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van Nederveen, G.A.; Soman, R. K.

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BIM AND INFORMATION SYSTEMS EDUCATION FOR THE CONSTRUCTION MANAGEMENT MSC PROGRAMME

Sander van Nederveen and Ranjith Kuttantharappel Soman
TU Delft, Faculty of Civil Engineering and Geosciences
Delft, the Netherlands

Abstract

The increasing digitization of the construction industry creates an urgent need for construction managers to be proficient in Building Information Modeling (BIM) and information systems. This paper investigates how to integrate these topics effectively into a broad and diverse Construction Management and Engineering (CME) master's curriculum. This has led to a flexible educational model that balances theoretical grounding with hands-on project work.

The findings show that while a single course can successfully raise awareness and introduce key concepts, students sometimes struggle with abstract modeling and data management topics. Nevertheless, the approach can indeed foster deeper engagement and inspire further exploration.

Introduction

The construction industry is undergoing a profound digital transformation. Technologies such as Building Information Modeling (BIM), digital twins, AI, and data analytics are becoming central to project delivery and lifecycle management. However, this shift has exposed a significant skills gap. Various reports have highlighted the slow pace of digital adoption and the pressing need for upskilling, particularly in digital methods for construction management (Deloitte 2025; Sawhney and Knight 2024). Bridging this gap is critical for future professionals leading and coordinating increasingly complex, data-driven projects.

Construction management plays a pivotal role in integrating diverse digital tools and information systems across project phases—from design and planning to execution, safety, and maintenance. It is at this intersection of decision-making and coordination that awareness and understanding of digital technologies become essential. While previous studies have advocated for the inclusion of BIM and digital skills in engineering education, there is a limited understanding and empirical evidence on how flexible, experiential learning models can be effectively embedded in construction management curricula. This study addresses this limitation by presenting the design and implementation of a foundational course that integrates theoretical instruction with project-based, hands-on learning to foster digital awareness, foundational competence, and student engagement. The course has been part of the Construction Management and Engineering (CME) program at TU Delft for over ten years, evolving through incremental iterations.

Reflecting over the experience from multiple iterations of the course, this paper's central research question is: *How can a foundational course on digital engineering for construction management balance theoretical grounding with hands-on project work to develop awareness and skillsets for future exploration in digital construction management?* The paper is structured as follows: Section 2 outlines the context of the CME master's program and its focus on digital transformation; Section 3 presents the objectives and pedagogical approach behind integrating digital technologies into the curriculum; Section 4 details the design, structure, and delivery of the foundational course "Information Systems for the Construction Industry"; It also discusses the role of advanced electives and Section 5 illustrates how students further develop their skills through graduation projects; Section 6 offers a discussion of key insights, challenges, and implications; and Section 7 concludes with reflections on the current outcomes and future directions for digital engineering education in construction management.

Construction Management and Engineering (CME) Master program

General Context

The MSc in Construction Management and Engineering (CME) at TU Delft is an interfaculty program designed to tackle the challenges and drive the reforms needed in the construction industry. It offers an interdisciplinary approach by integrating expertise from three faculties—Civil Engineering & Geosciences (CEG), Architecture & the Built Environment (ABE), and Technology, Policy & Management (TPM)—to provide a well-rounded education in both construction management and engineering. The CME master has about 90 students per year.

The program focuses on the management of large-scale engineering projects throughout their design, execution, and maintenance phases, while emphasizing the integration of technical knowledge with managerial skills to enhance societal value. Key themes include digitalisation, sustainability, and innovative management practices tailored to the evolving needs of the construction sector. Core themes that CME addresses are integral & collaborative design processes, optimization of project management, risk & asset management throughout the design and life-cycle, as well as the legal & financial aspects of construction projects" (CME, 2024). Additionally, the CME program is set in an international context, equipping students to handle global construction challenges through interdisciplinary and cross-cultural collaboration. The "Engineering & Systems" specialization within the CME program emphasizes systems thinking and decision support in the construction sector, focusing on the development of innovative systems to enhance performance in engineering management. Students engage in real-life problem-solving through system-development methods and apply decision-making tools under uncertainty using data-driven approaches. Core topics include systems engineering, asset management, information modeling such as BIM, risk analysis, safety management, supply chain optimization, and decision-making frameworks that account for assumptions, risks, and data analysis. This track equips students with the necessary tools to design and implement advanced information systems that improve efficiency and tackle complex logistical challenges in the construction industry.

Foundations for Digital Education in the CME Program

One of the characteristics of the construction industry is that has become more and more a digitalized industry. And this digital transition process is likely to continue in the foreseeable future with technological developmenst such as AI and digital twins (see for example Sacks et al (2018), pp 386-397). As a result, there is a clear industrial need for young professionals with digital knowledge, competences and awareness. In fact, companies more or less expect that recent graduates are familiar with the latest developments.

Our experience with BIM and information systems education goes back a long time ago, to the times when there was no Revit, and BIM was not a commonly used acronym (van Nederveen et al. 2006a, van Nederveen et al., 2006b). This has gradually changed over the years, first with the breakthrough of BIM as a mainstream technology, softwares such as Revit and Bentley, and later on the publication of high-quality textbooks by Eastman et al (2008), updated by Sacks et al (2018), and by Borrmann et al (2018).

This has led to the current situation in which BIM and information systems are rather mature technologies, although the field is constantly changing because of new technologies such as AI, digital twins, etc. Our current approach of BIM and information systems education is presented against this background.

Integrating Digital Technologies into the CME Curriculum

Objectives

For our BIM and information systems programme the following objectives have been formulated: (1) to create awareness of the importance of BIM and information systems in construction, (2) to develop a basic level of skills and understanding of BIM and information systems, and (3) to inspire and motivate students to develop themselves further in this direction.

Because of the broad character of the CME master programme, the possibilities for education on BIM and information systems are limited; choices had to be made on what to lecture, what to offer to all students, what to offer as electives and so on. This has resulted in a setup with one introductory course "Information Systems for the Construction Industry" for all students, a number of related courses that can be chosen as electives, and various possibilities to do a graduation project in this field.

Approach

The education approach that is used has also evolved over the years. In the early days courses were often characterized by classical lectures on theory plus hands-on training of BIM software using documentation developed by the vendors. Nowadays many education activities are using the so-called Open Design Learning (ODL) approach (Binnekamp et al 2020, Wolfert 2023 sections 6.1 and 9.2).

This approach uses many state-of-the-art educational concepts and methods such as active learning, problem-based/challenge-based learning and constructivist theory. These concepts are applied in a rather radical manner: students are asked to search and select a so-called project-of-interest (a construction project that is recently built, for which they have access to technical documents), apply course concepts to this project, and deliver a so-called ODL-response in which the applied concepts are presented. Assessment is fully based on these ODL-responses, no written or oral exams are taken. Following the "open" education approach, the ODL-response is free-format: it can be a report, a presentation, a video, a website, anything is allowed.

On the other hand, a practical problem with the approach is that students find difficulty in getting access to the needed technical information of their project of interest.

Curriculum Design - "Information Systems for the Construction Industry"

The introductory course "Information Systems for the Construction Industry" is offered to all CME students (and a few students from other tracks who can choose this as an elective). The main objective of this course is to *develop awareness of the importance of information systems, BIM and information management in building and construction projects*. The course has been running for over 10 years, with incremental changes every year.

This course's possibilities are limited: it is the only compulsory course about BIM and information systems, and its size is limited to 5 ECTS (140 study hours). In addition, the course is followed by students from different backgrounds, from different countries and cultures, with different undergraduate education, and with different levels of experience, ranging from several years of (BIM) practice to no experience at all.

For this audience, it was decided to offer a broad course with the following characteristics:

- Both (basic) theory on BIM & information systems and (essential) hands-on practice.
- A broad overview of the role of BIM & information systems in different phases and application fields of building and construction.

Theory and practice

For the theoretical part, we are really happy to have the textbooks by Borrmann et al. (2018) and Sacks et al. (2018) (after many years of teaching without having such textbooks and using fragmented book parts, research papers, and articles trying to cover the field). The textbooks may become a little outdated, as seven years is a long time in IT. However, they still provide an instrumental theoretical foundation for education, also with a lot of opportunities to dive deeper into topics. In addition, we refer to latest papers in the area to illustrate the state-of-the-art in construction management research.

Next to the theoretical part, students get some essential hands-on experience by doing simple modeling exercises and analysis using common tools such as Revit, Navisworks, Autodesk Tandem, etc. A thorough training in BIM is impossible because of time limitations and because the course is part of an academic curriculum. But at least a bit of basic hands-on experience was found essential. Future construction managers may not become professional modelers, but it is very likely that they will come to a position where they can decide upon the use of BIM and information systems. And then it is better that they do not have to rely on hearsay only.

Information theory and modelling fundamentals are difficult topics to teach in this introductory course. It is easy to ask for a system breakdown structure or a simple process model or flowchart. But discussion and reflection on model quality, how to model, abstraction mechanisms, UML class diagrams, etc., require more time than is available in this course.

Emphasis on construction phases and application fields

The central part of the course is dedicated to the importance and role of BIM and information systems in different lifecycle phases and application areas of construction projects. One of the main messages of the course is the existence of so many information systems for so many application areas and the difficulty and complexity of integrating information between these systems (see Figure 1).

The course was originally structured around the concept of "n-dimensional modelling" as proposed by Aouad et al. (2005), which served as a guiding framework to explore the various applications of BIM across the construction project lifecycle. This led to a sequence of topics including 3D geometric modelling with clash detection, 4D planning simulation, 5D cost estimation, 6D maintenance planning, 7D sustainability analysis, and 8D safety analysis.

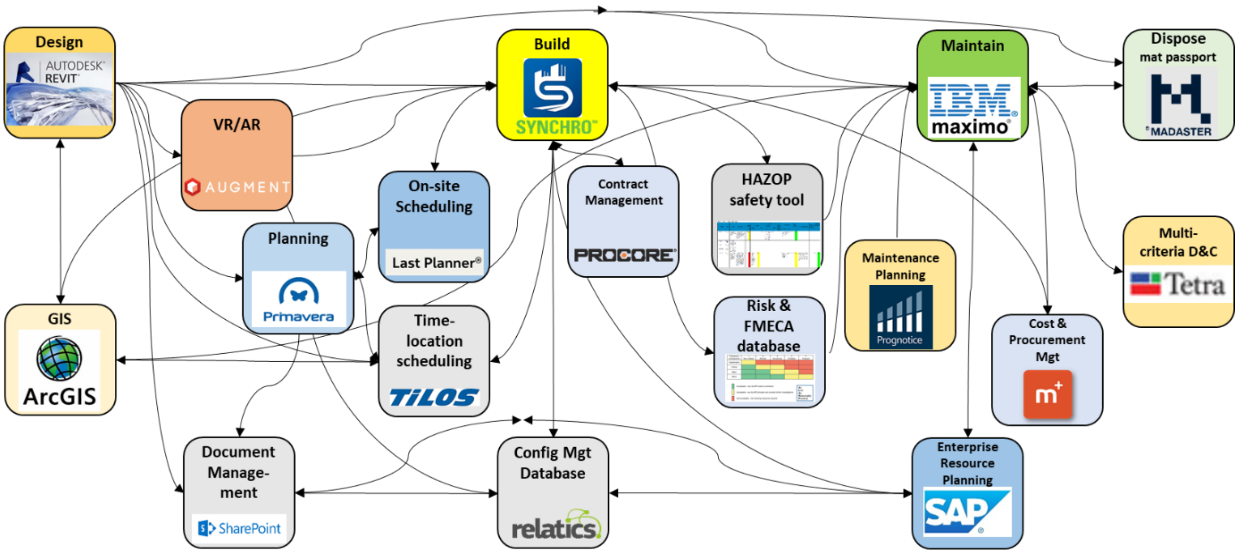

Figure 1 Information Systems landscape of a typical Design Build Maintain Disposal (DBMD) contractor (Wolfert et al, 2022)

However, it was later recognized that these so-called "dimensions"—particularly from 5D to 8D—are not truly independent or orthogonal in nature. A more detailed critique of this dimensional framework is provided by Koutamanis (2020).

Education approach and elaboration

The education approach used is based on the concept of ODL (see Section 3). The basic idea is that education is much more effective when students apply concepts in their own work than when teachers explain concepts in an instructive, one-directional manner.

The course is delivered over seven weeks, each introducing a new concept in an interactive classroom setting to help students contextualize it for their ODL project. This is supplemented by a lecture from practice so the student can understand what is happening beyond the academic world. In the second part of each session, students apply the concept to their chosen project of interest and reflect on their experience. For this course, students first had to search for and choose a project of interest that they could use for the concepts below. The sequence of course concepts is structured as follows:

- 3D Geometry: students are asked to develop a simple 3D BIM model in Revit (or any other software that they prefer);
- 4D Planning simulation: students are asked to develop a 4D simulation in Navisworks based on their 3D BIM model and a construction planning created in MS Project.
- Cost estimation: students are asked to create a simpe cost estimation using their 3D BIM model and cost data stored in Excel.
- Maintenance planning: Students are asked to design a maintenance management system using object data from their 3D model. They may use frameworks such as Autodesk Tandem or Bentley iTwin.
- Sustainability analysis: Students are asked to demonstrate how they can use BIM data to analyze a sustainability aspect of their choice (e.g., life cycle assessment, circular construction opportunities, etc.). They may use software such as Autodesk Insight or OneclickLCA.
- Safety analysis: students are asked to create a virtual safety walk during the construction phase using their BIM model and show how safety hazards can be identified.
- Future development: Finally, students are asked to elaborate on future developments that can greatly impact their chosen Project of Interest (digital twins, blockchain, AI, robotics, machine learning, large language models, etc.).

For each concept, students are required to produce a digital artifact and reflect on three key aspects: (1) the challenges encountered during its development and the reasoning behind their decisions, (2) how the artifact supports or enhances decision-making, and (3) how it influences collaboration or necessitates changes in roles. The final outcome is a comprehensive student project that touches on all application areas. Submissions are open format and may be a written report, slide deck (with or without voiceover), video, or website.

Assessment

The course uses a combination of formative and summative assessment to support and evaluate student learning. Formative assessment is provided continuously during practical sessions, offering students feedback to help them better understand the concepts, connect them to their own projects, and identify key challenges. Additionally, two peer feedback sessions are organized, where students present their work to the class and receive input from both peers and instructors. This process fosters deep learning by encouraging critical thinking, enhancing conceptual understanding through observation and discussion, and promoting the integration of new knowledge with prior experience. It also helps develop vital skills such as communication, collaboration, and self-assessment, while creating a supportive classroom environment that encourages open dialogue and correction of misconceptions.

Summative assessment is based on the evaluation of the student's ODL project submission, which is presented in an open format. Each concept is assessed using a predefined matrix, ensuring that learning outcomes are consistently and fairly measured.

Advanced Courses

While the introductory course equips all CME students with foundational knowledge and skills in digital engineering, the program also offers a suite of advanced courses as an electives for those who wish to explore these topics more deeply. This tiered approach is deliberate: not all students intend to pursue careers focused on digital technologies, and for them, a broad introduction is sufficient to operate effectively within digitally enabled construction environments. However, for students with a stronger interest or ambition to lead digital innovation, further study is both relevant and necessary.

However, for students with a stronger interest or ambition to lead digital innovation, further study is both relevant and necessary. These students can choose from a diverse set of electives:

- Virtual/augmented/extended reality;
- Parametric design and digital fabrication;
- Programming: all students get basic training in Python in one of the other compulsory courses, but there are many possibilities to further develop Python skills, or learn other languages;
- AI: the rapid developments in AI have also resulted in a rapid growth of courses on AI topics such as machine learning and data analytics. Most courses offered are not specifically directed towards the construction industry, but interested students can get out of it what they need.
- System Dynamics;
- Game Design.

While many of these courses are not construction-specific, they provide the flexibility and depth needed to develop advanced capabilities. This structure ensures that all graduates leave the CME program with the baseline digital competencies expected by industry—as highlighted in recent skills gap reports—while enabling motivated students to gain the expertise required to drive the sector's digital transformation

Graduation Projects

Student selection of graduation projects provides a valuable indicator of how the foundational and advanced courses in the CME program cultivate awareness and skillsets for future exploration in digital construction management. While many CME students choose management-related topics for their graduation projects—often employing methods such as stakeholder analysis, soft factor evaluation, interviews, surveys, and case studies—a significant number of students opt to focus on topics related to information systems. This is inspired by their exposure to the foundational course and subsequent electives. These projects span both fundamental research questions and applied industry-oriented challenges.

On the research side, students have explored questions such as how to integrate multiple digital twins to analyze emergent behaviors in complex systems. On the applied side, projects often address current priorities in the construction industry, including the development of Revit add-ons for automated model quality checks, or the use of BIM for AI-enabled asset monitoring. Other themes include sustainability, resilience, and supply chain optimization—often aligning closely with active industry agendas.

Across both types of projects, students draw from the foundational concepts introduced in the introductory course and combine them with advanced tools and methods. These may include Python and API programming, system dynamics, agent-based modeling, and discrete event simulation. Applied projects frequently involve collaboration with industry supervisors alongside academic mentors, ensuring that outcomes are relevant and aligned with company goals and innovation strategies. This dual engagement model reinforces both academic rigor and practical relevance, positioning graduates to contribute meaningfully to the ongoing digital transformation of the construction sector.

Several recent graduation projects illustrate the diverse ways in which students apply their digital engineering knowledge. For example, Van der Zwaag (2023) developed a conceptual design system for circular buildings by integrating multiple common software tools. Using Python scripts, the project connected Revit for BIM modeling, Excel for data management, and Power BI for analytical visualization—resulting in a prototype system to support circular construction design decisions (see Figure 2).

Another compelling example is Tian (2024), who created a digital twin framework to optimize supply chain coordination in prefabricated construction (see Figure 3). This project combined BIM principles with real-time data exchange between physical systems and virtual models. Techniques such as system dynamics modeling were employed to simulate and improve logistics and coordination across the supply chain.

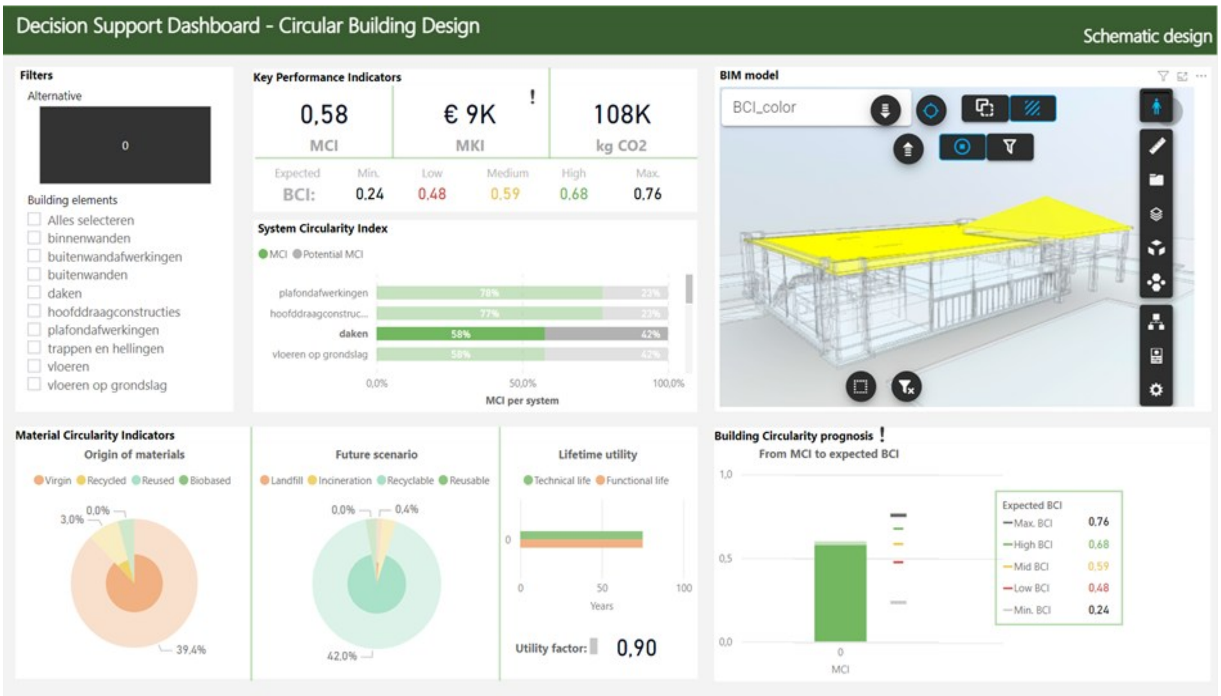

Figure 2 Decision Support Dashboard of the design system for circular building by van der Zwaag (2023)

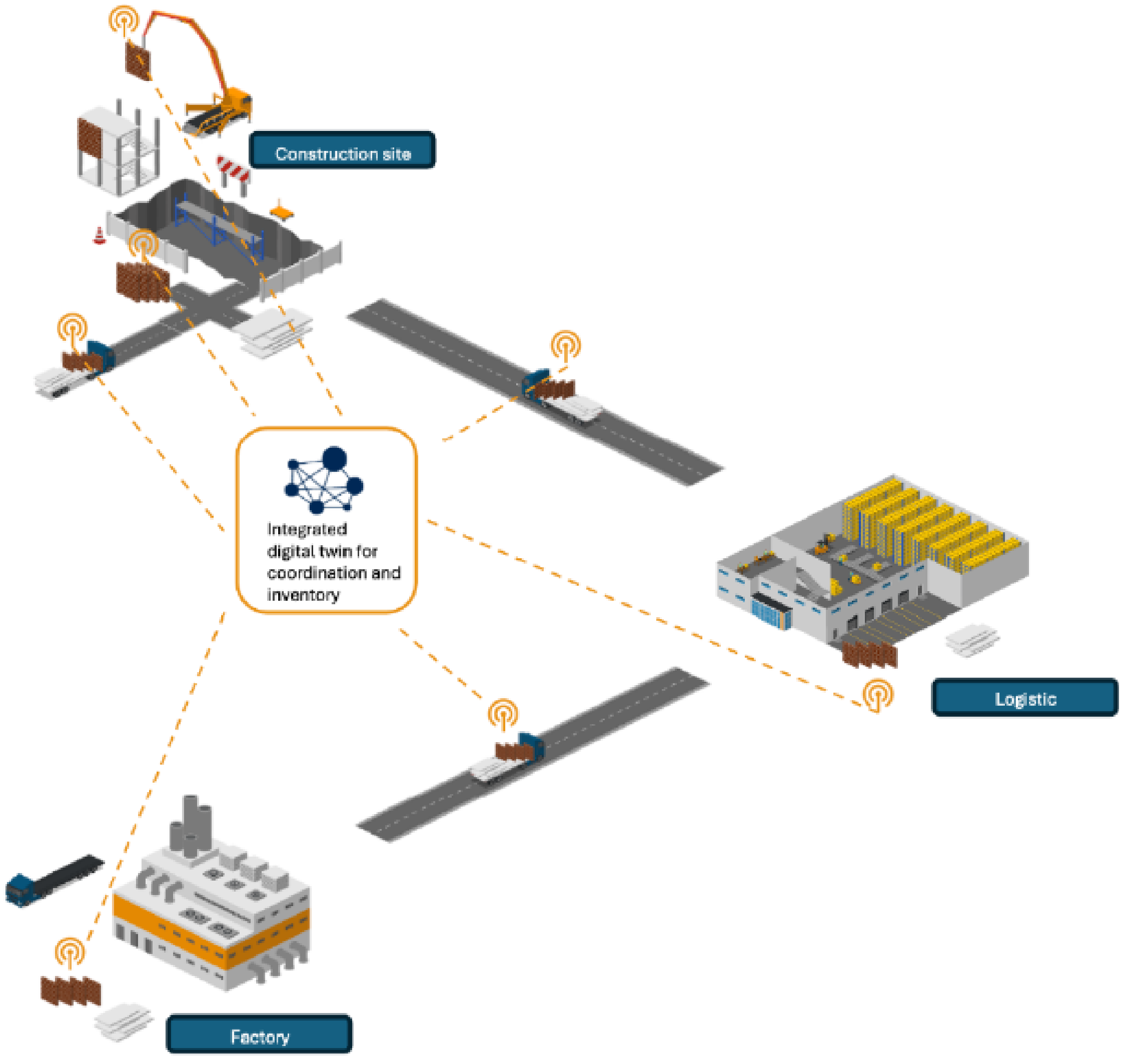

Figure 3 Overview of an integrated digital twin for prefabricated construction supply chain coordination (Tian, 2024)

Beyond these, other graduation projects have tackled a range of cutting-edge topics: parametric and generative design for infrastructure (e.g., bridges and viaducts), 4D planning simulations incorporating temporary spatial constraints, BIM-based safety analysis tools to detect hazardous construction zones, and machine learning models for analyzing asset management data—such as corrosion detection in sheet piles. Some students have also contributed to tool development, including a Revit add-on for automated model quality checks and a domain ontology for managing public sewerage infrastructure data.

Collectively, these projects demonstrate how CME students leverage foundational knowledge and advanced digital methods to address both theoretical questions and real-world industry needs.

Discussion

This paper has explored how a foundational course on digital engineering, situated within the CME program at TU Delft, can successfully balance theoretical grounding with hands-on project work to foster awareness and skill development in digital construction management. Drawing on over a decade of iterative course development, the study demonstrates that a carefully structured curriculum, underpinned by Open Design Learning (ODL), can provide students with a meaningful introduction to BIM and information systems while also encouraging critical thinking and further exploration. The main contribution lies in showing that even within the constraints of a 5 ECTS course, it is possible to achieve impactful learning outcomes that prepare students for both industry and research pathways.

The ODL approach has been instrumental in achieving this balance. By combining active learning with problem-based and constructivist methodologies, students are not only introduced to theoretical concepts but are also challenged to apply these ideas in real-world contexts through their own selected projects. This model shifts the educational focus from passive knowledge acquisition to experiential learning, where understanding is constructed through doing. The open-ended format of submissions—ranging from reports to videos and websites—further empowers students to engage with course content in ways that suit their learning styles and interests, while still meeting the intended learning objectives.

One key insight from our experience is that teaching specific software is not the core objective of digital engineering education. Instead, the course emphasizes foundational concepts of information systems—such as model structures, data flows, and lifecycle integration—while encouraging students to explore relevant tools and workflows through guided self-learning. Providing access to up-to-date tutorials, getting-started guides, and curated resources helps students gain practical skills that are adaptable to the fast-evolving software landscape. This approach ensures students are better prepared to work with emerging tools without being limited by the specifics of any one platform, which can quickly become outdated.

The CME program's layered structure, where the foundational course is augmented with a wide selection of advanced electives, has also proven to be effective. This tiered model acknowledges that not all students will pursue careers in digital technology, while still ensuring a minimum level of competency for all graduates. At the same time, it allows those with a strong interest in areas such as AI, simulation, programming, and extended reality to delve deeper and acquire the specialized skills needed to drive innovation and digital transformation in the industry. This ensures a balanced graduate profile: one that meets baseline industry expectations while nurturing future leaders in construction digitization.

Another challenge the course has successfully addressed is the diversity in student backgrounds. The CME cohort typically includes individuals with prior industry experience, some with hands-on BIM exposure, and others from non-engineering or policy backgrounds. Designing a course that can cater to this range of starting points has required careful scaffolding of concepts, flexibility in project selection, and personalized formative feedback. The use of real-world projects as the foundation for learning ensures that each student can engage with the material at a level appropriate to their background and interests, while still achieving core learning outcomes.

Despite its successes, the course faces limitations—particularly in covering advanced topics such as data analytics, conceptual modeling, or linked data technologies. These subjects require more time and depth than the current course structure allows, and students without practical industry context often struggle to appreciate the complexity involved. Moreover, concepts like implementation, standardization, and organizational change are difficult to internalize without exposure to real-world challenges. As such, these topics remain difficult to fully address within the time constraints of a single course.

Finally, while the paper provides a valuable case study of curriculum design within a single academic program, it is limited in scope. The observations and outcomes are primarily based on experience at TU Delft and may not generalize to other institutional settings without adaptation. Future research could explore longitudinal outcomes of graduates who pursued digital pathways, comparative studies across programs, or the development of standardized competency frameworks for digital construction education. Nevertheless, the findings here offer a replicable and adaptable model for integrating digital engineering education into construction management curricula.

Conclusions

This paper has presented an integrated approach to teaching digital engineering within the Construction Management and Engineering (CME) master's program at TU Delft, focusing on the design, delivery, and evolution of a foundational course on BIM and information systems. The course effectively balances theoretical knowledge with hands-on project work, fostering digital awareness and foundational competencies among students. Using the Open Design Learning (ODL) approach, students engage in active, self-directed learning by applying course concepts to real-world projects, preparing them for roles in an increasingly digitalized construction industry.

A key strength of the approach lies in its adaptability to the diverse backgrounds of CME students and its responsiveness to the rapidly changing digital landscape. Rather than emphasizing specific software tools, the course centers on conceptual understanding and empowers students to explore tools and workflows independently. This foundational learning is further supported by a suite of elective courses, allowing students with deeper interests in digital engineering to develop advanced skills aligned with emerging industry needs in areas like AI, sustainability, and data-driven decision-making.

While the course has achieved strong outcomes, certain limitations persist, particularly in addressing more advanced topics within a single course structure. Nevertheless, the layered curriculum model (combining foundational learning with elective specialization) ensures that all students graduate with essential digital competencies, while also enabling some to pursue expertise in driving the sector's digital transformation. This case study provides valuable insights for educators seeking to embed digital engineering in construction education, and offers a flexible model that can be adapted and scaled to other academic programs globally.

Looking ahead, the role of information systems in the CME curriculum is expected to become even more significant. As emerging technologies such as digital twins, AI, robotics, and blockchain continue to influence the construction sector, integrating these topics into the educational framework will be essential. While the short-term impact of such technologies may sometimes be overestimated (much like the early hype around BIM) their long-term importance is undeniable. To remain relevant and future-ready, construction education must continue to evolve in step with the digital transformation of the industry.

References

Aouad G, Lee A and Wu S (2005). "From 3D to nD modelling", ITcon Vol. 10, Special issue From 3D to nD modelling, pg. 15-16, http://www.itcon.org/paper/2005/2

Binnekamp, R., Wolfert, A. R. M., Kammouh, O., & Nogal, M. (2020, April). The Open Design education approach-an integrative teaching and learning concept for management and engineering. In 2020 IEEE Global Engineering Education Conference (EDUCON) (pp. 756-762). IEEE

Borrmann, A., König, M., Koch, C., & Beetz, J. (2018). Building Information Modeling. Springer.

CME (2024), "MSc Construction Management and Engineering", TU Delft, https://www.tudelft.nl/en/education/programmes/masters/cme/msc-construction-management-and-engineering

Deloitte. (2025). State of Digital Adoption in Construction Report 2025. https://www.deloitte.com/au/en/services/economics/analysis/state-digital-adoption-construction-industry.html

Eastman, C., Teicholz, P., Sacks, R. and Liston, K. (2008) BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers, and Contractors. 2nd Edition, Wiley, NJ. http://dx.doi.org/10.1002/9780470261309

Koutamanis, A. (2020). Dimensionality in BIM: Why BIM cannot have more than four dimensions? Automation in Construction, 114, Article 103153. https://doi.org/10.1016/j.autcon.2020.103153

Sacks, R., Eastman, C., Lee, G., & Teicholz, P. (2018). BIM Handbook. Hoboken, NJ, United States: Wiley.

Sawhney, Anil, and Andrew Knight. (2024). Digitalisation in Construction Report 2024. https://www.rics.org/content/dam/ricsglobal/documents/research/Digitalisation-in-construction-report-2024.pdf

Tian, S.Y. (2024), Integrated Digital Twins in Prefabricated Construction Supply Chain Coordination – a hybrid simulation method, MSc thesis, TU Delft, 2024.

van Nederveen, GA., Beheshti, MR., Dado, E., & de Ridder, HAJ. (2006a). ICT requirements for innovative dynamic building processes. In G. Aouad, M. Kagioglou, H. de Ridder, R. Vrijhoef, & K. Harris (Eds.), Proceedings 3rd International SCRI Symposium (pp. 328-338). University of Salford.

van Nederveen, GA., Beheshti, MR., Dado, E., & de Ridder, HAJ. (2006b). Towards information architecture for value-oriented building processes. In H. Rivard, E. Miresco, & H. Melhem (Eds.), Building on it. Conference program and book of abstracts + CD (pp. 1778-1786). Biblioteque de Quebec et Canada.

Wolfert, R. (2023). Open Design Systems. Research in Design Series; Vol. 10. IOS Press. https://doi.org/10.3233/RIDS10

Wolfert, R., Nederveen, S. van, & Binnekamp, R. (2022). "Fit for Purpose Building Information Modelling and Systems Integration (BIMSI) for Better Construction Projects Management". The Journal of Modern Project Management, 10(1), 174–187. https://doi.org/10.19255/JMPM029011

Zwaag, M. van der, Wang, T., Bakker, H., van Nederveen, S., Schuurman, A. C. B., & Bosma, D. (2023). Evaluating building circularity in the early design phase. Automation in Construction, 152, Article 104941. https://doi.org/10.1016/j.autcon.2023.104941