflected "design teams for circular reuse projects need BIM for match-making between material doner projects and new user projects, which demand a different skill set for designers and construction teams". Recent projects increasingly require BIM experts to manage product passports, survey and scan existing building stocks, plan project schedules for material reuse, and integrate BIM with supply chain management in the circular economy. These tasks highlight the growing complexity of real-world challenges, where BIM serves as a critical tool for sustainable and efficient project management. The above discourse of potential of BIM and CBL combination also leads to the discussion of current limitations and barriers, which is elaborated in the next sub-section.

Table 3: CBL topics and levels of application of BIM functionalities

Topics of CBL	BIM Functionalities applied by students
Course A	
Circular design	process mapping***, 3D modelling***, carbon footprint calculation*, data visualization**, material tracking** waste management**, compliance checking*, decision support**
Energy retrofit	energy simulation**, labelling and compliance checking**, surveying of existing built environment***, data visualization**, clash detection*, decision support**
Affordable housing & social inclusion	cost estimation***, schedule management*, business predictions*
Course B	
Reverse logistics & waste minimization	process mapping***, carbon footprint calculation*, data visualization*, material tracking**, process simulation & optimization***
Circular Business Models	cost estimation***, logistics flow optimization**, resource optimization*

* Student works show ***intensive/ **moderate/ little* application of the skill sets

Barriers to CBL and remarks on education design

While the courses contain highly relevant content to address the challenges, teaching real-world cases within the academic environment remains challenging due to the dynamic nature and scale of the industry. The "wicked" dual-transition challenge of the AECO industry is only partially processed by the students as BIM is used as a digital tool to help understand and support sustainability. However, the students are sometimes confused by the open-ended nature of the challenge and the multiple use scenarios of BIM. In both cases, students reflected that it is already challenging to gain new digital skills (such as both open and closed BIM softwares) while they also need to consider the application of the skills to support workflows in sustainable design or decision making.

Another hurdle to the implementation of CBL is its high expectation on collaborative, multi-levelled actions. Students are expected to analyse complex "wicked" problems, which can overwhelm those with less experience about managing socio-technical systems. Students of both cases has made great effort to conduct background research and gather inter-disciplinary knowledge. The intrinsic complex nature of the challenge dictates that the design solution must not be only technical but also with social and economic considerations. One particular example that the teachers and external experts identified from the students' work and reflection is the lack of understanding of business models integrated into the simulated projects, students find it difficult to justify what benefit does BIM bring to the specific industrial scenarios.

Lastly, difference in the ways of working in practice that is brought by BIM is observed in student work in CBL, similar to that happening to professional practices also undergoing a digital transition. It creates difficulty for team building and group work, where factors such as the differences in group members' prior knowledge of BIM, education background and work experience all influence the outcome of group learning. In both cases, student groups are either inter-disciplinary or from different bachelor's programs before doing the master's study in construction management. The great difference in experience in BIM and the AECO domain leads to uneven participation and communication gaps. The course review process suggests that CBL is difficult for student groups to distribute roles, and for educators to assess the work with consideration of individual contributions. In addition, the subjective and cultural differences appear to be a barrier to team building, as different communication styles, work habits and personal expectations seem to cause more friction in CBL compared to how that would be in a traditional group project. This issue is amplified in University curriculums with highly international participants with more diversity.

Discussion

This study explored the integration of BIM into CBL within two courses designed to address energy and circular challenges in the AECO industry. The findings from both Course A and Course B demonstrate the multifaceted role of BIM, as a broad definition for building information management, as a learning platform that bridges technical education, problem-solving, and systems thinking. A novel perspective is introduced to view BIM as a transition intermediary with a form of digital platform that potentially help students connect theoretical knowledge with practical applications. The results from education, student and expert feedback partially align with previous research by Obi et al. (2022), (2021) and Özener (2023) and highlights the interdependency between BIM and CBL for AECO education.

BIM's role as an education platform aligns well with CBL's emphasis on addressing challenges of multi-level, dynamic and ongoing transitions, which could not be tackled with one specific technology (Nowell et al., 2020). Students engaged in tasks requiring crossdisciplinary collaboration, integrating diverse skill sets to develop actionable solutions. The collaborative nature of CBL was evident in both courses. However, barriers emerged regarding the implementation of CBL in university curriculums, where students also had varying levels of prior BIM experience and education backgrounds. Findings highlight areas where students may struggle to develop a deeper understanding of BIM as both a technology and a platform, and the application in multi-level challenges regarding governance, stakeholders, business models and technologies. The study echoes prior research in the barriers of BIM education with open-ended assignments and multi-disciplinary groups (Huang, 2018; Obi et al., 2022; Özener, 2023).

Considering barriers, it will remain a critical decision point for educators to consider whether to incorporate more structured sessions to support problem definition and skill building, or to allow more freedom to navigate the challenges. There are no standard practices yet when it comes to complex (wicked) transition challenges. In addition, the inter-disciplinarity is a key contribution from this pedagogical research, as both courses involved students from mixed technical and management background. It was interesting to see that the students need to first "un-learn" some of their technical skills in order to be fully engaged in the management challenges, and then develop solutions based on new research efforts.

Clearly, this study is only conducted in two totally separate course cases within one academic year, and the second course only involved 3 students. There is no direct comparison between the two cases, neither is there a longitudinal assessment on the impact of the education methods. The student and expert reviews of course A showed positive attitude towards the new CBL group projects compared to more traditional learning, but we did not have the opportunity to further iterate the process and involve more internal and external evaluation. Similar to some other cases from different universities, the participation rate of the student course reviews is low, therefore did not provide more solid evidence on the performance of the courses. The cases can serve more as inspiration for the larger community of universities and institutions in designing future education systems and relevant policies to address challenges more interactively. Based on humble experience and findings, we envision more integrated education design in the next steps with BIM and CBL.

Conclusion

This study emphasizes the transformative potential of BIM as an education platform for CBL in AECO education. By embedding BIM into curriculums through a CBL module, the attempts to build up more relevant technical expertise, managerial capabilities, and systems-thinking skills essential to addressing "wicked" challenges such as energy transitions and circular economy. Two course cases are included in this research by conducting course designs, assessing student outcomes and reviews, and consulting external experts.

The findings from Course A and Course B illustrate BIM's capacity to engage real-world problem-solving scenarios, foster collaborative learning environments, and bridge between education and transition challenges as an education platform. At the same time, the study identifies critical barriers and areas for future efforts. BIM based CBL demands understanding of complex transitions that constantly bring new digital and sustainable topics. It requires students to navigate through multi-level systems and deal with frictions between different ways of working and work in groups with diverse disciplines and backgrounds. Future course design need to cautiously consider the level of freedom for problem and role-definitions in CBL, support knowledge transfer and team building while keeping openness to new solutions. Transparency, social and inclusive approaches are also necessary for the design of course content and rubrics.

Future research shall focus on understanding the long-term impacts of BIM-integrated CBL on student competencies and career outcomes, expanding the scope of BIM-supported CBL to larger and more diverse student cohorts, as well as focusing on the potential and impact of emerging new technologies such as digital twins and AI. The research trend holds significant promise for further enhancing the educational value and real-world relevance of AECO education programs.

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