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Creating a Model-Based Learning Environment in BIM Education through Case Studies

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Abstract

As demand in the construction industry continues to rise globally, universities have shown an increased interest in Building Information Modeling (BIM) education, leading to accelerated curriculum development studies. Previous research has identified several challenges associated with creating new BIM course curricula. Notably, the instructor's competence in delivering the practical components of the course and developing assignment content are significant issues. The development of case studies aims to enhance the BIM proficiency of course instructors and to generate course materials suitable for practical application. This paper outlines the design of course content for BIM curriculum development through the use of case studies. Case studies from various building programs are evaluated and compared based on their BIM maturity levels. The resulting course materials are implemented in a graduate course offered each year and assessed through student surveys. The intricate nature of BIM is explained within a model-based learning environment. By analyzing the learning environment using data gathered from student surveys, this study aims to provide insights for future improvements.

Keywords: *BIM curriculum development, BIM maturity level, model-based design, virtual construction.*

BIM Eğitiminde Model Tabanlı Öğrenme Ortamının Örnek Çalışmalar Üzerinden Oluşturulması

Öz

Dünya genelinde inşaat sektöründe artan talep üzerine üniversitelerin BIM eğitimine olan ilgisi artmış ve müfredat geliştirme çalışmaları hız kazanmıştır. Önceki çalışmalar incelendiğinde, yeni bir BIM dersi müfredatı oluşturulurken bazı zorluklar olduğu görülmüştür. Özellikle dersin uygulama kısmının yürütülmesine dair eğitmenin yetkinliği ve ödev içeriklerinin oluşturulması ana problemi oluşturmaktadır. Örnek çalışmaların geliştirilmesi ile dersin eğitmeninin BIM yetkinliğinin sağlanması ve dersin uygulama kısmında kullanılabilecek ders materyallerinin elde edilmesi amaçlanmıştır. Bu çalışmada, bir BIM müfredatının geliştirilmesi için ders içeriğinin nasıl tasarlandığı örnek çalışmalar üzerinden açıklanmaktadır. Farklı bina programlarından oluşan örnek çalışmalar BIM olgunluk seviyesi açısından değerlendirilmekte ve karşılaştırılmaktadır. Üretilen ders materyalleri, bir dönemlik bir yüksek lisans dersinde her yıl tekrar ederek uygulamaya geçirilmiş ve öğrenci anketi ile test edilmektedir. BIM' in karmaşık yapısı, üretilen model tabanlı öğrenme ortamı üzerinden anlatılmaya çalışılmıştır. Öğrenci anketi ile elde edilen bulgular üzerinden öğrenme ortamına ilişkin değerlendirme yapılarak, geleceğe yönelik projeksiyon ortaya konmaya çalışılmaktadır.

Anahtar kelimeler: *BIM müfredatı geliştirilmesi, BIM olgunluk seviyesi, model tabanlı tasarım, sanal inşaat.*

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1. Introduction

Construction productivity metrics indicate that productivity in manufacturing has nearly doubled, while in the construction sector, it has remained stagnant or declined over time (Smith & Tardiff, 2009). This stagnation has prompted the construction industry to seek more efficient business models in an increasingly competitive market. Building Information Modeling (BIM) is considered a catalyst for change, poised to reduce industry fragmentation, enhance efficiency and effectiveness, and lower the high costs associated with inadequate interoperability (Nagarajan, 2011).

BIM aims to address efficiency challenges in the construction sector. Rather than physically constructing a building, BIM focuses on creating a virtual model to identify and resolve potential design issues. BIM is an intelligent, model-based process that utilizes various computer software tools, enabling more efficient planning, design, construction, and management processes. One of the primary advantages of BIM is the early and rapid detection of design errors or conflicts. Additionally, to enhance productivity, BIM tools strongly encourage improved communication among team members and foster collaborative teamwork.

BIM is not merely a software application; it is a comprehensive business model characterized by specific workflows and supported by information technology. BIM is defined as a digital simulation that consists of three-dimensional (3D) models across various disciplines, containing detailed information about the building components. The adoption of BIM continues to grow at an accelerated pace. In the early 2000s, the term BIM was first introduced to the construction industry by a leading software company, prompting other firms to pursue involvement in this field. The BIM maturity model outlines this progression across three levels: Level 1 addresses early adoption with two-dimensional (2D) CAD drawings alongside 3D implications; Level 2 incorporates 3D drawings along with four-dimensional (4D) and five-dimensional (5D) capabilities; and Level 3 defines a six-dimensional (6D) vision for building life-cycle management (Barlish & Sullivan, 2012; Sacks et. al., 2018).

The significant increase in the use of BIM in the construction industry on an international scale over the past decade has led to a rise in academic activities focused on this subject. Public institutions are also transitioning to e-procurement processes, and the integration of BIM into these processes is currently under discussion (Pınar, 2022). Students aspire to compete in the global construction industry and secure employment upon graduation. Consequently, the development of new courses and the assessment of learning outcomes related to BIM education have been incorporated into university curricula at both the undergraduate and graduate levels. Departments are requesting BIM education from their professors to better prepare their students for competition in the construction sector after graduation. Given the increasing demand from the construction industry, BIM education is expected to enhance students' employment opportunities.

2. Literature Review

The literature review conducted at the beginning of this study examines how a BIM curriculum is developed, the strategies employed, and the challenges encountered. BIM encompasses more than just software packages or the apprehension associated with new technologies in the industry; it represents a cultural shift in the way projects are executed and managed (Barison et al., 2010; Kazaz & Ergen, 2017). The existing curricula at universities in the fields of architecture, engineering, and construction (AEC) need to be revised to incorporate BIM (Rodriguez et al., 2017).

A questionnaire-based study was conducted to assess BIM knowledge among graduate-level students at two universities, one in Brazil and the other in the USA. The study concluded that BIM needs to be better integrated into the curriculum (Arrotéia et al., 2018). Another study in the United States examined existing civil engineering curricula and conducted interviews with BIM experts in the construction industry. Based on industry expectations regarding the use of BIM and the current structure of academic programs, several strategies for curriculum development and improvement were suggested (Song et al., 2022). In addition to construction programs, both introductory and advanced BIM courses have been incorporated into the new curriculum of architecture departments (Hon & Drogemuller, 2016). Research has also been conducted on the application of BIM in design studios. For instance, parametric design, digital fabrication of buildings, and interactive technology applications are frequently explored in such studies (Baldessin et al., 2020; Uzun & Çakır, 2020; Wu & Jeng, 2012). A study conducted in Turkey proposed a three-stage model for integrating BIM education into the design studio: first, a training and learning process; second, a design process; and finally, a questionnaire survey and evaluation process (Uzun & Çakır, 2022).

2.1. Types and Levels of BIM Courses

BIM topics taught in higher education can be categorized into three primary areas: conceptual BIM knowledge, BIM software, and BIM applications (Guo et al., 2022). In undergraduate education, BIM is primarily taught at the senior level (Barison & Santos, 2011). Typically, BIM courses are defined as introductory-level courses within undergraduate programs (Lassen et al., 2018). Several studies have been conducted to explore how to integrate BIM into educational curricula and to design BIM course content for both undergraduate and postgraduate students, addressing the growing demand for BIM professionals in the industry (Kazaz & Ergen, 2017). Many programs in the AEC field are attempting to incorporate BIM content into their curricula, often replacing traditional CAD courses with introductory BIM courses (Eldin & Nawari, 2010; Huang, 2018). In architecture and civil engineering programs, BIM proficiency is categorized into introductory, intermediate, and advanced levels (Barison & Santos, 2011; Barison & Santos, 2013). When developing a new BIM course curriculum, it is essential to select one of the specified BIM competence levels and ensure that it aligns with the objectives of the chosen level (Barison & Santos, 2013). A study conducted across eleven leading universities in the United States revealed that there are three introductory courses designed to teach the concept of BIM to undergraduate students, while only one introductory course is offered to graduate students. This indicates that the primary focus of BIM education is at the graduate level. Consequently, it has been concluded that introductory courses should be incorporated into the undergraduate curriculum, while intermediate or advanced courses should be introduced and taught at the postgraduate level (Kazaz & Ergen, 2017). The goal is to improve the skills of a beginner-level BIM user at introductory level. The objective is to learn about various BIM tools and advanced techniques in 3D modeling, as well as to explore the features of families within a BIM tool at an intermediate level. The aim of the instruction is to refine certain skills of a BIM Manager at an advanced level (Barison & Santos, 2011).

Some universities have established stand-alone courses dedicated exclusively to BIM, while others have opted to provide seminars featuring industry experts. The integration of BIM at the program level, such as its inclusion in a capstone project or the creation of an individual course within the program, is also discussed and compared (Arnett & Quadrato, 2012). Many programs have implemented strategies for teaching BIM, categorizing them into four main types: stand-alone courses, cross-disciplinary courses, capstone or graduation project courses, and integration into existing courses (Abbas et al., 2016; Clevenger et al., 2010; Ghanem, 2022; Huang, 2018; Jurado et al., 2017). It is recommended to offer complementary courses in addition to independent stand-alone BIM courses to enhance students' long-term learning (Clevenger et al., 2010; Ghosh et al., 2013).

The evolution of BIM education can be conceptualized into three developing stages: (a) BIM-aware, which involves educating students about BIM and its advantages; (b) BIM-focused, which teaches students how to perform specific tasks related to the use of BIM; and (c) BIM-enabled, which emphasizes the realization of learning in a virtual BIM environment and the use of BIM as a tool for learning (Olowa et.al., 2023; Underwood et.al., 2013; Witt & Kähkönen, 2019). Research indicates that BIM-aware and BIM-focused education is generally accepted, and the effort to integrate BIM into program curricula is becoming increasingly widespread (Olowa et al., 2019). Additionally, a study conducted in Korea describes how the entire curriculum of the construction engineering department was transformed into a BIM-based education model (Lee et al., 2019).

One of the key advantages of incorporating BIM into the curriculum is its ability to facilitate collaborative learning (Witt & Kähkönen, 2019). Through BIM software, students can work together on a single project, sharing real-time updates and feedback (Ambrose, 2012). Many authors have noted that groups of more than two students from different disciplines collaborate, and this teamwork enhances the collaborative learning experience (Puolitaival & Kestle, 2018). Collaborative education involving participants from various majors is strongly recommended and even considered essential in BIM education (Ofluoglu, 2017; Macdonald, 2012).

On the other hand, online video tutorials are highly popular among students because they allow for flexible study schedules and personalized learning progress. Video-based learning (VBL) is more memorable than traditional lecture-based environments. Studies conducted on publications between 2003 and 2013 found that VBL is both effective and efficient for education (Tsai et al., 2019).

2.2. Course and Assignment Content

Starting with BIM technical content, a BIM curriculum should guide students through the acquisition of knowledge, software skills, and the application of this conceptual learning process. It must lead students to seek answers to the questions of what, why, and how. This approach encompasses the use of BIM, an understanding of case studies, and conflict resolution (Kymmell, 2008). Three skill categories defined in the learning outcomes should be targeted in each BIM application: technical skills (software tools), conceptual skills (management processes), and soft skills (teamwork). The level of detail and complexity of the subjects covered in the assignments may increase depending on the level of the BIM course (Kymmell, 2008). A comprehensive understanding of BIM and the development of problem-solving skills can be achieved by offering nD education, particularly in programming (4D), management (5D) and energy analysis (6D), in addition to 3D education (Lee et al., 2019). While the creation of a common digital model by students from various disciplines represents the primary working method of BIM, it also facilitates discipline-specific work (Károlyf et al., 2021). In a BIM working environment, group members assume different roles, such as facility manager, project manager, designer, and consultant (Lassen et al., 2018). In BIM courses conducted within architecture, civil engineering, and construction management departments, students from different disciplines often collaborate on semester projects based on 3D and 4D models within a single digital file (Charlesraj et al., 2015; Károlyf et al., 2021; Taylor et al., 2007; Tsai et al., 2019). A study conducted among postgraduate students in Nigeria examined the level of awareness and proficiency in BIM, revealing that students were more proficient in BIM 3D and more aware than proficient in BIM 4D (Maina, 2018).

2.3. Challenges of Incorporating BIM into the Curriculum

This section discusses the challenges encountered when integrating BIM into the existing curriculum and the issues surrounding BIM education. Research indicates that numerous obstacles exist in adapting BIM to the educational field (Ao et.al., 2022; Rodriguez et.al. 2017). Barriers to the integration of BIM into the curriculum include the concepts and tools of BIM, as well as the structure of the academic environment (Eldin & Nawari, 2010). One of the primary hurdles is the necessity for both faculty and students to adapt to the new software and workflows associated with BIM (Berwald, 2008).

Another significant challenge in BIM education is that most educational institutions are slow to adopt change (Eldin & Nawari, 2010). Additionally, the most common barriers to integrating BIM into the curriculum can be categorized as follows: the need for a shift in mindset regarding the process, lecturers' knowledge of the subject, lack of support for faculty, complexity of the software, availability of equipment, and time constraints (Ao et al., 2022; Huang, 2018; Olowa, 2023; Pillay et al., 2019; Witt & Kähkönen, 2019). The delivery of BIM courses necessitates additional teaching staff and the upskilling of existing academic personnel (Hon & Drogemuller, 2016). To effectively integrate BIM into academia and promote its adoption among faculty members, training opportunities should be provided by university senior management on course topics and materials (Abdirad & Dossick, 2016). Often, current faculty members lack the necessary skills to teach BIM and may not possess basic modeling competencies. To address this issue, universities often invite industry representatives or external stakeholders who are BIM experts to provide support (Lee at.al., 2019). Furthermore, inviting various BIM experts from the construction industry as guest speakers and organizing activities such as conferences, seminars, and workshops significantly enhance BIM education. The lack of continuity in the supply of BIM experts to the academic community has also created serious challenges in BIM education. In other words, even when an educational institution expresses a desire to incorporate BIM education into its curriculum, a critical issue remains: identifying qualified instructors to teach these courses (Christopher & Daniel, 2023).

3. Materials and Methods

As the methodology, a literature review on BIM education is first conducted, followed by the formulation of a problem statement to develop a BIM course curriculum based on this review. Subsequently, the aim, methodology, and scope of the research are presented. The objective is to create an original course curriculum that aligns with widely accepted standards. The success of the newly introduced curriculum is assessed through a student survey. Based on the survey results, projections for future studies are outlined. In summary, the methods employed in this study include curriculum design, the production of course materials, the definition of the necessary course environment, the scope of student assignments, and the evaluation of learning outcomes through a questionnaire.

3.1. Problem Statement

Some publications on course content and learning outcomes were identified, and most of the case studies were student projects presented at the end of the course (Baldessin et.al., 2020; Uzun & Çakır, 2020; Wu & Jeng, 2012). In developing the course syllabus, a sufficient number of textbooks were accessed and cited as references. Additionally, lecture notes were prepared with the assistance of these references and textbooks. However, the format and scope of the assignments for the laboratory component of the course were not clearly defined. Furthermore, the lecturer's competency in BIM posed another challenge in preparing the BIM course curriculum. It was also frequently observed that in the newly introduced BIM courses, an external consultant with industry experience was engaged to assist the lecturer in delivering the theoretical content and conducting the practical applications/laboratory work. In situations where support from professionals is not always feasible, it is crucial for the primary lecturer to possess the knowledge and experience necessary to conduct laboratory work effectively. It is strongly recommended that the lecturer assigned to the course complete BIM training prior to instruction. The literature consistently emphasizes that the development of materials suitable for the practical component of the course is a significant concern. From this perspective, the production of case studies, along with the lecturer acquiring the necessary BIM competencies, represents a primary challenge in BIM education. The hypothesis of this study is that the creation of detailed assignments and case studies will positively enhance the practical aspect of BIM education in the laboratory setting.

3.2 The Aim of the Study

The aim of this study is to describe the assignments to be completed in the laboratory component of a newly developed BIM course and to present case studies that contribute to the creation of a model-based learning environment. The term "model-based" in this context refers to the 3D, 4D, and 5D levels of BIM maturity.

3.3. The Scope of the Study

The syllabus for a graduate-level course was developed after examining various examples. Lecture notes were created by reviewing a range of textbooks, articles, and online resources. In addition to the theoretical components, there is a recognized need for materials suitable for a course structure that emphasizes practical application. Specifically, the content of assignments has been studied in detail, with research focusing on these defined assignment elements. The assignment content, categorized according to BIM maturity levels, is related to its applicability across different types of courses. In selecting case studies, a method is employed that progressively broadens the scope and complexity of design as practiced in architectural design courses within architecture departments. For instance, Architectural Design 1 begins with a project of minimal scale, while Architectural Design 8, also referred to as the Diploma Project, involves a larger-scale project. Likewise, the case studies commence with a small-scale clubhouse, gradually increasing in size and design complexity to include a habitat home, a commercial building, and ultimately culminating in a multi-storey office building.

4. Developed Graduate-Level Curriculum Content

According to the literature review, a graduate-level course is being developed, specifically designed as a BIM-focused curriculum. This newly created BIM course can be classified as a stand-alone course at the intermediate level, as it spans only one semester and includes specific assignments. The lecture notes presented herein cover BIM tools and modeling, integrated project delivery, and the construction process. These notes aim to introduce the fundamental principles of BIM solutions as a business model, promoting project-based learning through cross-disciplinary collaboration. Graduates in construction-related fields will be introduced to parametric modeling tools and cloud applications. The primary objectives include utilizing models for constructability reviews, enhancing time efficiency, and creating BIM content. The lecture notes also contribute to the development of engineering communication skills for students with backgrounds in the AEC domain. Before enrolling in this course, students should have a foundational understanding of topics such as building science and technology, practical experience, materials and methods of building construction, and design fundamentals, including orthographic drawing. If this course were offered at the undergraduate level, the content would be significantly limited, focusing solely on 3D parametric modeling.

Students in the AEC field should acquire fundamental skills in graphical drawing for building construction projects, editing 3D simulation models, creating virtually generated models, and processing all relevant data. This course promotes project-based learning through interdisciplinary collaboration. Students will learn 4D scheduling and simulation techniques essential for construction management, as well as specific BIM applications such as quantification, clash detection, and code compliance. The course covers the basic principles of BIM using Autodesk's BIM solutions. Students will be introduced to parametric modeling tools and cloud applications, enabling them to develop a foundational understanding of BIM. They will also gain familiarity with essential BIM tools. Throughout the course, students will explore the application of BIM across various disciplines and comprehend the advantages provided by the BIM process. The following is an outline of the course topics and associated readings from class textbooks or handouts: computer-aided design, building information modeling, BIM tools, integrated project delivery, parametric modeling, structural and MEP (Mechanical, Electrical, and Plumbing) modeling, clash detection, constructability and interference analysis, 4D scheduling, simulation and visualization, quantification, and estimating.

In designing the course curriculum, textbooks were initially utilized, followed by the determination of the targeted course content and activities. The course is divided into various BIM maturity levels, with course materials corresponding to these modules. Lecture notes, assignment content, presentations, and case studies are examined collectively. Given that not all modules can be addressed as homework activities within a one-semester course, two alternative approaches are proposed for the content of homework assignments, tailored to one-semester and two-semester courses (see Figure 1). The course curriculum is structured according to a BIM-focused methodology.

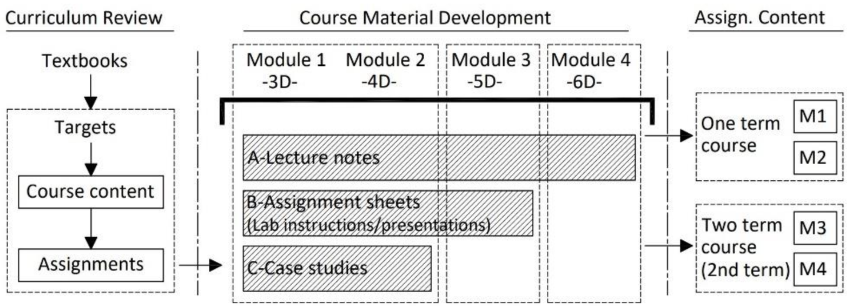


Figure 1. The workflow of course curriculum design (Yıldırım, 2018)

4.1. Targeted Assignments

BIM assignments may involve designing a new building, conducting a constructability review, and creating a virtual building model. Alternatively, students may develop a BIM model based on a project designed in another course or a building that exists on campus. In addition to individual learning in the production of the BIM model, it is beneficial to incorporate group activities into certain aspects of the work.

A cross-disciplinary work environment, the use of advanced collaboration technology, time management, and team coordination are the major challenges facing the teams. Architects, structural engineers, MEP engineers, and construction managers play a principal role in assignments mostly arising in a student BIM execution team. Working in teams of students from different disciplines to simulate the design and construction processes of a real-world project will give them an insight into the work environment they will encounter in their professional lives. In this way, they will have the opportunity to test BIM applications and develop their creative and innovative practitioners. Team communication and coordination of work are made possible by advanced collaboration technology. Through lectures and assignments, students can develop basic skills related to the activities covered in the course. In fact, it is often the case that this advanced level of exposure to technology is ahead of its industry application so that students will be more competitive and advantageous in the industry when they complete their studies. Each group should create its own collaborative platform, provide workflow on this digital platform, and work on BIM/CAD standards. How architectural and engineering problems are addressed and solved will be evaluated using the BIM model developed by the students. The assignment performance expected from students in an advanced level BIM course can be defined as follows; developing an integrated building model, constructibility reviewing, identifying conflicts of design in different disciplines, 4D work schedule and simulation, taking bill of quantities, cost calculation, and testing how to make more efficient work tracking in the construction process with cloud applications. Targeted assignments for an ideal advanced-level BIM course are presented in Table 1. Assignments are group projects comprising the entire range of topics covered in the course.

Table 1. Targeted assignments' content for BIM courses at graduate level (advanced level)

Descript.	Activity	Submission	Descript.	Activity	Submission
1- Integrat. Building Design	Families View properties Edit & modify Parametric drawing	**A**-Views in project browser **B**-3D parametric drawing	**5- 4D Simula_ tion**	Animation tool Animation script Simulation settings Single vs multiple parts	**A**-Viewpoint animation **B**-Timeliner simulation
2- Design Review	Shared parameters 4D navigation Review & mark up Adding tags	**A**-4D task ID list in "search sets" **B**-Review report	**6- Quantif_ ication**	Model takeoff Item & resource catalog Change analysis Quantity takeoff report	**A**-Item & resorouce catalog **B**-Quantity takeoff report
3- Clash Detec_ tion	Clash test options Status of clashes Reviewing clash view Clash result table	**A**-Hard, clearance clashes' views **B**-Clash result report	**7- Cost Estima_ tion**	Schedule report Assemble report Online cost data Cost analysis	**A**-Schedule report **B**-Cost analysis report
4- 4D Schedul_ ing	Creating tasks Linking with "sets" Gantt chart review Exporting CSV file	**A**-Timeliner tasks and linking "sets" **B**-Exporting gantt chart as CSV file	**8_ Cloud Applica_ tion**	Navigation in cloud app Constructability review Navigation in documents Field activity report	**A**-Constructability review report **B**-Field activity report

In order to successfully complete assignments in a virtual environment, students must possess a certain level of construction knowledge. Lab assignments will begin with the formation of teams and the development of a BIM execution plan. To initiate a "BIM kick-off" at the start of the course, all team members are required to review the draft of the BIM implementation plan. The objectives of the project execution and its various phases will be discussed by the students, and collaboration on best practices is encouraged during this meeting. Centered on problem-based tasks, BIM model assignments are developed in 3D, 4D, and 5D using CAD/BIM software such as Autodesk Revit®, Autodesk Navisworks®, and cloud applications like Autodesk BIM 360 Glue®, Field®, and Docs®, as well as Microsoft Project. The instructor provides a hands-on environment for students and introduces core techniques for practicing these skills through exercises and group work. The assignments offer a task-oriented opportunity for students to enhance their abilities. Each team will select a pre-designed project, and all assignments will be applied to this case study throughout the semester. Projects must reach at least the conceptual/schematic design (SD) level to emphasize BIM execution as construction documentation (CD) rather than architectural design development. The final project requires the creation of a comprehensive BIM model of a building or house in Autodesk Revit®, which includes a complete 3D model, construction documentation, 4D scheduling and simulation, material and quantity takeoff, and cost estimation (5D). The final presentation will be based on the assignments, and team presentations will be required at the end of the semester. Student teams will present their work to the instructor and peers, facilitating an exchange of ideas.

4.2. Case Studies: Housing, Commercial, and Office Buildings

While preparing the content for the BIM course, it was determined that supporting the application phase with case studies, in addition to the theoretical components, would be beneficial. In this regard, sample studies have been developed for use in laboratory applications, which can be shared with students. The developed case studies were aligned with the targeted tasks presented in Table 1. These case studies illustrate how students should approach their assignments. It was decided that the case studies would encompass various building programs and architectural concepts. Additionally, the aim is to guide architects and engineers who are using BIM to digitally construct a building for the first time. Consequently, the course begins with a single-storey clubhouse, followed by a single-family house. After mastering 3D parametric modeling with BIM, students designed and digitally constructed a two-story commercial building. Finally, a BIM project for a mid-rise (seven-storey) office building was developed. Table 2 presents a comparison of the architectural, structural, and MEP projects, along with the BIM features of the developed case studies.

Table 2. BIM maturity levels of case studies encompassing architectural, structural, MEP, and software features

	Features	Case Studies			
		1.Club House (CS1)	**2.Habitat Home (CS2)**	**3.Commercial Build. (CS3)**	**4.Mid-rise Office (CS4)**
Architectural	Build. program	Housing	Housing	Commercial	Office
	Number of floor	1	1	2	7
	Basement	NA	NA	Yes (partially)	√
	Staircase	NA	NA	√	√
	Roof	Hip roof	Hip & valley roof	Gable & flat roof	Flat roof
	Facade	Brick veneer	Brick & precast veneer	Curtain wall & brick	Curtain wall & brick
Structur.	Structural system	NA	Framing	Framing	Framing
	Framing member	NA	Timber (LTF)	Steel (HSS)	Steel (HSS)
	Foundation	R.C.	R.C.	R.C.	R.C.
	Basement wall	NA	NA	R.C.	R.C.
MEP	Mechanical	NA	NA	NA	√
	Electrical	NA	NA	NA	√
	Plumbing	NA	NA	NA	√
BIM	2D constr. project	NA	√	√	√
	3D param. draw	√	√	√	√
	4D scheduling	NA	√	√	√
	4D simulation	NA	√	√	√
	Revit ©	√	√	√	√
	Navisworks ©	NA	√	√	√

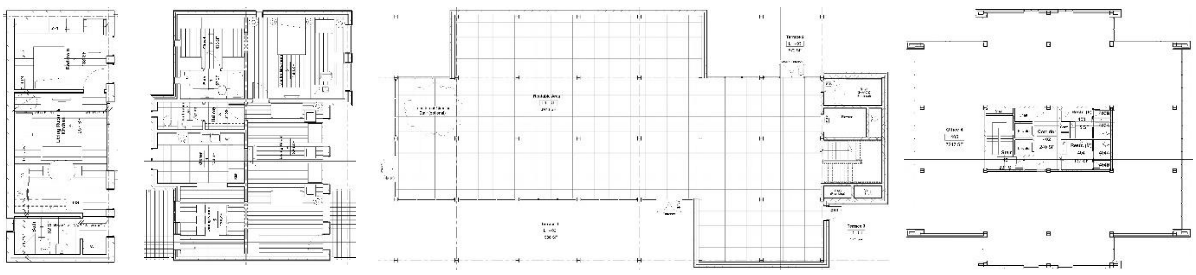
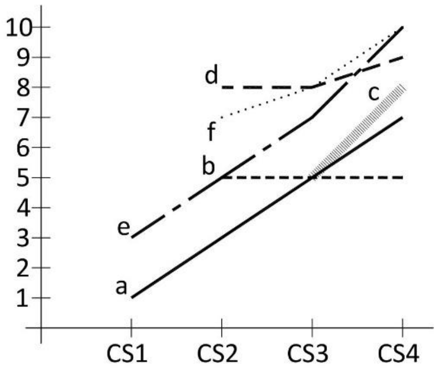


Figure 2. Architectural layouts of the case studies (from left to right: CS1, CS2, CS3, and CS4) (Yıldırım, 2018)



	Features	CS1	CS2	CS3	CS4
a)	Level of intricacy of architect. design	1	3	5	7
b)	Level of intricacy of structrural design	NA	5	5	5
c)	Level of intricacy of MEP design	NA	NA	5	8
d)	Maturity level of 4D features	NA	8	8	9
e)	Level of effort on Revit ©	3	5	7	10
f)	Level of effort on Navisworks ©	NA	7	8	10

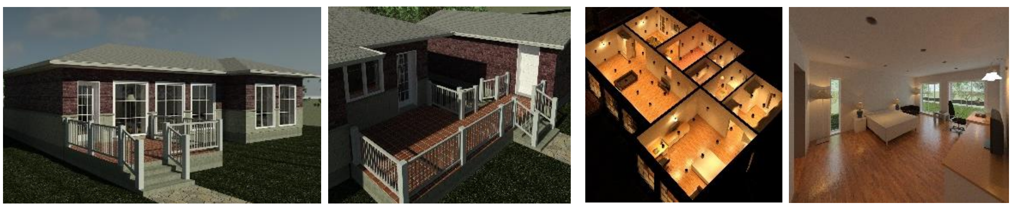
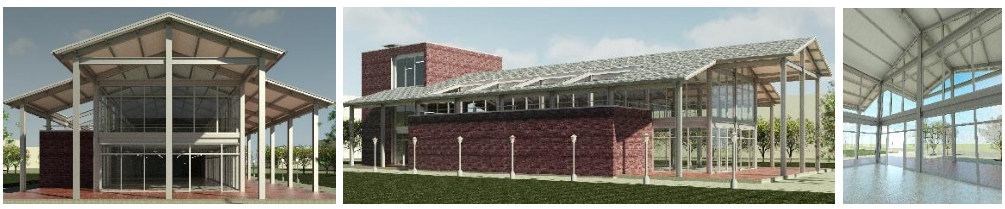
Figure 3. The difficulty level of case studies, as indicated by the author

Data on the architectural plans of the case studies are presented in Figure 2, which illustrates typical floor plans. In particular, a clear differentiation was attempted in the building program and floor usage. From case studies 1 to 4, there is an increasing utilization of square meters and the number of floors. For items a through f, a scale of 1 to 10 (with 1 indicating very easy ……. and 10 indicating very difficult) is employed as a measure of difficulty, as stated by the author in Figure 3.

4.2.1. 3D parametric modeling with architectural components

In traditional architectural project design, any modifications made by the designer necessitate the repetition of all project stages. In contrast, parametric design allows for automatic updates to the design whenever any parameter is altered. This study utilized Revit® software, a product of Autodesk, as a parametric drawing tool for the 3D modeling of buildings within a virtual environment (see Table 3).

Table 3. Parametric modeling of architectural components (Yıldırım, 2018)

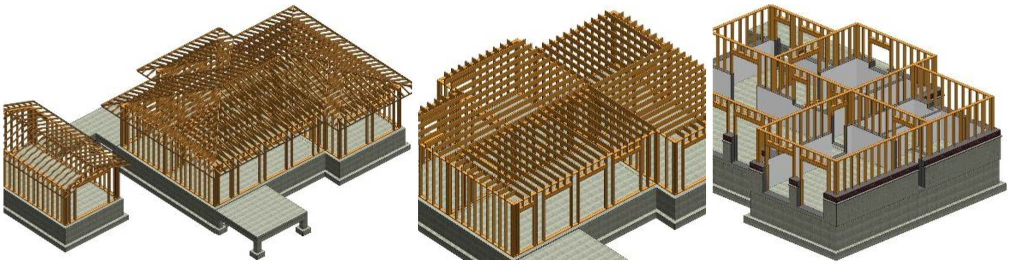
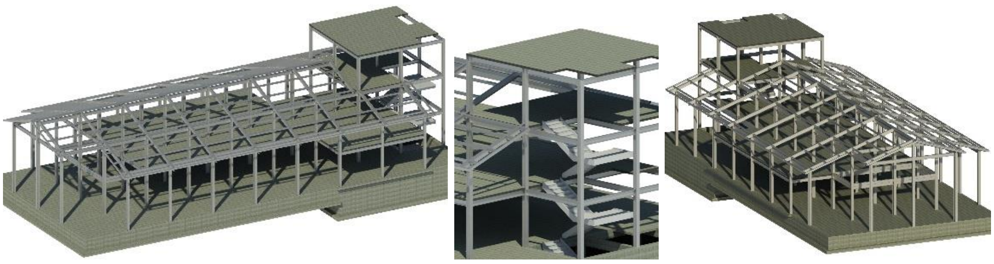
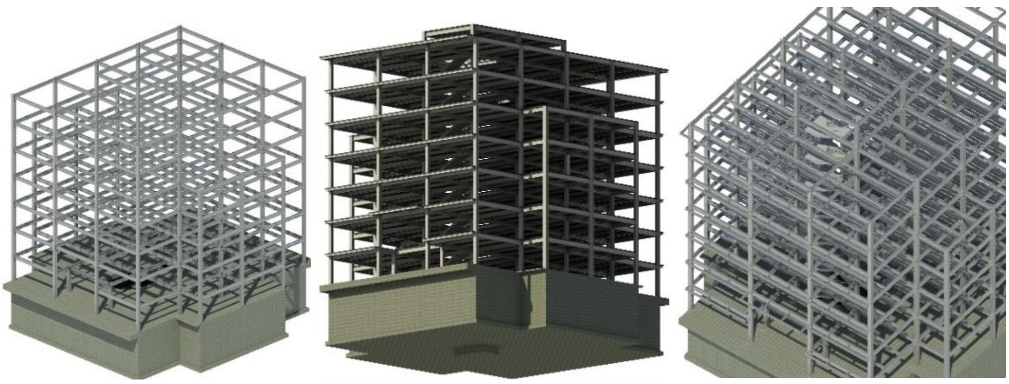
	Architectural Visuals of the Case Studies
(a) CS1 Club house;	
(b) CS2 Habitat home;	
(c) CS3 Commercial building;	
(d) CS4 Mid-rise office building	

The variables of architectural components, such as walls, floors, doors, and windows, were examined across different layers. Additionally, Navisworks® software, also developed by Autodesk, serves as a tool for 4D scheduling and simulation. To establish a foundation for the studies conducted in Autodesk Navisworks®, the architectural components in Autodesk Revit® were not utilized in a conventional manner. Some components were subdivided into parts in accordance with 4D scheduling, and corresponding 4D Task IDs were created. During the creation of these parts, both horizontal and vertical construction were considered in stages, with modifications made to align with the simulation. For instance, in CS3 and CS4, the exterior walls were not constructed as a single component extending from the ground floor to the upper floors; instead, they were created as separate walls for each floor. Similarly, in CS4, the curtain wall was not designed as a single component spanning from the bottom to the top floor, but rather was constructed separately for each floor. Additionally, in CS2, CS3, and CS4, the exterior walls were divided into layers and assigned distinct 4D Task IDs.

4.2.2. 3D parametric modeling with structural components.

Structural components in Autodesk Revit® are utilized only in CS2, CS3, and CS4, but not in CS1 (see Table 4). In all case studies, the foundation and substructure were constructed using reinforced concrete. For the superstructure, timber members were selected for CS2, while steel members were chosen for CS3 and CS4.

Table 4. Parametric modeling of structural components (Yıldırım, 2018)

	Structural Visuals of the Case Studies
(a) CS2 Habitat home;	
(b) CS3 Commercial building;	
(c) CS4 Mid-rise office building	

As is common in architectural studies, prescriptive methods were employed for component size selection, and no structural analysis was conducted. For the structural construction, which is designed to be a moment-resistant frame, further verification through structural analysis should be conducted. For the 4D simulation, a horizontal and vertical construction schedule was developed for the structural components, and groupings for 4D Task IDs were created based on this schedule. In the timber light framing structure designed in CS2, wall studs, floor joists, and roof rafters were divided into distinct parts. A similar approach was implemented for CS3 and CS4, utilizing hot-rolled steel sections (HSS). This method allows for detailed processing of the phases of work within the same item in the 4D construction schedule. Consequently, architectural and structural components are integrated into a single digital file. However, there are instances where these digital files must be uploaded separately when importing them into Autodesk Navisworks, particularly for the review and simulation of construction activities such as clash detection and object animation.

4.2.3. 3D parametric modeling with MEP systems

Parametric mechanical, electrical, and plumbing (MEP) components have been developed exclusively for CS4. System tools were utilized for the MEP system in Autodesk Revit® without conducting engineering calculations. The dimensions of component cross-sections were determined based on specific assumptions (see Figure 4).

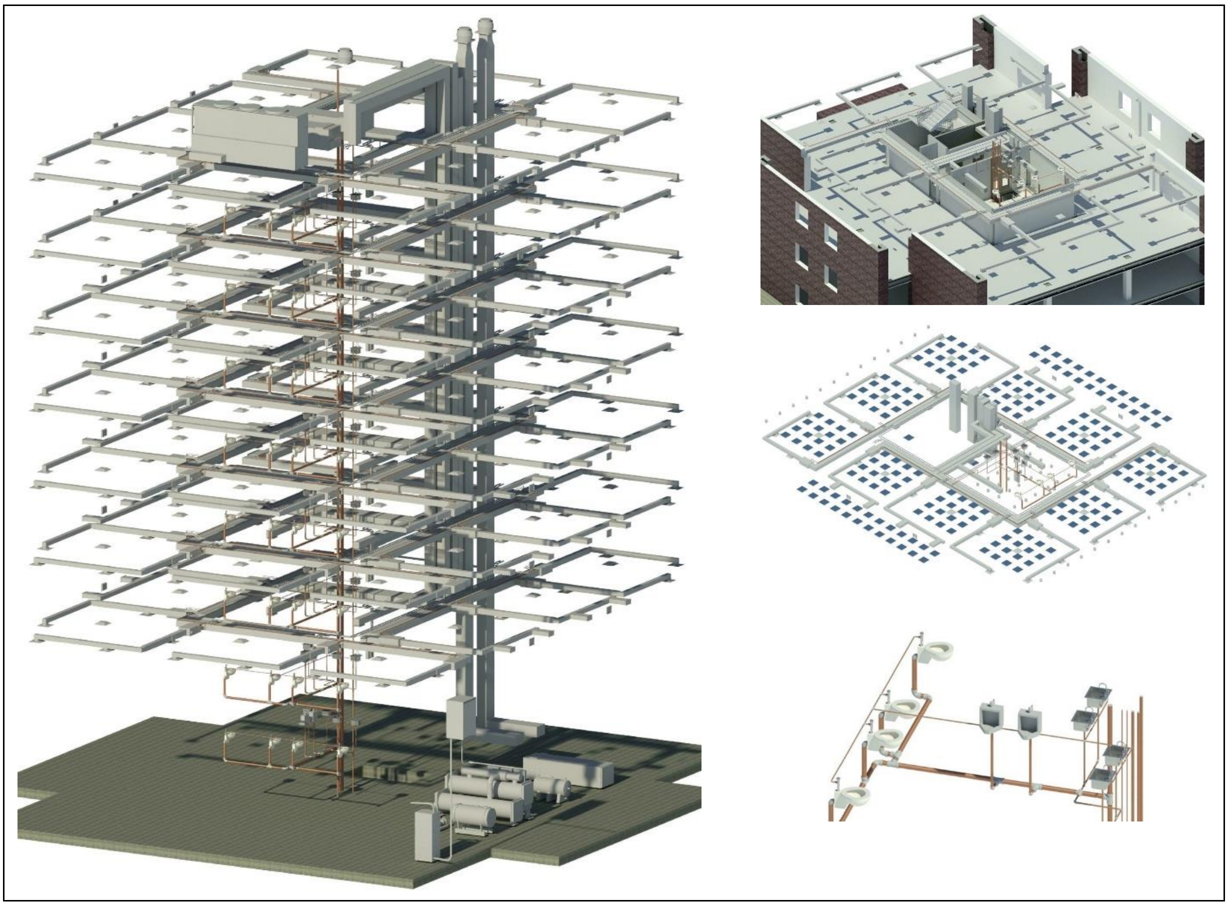


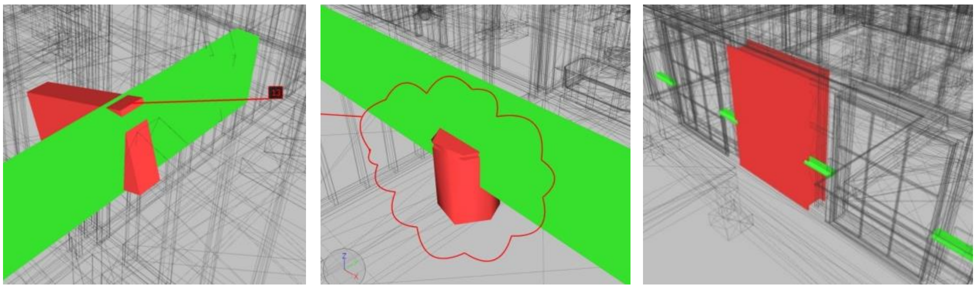
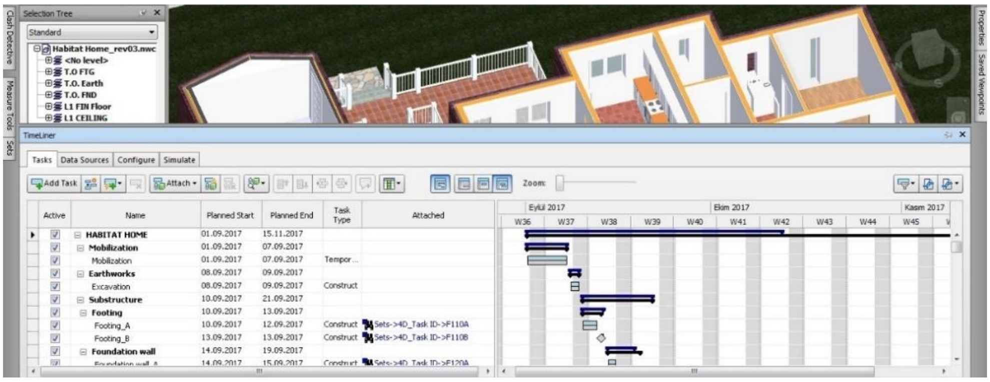
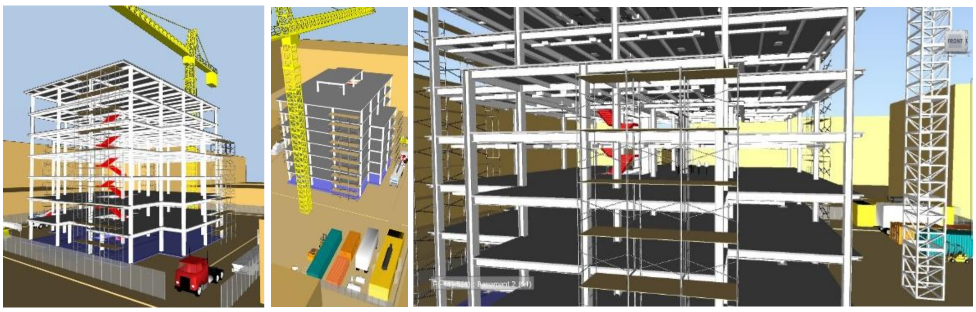
Figure 4. Parametric modeling of MEP components of the case study 4. At left; vertical and horizontal distribution of mechanical systems, at right top; ceiling and building core, at right middle; lighting fixtures integration and at right bottom; plumbing fixtures are depicted (Yıldırım, 2018)

For instance, since the height of the suspended ceiling is specified in the architectural design as 40 cm, it is anticipated that the supply and return diffuser sections/heights will be approximately 30 cm. It is also expected that an electrical cable tray can be positioned either above or below the ceiling. The electrical distribution scheme for lighting within the suspended ceiling was drafted in the plan. However, wall sockets and other electrical installations are not included in this study. The produced parametric model serves as an illustrative tool to demonstrate how various engineering disciplines can collaborate effectively. Special emphasis was placed on the suspended ceiling, as well as the plumbing solutions for restrooms, the basement, and the equipment to be installed on the roof. In addition to the general horizontal distribution of the MEP systems, the vertical distribution was also analyzed within the vertical shaft. Beyond this study, comprehensive engineering calculations and verification of all MEP systems are necessary. Furthermore, for the 4D simulation to be conducted in Autodesk Navisworks®, distinct 4D Task IDs were assigned on a floor-by-floor basis in Autodesk Revit®, thereby facilitating a simulation that aligns with the construction work schedule. Detailed procedures for performing clash detection in Autodesk Navisworks® are outlined at this stage. Subtopics such as hard clashes, clearance clashes, and time-based clashes are elucidated through the case studies presented herein.

4.2.4. 4D features of parametric modeling

The 4D features generated for CS 2, CS 3, and CS 4 are presented in Table 5. Following the production of 3D parametric models as part of the integrated building design in Assignment 1, a design review was conducted on the projects in Assignment 2. This design review aimed to create a constructability report by utilizing the "Clash Detective" tool in Autodesk Navisworks®. The tool was employed to identify hard, clearance, and time-based clashes separately for architectural, structural, and MEP components. Necessary revisions were made to the project by addressing the conflicts detected with the "Clash Detective tool. In traditional construction management, a bar diagram, commonly referred to as a Gantt chart or construction schedule, is created using software such as Microsoft Project or Excel. In the BIM described here, 4D scheduling is generated using the "Timeliner" tool integrated into Autodesk Navisworks®. The 4D Task IDs defined in Autodesk Revit® play a crucial role in this process and serve as the primary basis for 4D simulation. The communication between the "Timeliner" tool and the 3D model is facilitated by these 4D Task IDs, which are specified separately for each work item. 4D simulation can be conducted after inputting the work program into the tool. Additionally, components such as temporary equipment can be uploaded to the Navisworks® file, enhancing the 4D simulation with the "object animation" feature.

Table 5. Samples of 4D features (Yıldırım, 2018)

	4D Visuals of the Case Studies
(a) Clash detection for CS2 (hard, clearance and time-based clashes)	
(b) 4D scheduling for CS2 in Autodesk Navisworks® Timeliner tool	
(c) 4D simulation for CS4 in Autodesk Navisworks® Timeliner tool and object animation	

5. Implementation and Testing of the Developed Course Curriculum

Lecture notes and assignment content were developed using the case studies produced as part of the curriculum development process. This course material was utilized in a course titled "Building Information Modeling" (BIM) within the Master of Science in Architecture program. The course, which spanned one semester, was conducted for three hours each week. It was observed during the course that the eight targeted activities listed in Table 1 were excessive for completion within a single semester. Although all topics related to the eight assignments were covered in the theoretical portion, only the first four activities were included in the lab sessions. A survey was administered at the end of the semester to assess the effectiveness of the course materials and the learning outcomes.

5.1. Feedback from the Student Assessment

A total of eighteen questions were posed to the students, with the first five questions designed to gather information about their backgrounds. In the first year, ten students participated in the survey, while four students participated in the second year. Among the participants, 80% held a bachelor's degree in architecture in the first year, and this figure increased to 100% in the second year. The proportion of female participants was 90% in the first year and decreased to 75% in the second year. Regarding construction work experience, 40% of the participants had less than six months of experience, and 30% had between one and two years of experience in the first year. In contrast, 75% of the participants in the second year reported having less than six months of construction experience. At the beginning of the course, when the students' knowledge of Revit® was assessed, 90% indicated that they were unfamiliar with the program in the first year. However, by the second year, all participants reported having at least a basic understanding of Revit®. At the beginning of the course, an evaluation of the students' knowledge of Navisworks® revealed that all first-year students and 75% of second-year students reported being unfamiliar with the Navisworks® program. Table 6 presents the survey results for questions 6 through 18, which follow the initial five questions. The questions were categorized into three groups: the first group focused on course materials, the second group addressed homework activities, and the third group assessed student evaluations of learning outcomes. In Tables 6A, and 6Bstudents rated the importance of each item on a scale from 1 to 10, where 1 indicates unimportant and 10 indicates important in Table 6C aimed to measure students' competencies. The questions in Table 6C aimed to assess students' competencies. The average significance rating for each question is illustrated in Figure 5, which depicts the survey results.

Table 6. Student assessment for course delivery (Y1 refers to Year 1, and Y2 refers to Year 2)

A. Course Material	**Rate**		**B. Activity**	**Rate**		**C. Learning Outcomes**	**Rate**	
	Y1	**Y2**		**Y1**	**Y2**		**Y1**	**Y2**
Lecture notes	8,80	10,00	3D build. design	8,60	9,75	Competency in using Revit	8,00	9,25
Case studies	8,40	9,75	Design review	8,40	8,25	Compet. in using Navisworks	6,40	7,75
3D modeling	9,80	9,25	Clash detection	8,70	9,75	Delivery of online classes	6,50	10,00
4D modeling	8,50	8,00	4D scheduling	8,60	8,50			
			4D simulation	8,40	8,50			
			Quantification	9,20	8,33			

The course is divided into two modules. The first module focuses on assignment one: integrated building delivery and assignment two: construction review, utilizing Autodesk Revit®. The second module focuses on assignment three: 4D scheduling and assignment four: 4D simulation, employing Autodesk Navisworks®. As indicated in item c of Table 6, students report feeling more competent in Revit® than in Navisworks® by the end of the course. Based on the results of student feedback collected through surveys, it has been concluded that Assignments five through eight should be offered in a subsequent course that builds upon this one. Furthermore, there are plans to continue administering the questionnaire in the coming years to evaluate student grades and competencies and to analyze the results.

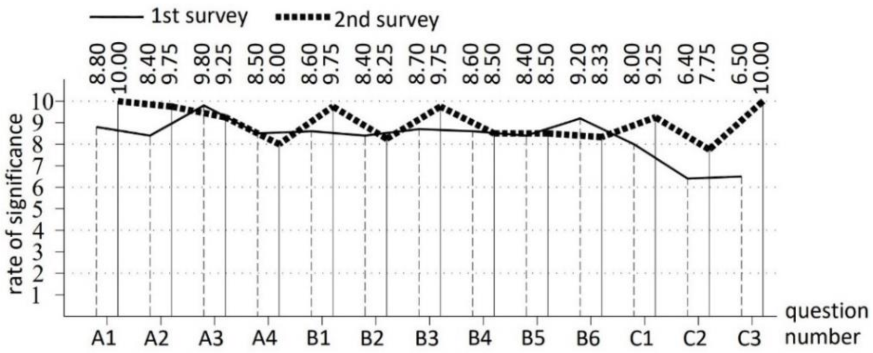


Figure 5. The average significance rating of each question reflects the results of the surveys

5.2. Evaluation of Course Materials and Findings

During the preparation of the case studies, the primary objective was to develop the content for the assignments listed in Table 1. Based on the experience gained, it has been determined that the eight assignments in Table 1, which are derived from previously prepared case studies and course materials, can be incorporated into the BIM course over two semesters. However, since this is a one-semester elective course, it was decided to limit the suggested assignments and provide students with appropriate alternatives. It is recommended that these eight assignments be categorized into three groups based on students' desired areas of improvement and their prior knowledge of Autodesk Revit® (see Table 7). All students will complete the activities in Module 1, after which they can choose one of the remaining modules. This approach allows students to select the content of the course for their lab work or homework assignments. Students will have the option to complete these assignments individually or in groups, with a strong encouragement for group collaboration.

Table 7. Grouping assignments according to BIM maturity levels, as adapted from Table 1 (intermediate level)

Module 1 - 3D		Module 2 - 4D		Module 3 - 5D	
A1.	Integrated build. design	A3.	Clash detection	A6.	Quantification
A2.	Design review	A4.	4D scheduling	A7.	Cost estimate
		A5.	4D simulation	A8.	Cloud application

In terms of 5D features, the quantification in assignment 6 and the cost estimation in assignment 7 have seen very limited progress. Lecture notes on utilizing the "Quantification" tool in Autodesk Navisworks® have been prepared; however, no case studies have been developed. Currently, only the tool in Autodesk Revit® is employed for quantification in CS2, CS3, and CS4. Overall, there is a need to further develop the 5D features of case studies in Autodesk Navisworks®.

In the current study, although the course content was designed for students from various disciplines, a multidisciplinary approach could not be implemented each term because the majority of students in the Master of Architecture program are architects. Consequently, a reluctance was observed among architecture students regarding certain assignment topics. It would have been beneficial to include team members such as civil engineers and/or mechanical engineers in the working group.

At the beginning of this study, Revit® courses were offered at the undergraduate level during the pandemic, and video recordings of these online classes were made available to students through the university's web portal. During this process, it became evident that the student satisfaction reported in previous research was being realized in practice. However, since the focus of this paper was on face-to-face instruction, no video recordings were shared with the students. For a course that includes such an in-depth lecture on software learning, students frequently expressed that having access to a video recording, as was provided during the pandemic, would be beneficial.

According to the survey results, it was observed that by the end of the BIM education program, students demonstrated greater competence in BIM 3D compared to BIM 4D. Furthermore, to address the knowledge gap of the instructor, it is essential that the instructor completes BIM training and attains proficiency while preparing the BIM course curriculum. Consequently, the development of case studies was a crucial activity for the instructor to comprehend the intricate structure of BIM. From the outset, it was planned that the exercises conducted during the learning process would be incorporated into the assignments ultimately shared with the students. This aspect can be highlighted as the most significant topic of discussion and the primary objective achieved by this study. In other words, we can observe how the case studies produced through a model-based learning process have been integrated into the course curriculum.

6. Conclusion and Suggestions

Initially, the goal was to create an advanced-level course comprising eight assignments and accompanying lecture notes; thus, course materials were prepared accordingly. However, due to the constraints of a one-semester class and the extensive content of the assignments, a stand-alone, intermediate-level BIM-focused course was ultimately developed. In designing the BIM course curriculum, it was anticipated that, in addition to the theoretical components, a practical application or assignment section would also be included. Regarding the homework section, if the projects do not originate from the course instructor, there are potential copyright issues associated with selecting and sharing sample projects with students. Furthermore, obtaining external professional support to facilitate the practical aspects of the course is not always feasible. To address these challenges and ensure that both the theoretical and practical components of the course are effectively delivered by the instructor, case studies have been developed as part of this study. The case studies produced range in complexity from levels 1 to 4, with an increasing BIM maturity level. Various building programs and floor heights were utilized, and architectural, structural, and MEP components were generated parametrically.

In preparation for 4D scheduling and simulation using Navisworks®, 4D task IDs have been assigned to components in Autodesk Revit®. Additionally, the "parts" tool in Revit® was utilized to stage the work schedule. This distinction sets 4D drawings apart from standard 3D drawings in Autodesk Revit®. The structural and MEP components produced were selected based on indicative prescriptive codes, and each component must be individually verified through calculations. These calculations fall outside the scope of this study and should be assessed separately. For case studies two through four, 4D simulations were conducted in Navisworks®, which significantly aided in illustrating the construction phasing during the course. Of the eight assignments planned, only the first four were applicable to the laboratory component of the one-semester course, while the remaining four were discussed solely in theoretical terms.

According to the results of the survey, which evaluated course materials, the learning environment, and student outcomes, students provided generally positive feedback. The data obtained from the questionnaire, it was evident that students held favorable opinions about the course. The questionnaire results presented in Figure 5 comprise thirteen items, with an increase observed in eight of these items in the second year. Notably, the responses regarding course materials and assignments (Figures 5a and 5b) all scored above 8 out of 10. In the second year, the lecture notes and the online delivery of the course received perfect scores from the students. Conversely, students' interest in case studies was rated at 8.40 points in year one and increased to 9.75 points in year two. By the end of the course, students' Revit® competency score was 9.25, surpassing the Navisworks® competency score of 7.75. Analyzing the responses to the questions about Navisworks® in section C reveals that students' interest in Navisworks® was limited. The delivery of the online course received full points in the second year because the recorded lectures can be uploaded to the university's web system.

Consequently, it is recommended that the eight assignments be divided into three groups, allowing students to select one of these assignment packages based on their undergraduate education and research interests. This approach will ensure that only interested students choose the Navisworks® assignments, as survey results from the first two years indicate limited student interest in this area. Students with diverse backgrounds, in addition to architecture, such as civil engineering and mechanical engineering, will contribute significantly to the formation of diverse teams for the term project. It is anticipated that a more effective educational environment will be fostered in classroom studies through teams composed of individuals from various professional disciplines. In the future, the goal is to establish such teamwork, and there is a need to evaluate the outcomes of the learning environment created here. As long as the course is offered annually, the assessment of learning outcomes will continue.

Acknowledgments and Information Notes

The article complies with national and international research and publication ethics. Ethics committee approval in the study was taken from the ethics committee of Istanbul Gelisim University with the decision number 2024-09-32 at the meeting held on 14.06.2024. The four case studies mentioned in the article were designed and drawn from start to finish by the author to be used as course materials in the classroom for educational purpose. Revit® and Navisworks® are trademarks of Autodesk, Inc. Mentioned softwares were legaly used in the classroom in Istanbul Gelisim University with educational purpose.

Author Contribution and Conflict of Interest Declaration Information

The article was written by a single author. There is no conflicts of interest.

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