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Research Article

INTEGRATING 4D & 5D MODELLING INTO CONSTRUCTION MANAGEMENT EDUCATION IN ARCHITECTURE: A DIGITALIZATION FRAMEWORK

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Abstract

In architecture education, the conventional method for construction management subjects is a theoretical approach in general, which is limited to satisfying the emerging needs of Construction 4.0 in the AEC industry. This study aims to develop and integrate a 4D & 5D modelling framework to construction management courses for architecture students to be able to fulfil the AEC industry's qualification demands, as a part of Construction 4.0. The methodology of this research consists of the establishment of a framework structured upon theoretical background on construction management current industry requirements and its implementation into "construction management and economics" course in architecture education. Additionally, a survey was conducted among the students to evaluate the efficiency of the framework. One of the key findings of the study is the development of a framework to integrate 4D-5D modelling into a construction management course in architecture. It was developed in intersection clusters between BIM, AR, and VR to perform 4D visualization of construction, monitor the whole process, and detect clashes. According to the survey and results, the 4D-5D BIM-based framework is considered beneficial and enhances perception and understanding of cost and time management. This study involves a new digitalization framework that is adaptable to construction management courses employing a systematic approach. Additionally, this framework has the potential to be employed by industry professionals.

Keywords: 4D simulation, 5D, architectural education, BIM, construction management, modelling

Araştırma Makalesi

4B & 5B MODELLEMENİN MİMARLIKTA YAPIM YÖNETİMİ EĞİTİMİNE ENTEGRASYONU: BİR DİJİTALLEŞME ÇERÇEVESİ

Özet

Mimarlık eğitiminde, yapım yönetimi konularına yönelik geleneksel teorik anlatım yöntemleri, İnşaat 4.0 çağının inşaat endüstrisinde oluşturduğu ihtiyaçları karşılamakta sınırlı kalmaktadır. Bu soruna yönelik olarak bu çalışma, mimarlık öğrencilerinin sektörün İnşaat 4.0'la oluşan yeterlilik taleplerini karşılayabilmeleri için yapım yönetimi derslerine 4 boyutlu (4B) & 5 boyutlu (5B) modellemeyi entegre etmeyi amaçlanmaktadır. Bu bağlamda çalışmanın metodolojisi, sektörün mevcut gereksinimlerine ilişkin teorik arka plan üzerine yapılandırılmış bir dijitalleşme çerçevesinin geliştirilmesi ve bunun mimarlık eğitiminde "yapım yönetimi ve ekonomisi" dersine uygulanmasından oluşmaktadır. Çalışmanın önemli bulgularından biri, yapım yönetimi dersleri için 4B-5B modellemeyi içeren bir dijitalleşme çerçevesinin ortaya konulması, uygulamaya geçirilmesi ve değerlendirilmesidir. Önerilen çerçeve, yapımın 4B görselleştirmesini gerçekleştirmek, tüm süreci izlemek ve çakışmaları tespit etmek için yapı bilgi modelleme (YBM), artırılmış gerçeklik ve sanal gerçeklik arasındaki kesişim kümelerinde geliştirilmiştir. Ayrıca, önerilen çerçevenin etkinliğini değerlendirmek için öğrenciler arasında bir anket çalışması yapılmıştır. Anket bulguları göstermiştir ki, 4B&5B model için önerilen çerçeveyi öğrenciler faydalı bulmuş ve maliyet-zaman yönetimi algısını geliştirdiğini belirtmişlerdir. Bu çalışma, sistematik bir yaklaşımla yapım yönetimi derslerine uyarlanabilen yeni bir dijitalleşme çerçevesi önermekle birlikte sektör profesyonellerinin de kullanım potansiyeline sahiptir.

Anahtar kelimeler: 4B simülasyon, 5B, mimarlık eğitimi, modelleme, yapım yönetimi, YBM

1. INTRODUCTION

Construction 4.0 is the reflection of Industry 4.0 in the Architecture, Engineering, and Construction (AEC) industry which directs it to transform into technology-driven. It enhances the traditional processes with the help of innovative technologies and collaboration methods to redesign the industry. Construction 4.0 demands the alteration of the AEC industry's work items and sequences towards Industry 4.0 (García de Soto et al., 2019; Osunsanmi et al., 2020; Osunsanmi et al., 2022). In addition, Construction 4.0 is a stage to employ digitalization in AEC which consists of building information modelling (BIM), augmented reality (AR), virtual reality (VR), mixed reality (MR), artificial intelligence (AI), internet of things (IoT), cloud computing, robotics and their integrated applications on construction.

Among these technologies, BIM could be considered the most noticeable and widespread. BIM creates virtual information-based data-driven model environments to manage multi-dimensional (n-D) knowledge layers during the whole project life cycle (Alizadehsalehi et al., 2020). Oesterreich and Teuteberg (2016) mentioned that BIM and cloud computing has reached market maturity level whereas AR-VR-MR is still behind this stage. AR-VR-MR focuses on virtual applications to augment reality and level of experiences for all phases while BIM functions in modelling, simulating, and organizing (Sawhney et al., 2020). BIM has changed the logic of modelling as it brings elements with an additional information layer that enables BIM users to realize the benefits of digital information management. The methodology of BIM is to integrate the entire building information along the life cycle of the buildings, from planning to construction to operation till demolishment (Cheng&Ma, 2013; Koc et al.,2020). BIM provides a shared data environment for an integrated project delivery system (IPD) by ensuring communication among project participants in a single common data platform for a common purpose (AIA California Council, 2010; Liu, 2013). BIM and IPD contribute to the digitalization of the AEC industry and enhance communication and collaboration between participants. IPD is an alternative to traditional segmented project delivery methods which causes time overruns, misunderstandings, and inefficiencies because of poor communication and lack of coordination (Evans et al., 2021, pp. 3). The nature of IPD suggests involving all the project participants such as architects, engineers, and construction management professionals at the earliest stages of pre-construction in the project life cycle.

There are various examples and near-future plans for transforming the industry into digital. For instance, UK Construction Strategy foresees that the AEC industry will improve its performance thanks to digitalization, reducing overall time and cost overruns by 50% (Abanda et al., 2017, pp. 5). Also, almost 60% of European Union (EU) countries have been preparing policies targeting the digitalization of the AEC industry (ECSO, 2021, pp. 120). Additionally, BIM is estimated to grow by 18% annually between 2019 and 2027 (ECSO, 2021, pp. 39). The benefits of AEC digitalization are to improve efficiency and effectiveness in terms of cost & time savings, more accurate time and cost predictions, increased quality, and safety, and improved collaboration and communication (Sawhney et al., 2020). Mentioned benefits are mainly subtopics of construction management which is becoming extremely necessary in dealing with complex processes and projects. As smart, sustainable, adaptable, and multi-functional projects are common in today's built environment, they require a high level of performance in construction management. Therefore, the role of architects and related professionals is a critical factor to manage this complexity. Additionally, in Turkey, construction management is the only alternative profession area for architects and civil engineers, as there is not any undergraduate level of education specified in construction management or project management.

Professionals in the AEC industry and the academia have to recognize emerging needs and direction of current trends and adapt themselves on transforming itself (Koc et al., 2020, pp. 462). Also, as Sawhney et al. (2020) emphasized, technology innovators, professionals and academia have to make collaboration to imply essentials of Construction 4.0. In addition, new and future graduates should have qualifications, skills and perspectives to be a part of digitalized AEC industry. In this regard, to educate and prepare prospective architects to be able to fulfil the AEC industry's current needs in relation to Construction 4.0, this study aims to develop a novel framework with a digitalization approach. This framework is developed to apply on a construction management course for undergraduate architecture students.

2. MATERIALS AND METHODS

BIM is a comprehensive notion which is broader than generating only 3D visual representations. Even though, first applications of BIM were experienced in 3D modelling, then expanded to multi-dimensional (nD) applications in which additional information layers were integrated (Ying et al., 2014; Yung&Joo, 2011). Information within BIM are commonly described in dimensions (D) such as 3D (graphical model and non-graphical information), 4D (time), 5D (cost), 6D (facility management), 7D (sustainability) (Eastman et al., 2010). Also, AIA (2013) released a form about project BIM protocol that mentioned BIM integration with construction management contents especially focusing on cost, schedule and coordination. Moreover, integration of 3D-4D-5D modelling, BIM and VR-AR visualizations students are able to experience a wide range of diversity in scenarios and be active participants of discovery process (Messner&Horman, 2003, pp. 145). Also, BIM benefits were highlighted as follows: improving performance, shortening the project duration and decrease in waste (Diaz, 2016, pp. 10). Additionally, feedback and accuracy are key elements to monitor and plan the project efficiently as BIM directs a process-based database platform among all participants (Pan et al., 2018, pp. 24). In a recent study, schedule and cost management are mentioned as an increasing impact of applying project management knowledge areas using BIM by 81% and 82% respectively (Shaqour, 2022, pp. 5). In this study, 4D BIM and 5D BIM are expanded further in below respectively.

2.1. Scheduling and 4D BIM

The AEC industry transforms facilitating digital technologies to shorten the time and lower the cost of the project. Howell&Lichtig (2008, pp. 1) mentioned that only 55% of planned construction work is completed aligned with the schedule. According to a study of Assaf&Al-Hejji (2006, pp. 350), average of delays in construction is noted between 10-30% of the planned schedule. To reduce overall project time and to complete the construction on time, scheduling and time management play a critical role, especially for complex projects. There are many schedule planning softwares such as Primavera, Microsoft Project. However, each of them has limitations as they only generate schedules and charts, not providing connection for the visualization of the construction process. Visualization of the construction and sequences of the work have been neglected to cognitive imagery of the professionals which could result in errors and misunderstandings which revealed the concept of 4D BIM.

4D BIM combines the sequence of work items in a project with the 3D BIM building model. Also, it enables users to communicate and collaborate visually while scheduling sequences of work items by linking the BIM model (Crowther&Ajayi, 2019; Hadavi&Tavakolan, 2018). In addition, 4D simulations raise communications by detecting potential bottlenecks and technics to boost interrelations among participants (Wang et al., 2019). Charlesraj&Dinesh (2020, pp. 200-201) indicated 4D BIM is highly beneficial to manage people and resources in project planning, scheduling and progress monitoring. It supports to lower the risks and increase precision project planning by reducing the errors and clashes. Since the building requirements are extended, not only BIM is beneficial for 4D and scheduling, but also there are studies in the literature that combine AR-VR technologies with time management. 4D BIM is extended by VR applications for scheduling and construction sequence simulations to explain the project (Ikerd, 2013). AR-based applications can be seen in the works of Shakil (2019) and Wang et al. (2014) for scheduling, monitoring and controlling the time.

2.2. Cost Estimation and 5D BIM

The purpose of the cost estimation is to calculate a realistic budget of the project. Cost planning focuses to establish an optimised cost framework (Lu et al., 2018). Quantity surveying is an important part of cost estimation. Traditionally, 2D drawings are examined to calculate quantities to reach project cost (Pittard&Sell, 2016). Since the AEC industry transforms and projects complexity increase, manual measurement and calculations are time consuming, bring a lot burdens and open to errors.

The use of BIM appears in quantity surveying and cost estimation which is called 5D BIM which has potentials to reach more accurate project budgets and impoved cost estimating (Bryde et al., 2013). Also, Davidson (2009) suggests that cost analysis can be conducted at any phase as a part of 5D BIM technology. According to Aouad et al. (2007), 5D BIM supports rapid automation of cost schedules. Its applications are composed of cost estimation, simulation, optimization and control (Xu, 2017). In addition, 5D BIM is accepted as an essential part of the BIM integrated project delivery approach (Smith, 2014, pp. 475). Moreover, Wong et al. (2014, pp. 287-289) stated that both time and cost-saving opportunities are available to the project managers by using AR technologies as AR enables interactive 3D/4D/5D models and Gantt charts.

The methodology of this research consists of establishment of a digitalization framework (Section 3.1) and its application into "construction management and economics" undergraduate course in architecture (Section 3.2). The framework was structured upon theoretical background on current requirements of cost and time management in the AEC industry. In addition, a survey-based evaluation was conducted among the targeted group of students.

The framework was developed according to the project-based learning point of where students directed to "do" and experience the projects individually. Instead of being only listeners of theoretical courses, student became active participants and learners. In relation with constructivist approach which focuses learning based on the idea according to individuals' experiences (Kurt, 2011). Additionally, Duit (2016, pp. 68-73) emphasizes that constructivism has become an indispensable ideology for teaching/learning technical courses, and "construction management and economics" is one of them in the architecture education. This approach is also aligned with Bloom's taxonomy (1956) which evaluates learning of students systematically: analysis, synthesis and evaluation.

2.3. Development of the 4D-5D BIM-based Framework

In this study digitalization approach focuses on AR, VR and BIM integration and interaction. Also, BIM was considered as a base system to develop the framework and a linkage between AR-VR. Additionally, BIM improves the effectiveness and efficiency of these technologies (Abrishami et al., 2015; Noghabaei et al., 2020). Revit was selected as a designing and modelling BIM tool because of its wide range of usage and compatibility with other software. Bexel Manager was used for 4D BIM scheduling and simulation. The framework was shown in Figure 1. The framework was generated with a systematic approach that is composed of main dimensions of BIM. The framework illustrated the interrelations between instructors and students. The feedback loop was constructed to improve learning outcomes of the students. Also, self-learning and self-checking mechanism of the students were introduced as a part of the constructivist approach, to direct students learning via projects. Feedback loop was represented with two-sided arrows between instructors and students, and self-checking mechanism was illustrated with two-sided arrows among students. Also, the deliverables of each stage were input for the next stage.

1D BIM stage covered the theoretical explanations that are given by the instructors about BIM, nD, LCA, building program, function and requirement list, site information and environmental constraints. The students were expected to remember and understand the basic information and then proceed to research and analyses. This workflow was also aligned with Bloom's taxonomy (1956), as creation is the further and final step of remembering and understanding. The students were expected to research about similar buildings. Adobe Photoshop, Microsoft Word and Power point were advised to be used. This stage was planned with a duration of one week.

2D BIM and 3D BIM stages were being continuously in a relation to each other. 2D BIM stage began with theoretical explanations from instructors about building materials, elements, and systems. According to these, students were asked to give these decisions and implement them on the drawings. In regards to design and material decisions, students communicated with the instructors. Instructors gave feedback and revisions involving error detections and corrections. Considering these revisions' requirements, students developed their BIM models in Revit. As a characteristic of Revit, 2D plans, sections, and elevations were generated automatically from the 3D model. So, students were being planned to experience continuing feedback loop and self-checking mechanism. Self-checking mechanism mainly was provided through section perspectives, exploded perspectives, axonometric drawings from Revit, and walkthrough simulations from Sim-Lab. For this stage, Revit and Sim-Lab were integrated into the framework. Sim-Lab is a 3D software that enables interactive VR and improves the perception of the designed building. It extends the Revit BIM model in terms of material information and environmental conditions by providing a real-time simulation. Also, when changes are made in Revit, they are directly reflected in Sim-Lab which shortens the whole process. In addition, QR Code generation, as an AR implication, was used to visualize 3D representations and simulations from a set of a paper. The duration of these stages was 5 weeks, 2 weeks for 2D and 3 weeks for 3D was suggested, but students were flexible to organize these 5 weeks. In addition, Adobe Photoshop was used to organize presentation boards.

4D BIM stage was about scheduling and time management. Firstly, students were given lectures about time management, work breakdown structure (WBS), scheduling methods, 4D BIM, and the definition of each work item by the instructors. Also, Bexel Manager was introduced and shown how to use necessary functions inside of the software. Students were expected to build a linkage between Revit and Bexel Manager. Then, the identification of work items, sequences, relationships, and definition of the durations was proceeded by the students in Bexel Manager. Thanks to the VR integrated BIM, the 4D BIM model allowed students to visualize the schedule and optimize the sequencing of the building construction (Sampaio, 2018). Therefore, the 4D BIM-VR applications demonstrate the construction process, avoiding clashes and building errors. Moreover, it provides better communication and interaction between students and instructors. As a 4D BIM-VR tool, the Bexel Manager creates the interrelations among the 3D models, grouped in sets, and the related task following the activity sequence for the construction. The 4D model adds the time parameter to the 3D-BIM model, generating the visual simulation of the construction work. In addition, the automatic data exchanges and updates between Revit and Bexel Manager resulted in an advance of VR integrated BIM technology as bidirectional data exchange occurred. The deliverables of this stage were the schedule of the building construction process as a Gantt chart and a 4D BIM simulation of the construction. The simulation was represented with a QR code. The duration of this stage was 4 weeks.

5D BIM stage involved quantity survey and cost estimation. In the beginning, instructors gave lectures on quantity calculations and cost estimation methods. Students generated quantity lists and room lists of the buildings from Revit and organized them in Microsoft Excel. They got revisions and corrections from the instructors and then continued to the cost estimation. For this stage, the unit-price method was used based on real-time unit price data, which was provided from governmental sources (URL-1). Calculations were conducted in Revit and organized in Microsoft Excel. The deliverables of this stage were quantity list, room list, and cost estimation. The duration of this stage was 4 weeks.

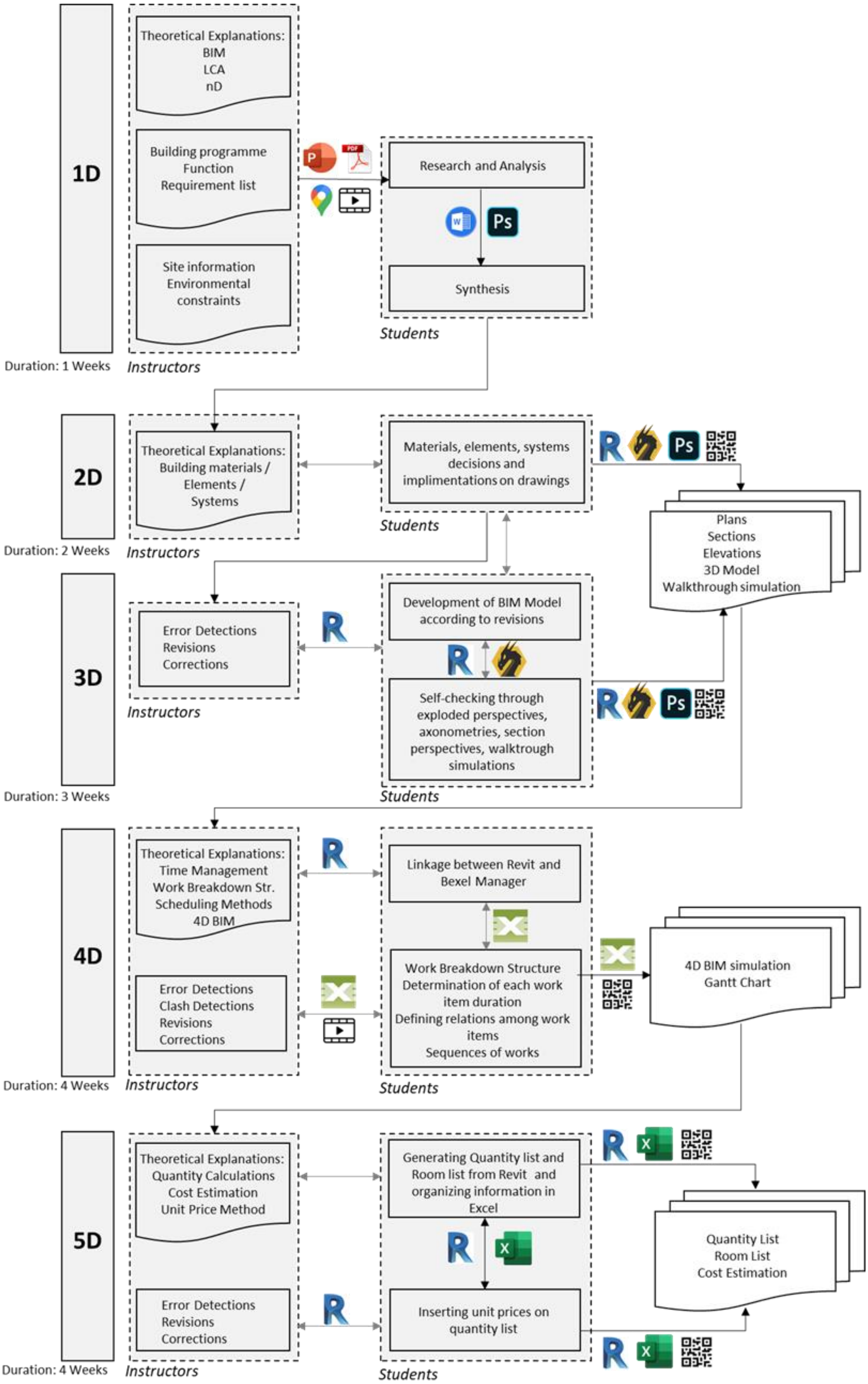


Figure 1. 4D-5D BIM Framework for digitalization approach of construction management course

2.4. Application of the framework

The framework was implemented in the "Construction Management and Economics" course for fourth-year Bachelor of Architecture Students in the 2021–2022 fall semester at Beykoz University, Turkey. The target students had a background by completing all building construction courses in the curriculum. In addition, students can use Revit, Autocad, and Excel. During the course, the students were guided to perform in Bexel Manager. The course duration was 14 weeks. A project was formulated by the ,instructors as the project-based learning (PBL) component of the course. The project comoponent formulation involved students to produce schedule and cost estimate information for a residential building that they prepared by using Revit in one of their previous courses.

The 4D-5D BIM framework was applied on a residential building with 6 floors consist of basement, ground and 4 normal floors, having a construction area of approximately 1,500 m2 in Kadikoy district in Istanbul, Turkey. The building structure was reinforced concrete skeleton system with a raft foundation, whereas the roof was wooden structured hipped type. Students gave their own decisions on finishing materials. In addition, students were guided about the codes and building regulations. WBS was prepared, assigning a duration for each work item, relationship types among work items defined and connected accordingly. Construction process simulation generated simultaneously which helps to provide a feedback environment to detect clashes or errors. In relation to 5D, the quantity list and room list were generated from Revit and then revised in Excel since Revit provide a raw document which needs to be filtered and organized. Considering the unit price policy of the government (URL-1), the cost estimations were established in Revit and Excel by the students. BIM was used through Revit and Bexel Manager. At the same time, Bexel Manager was an AR simulator of 4D BIM construction process, while SimLab was used as VR simulator. Submissions were expected to be QR codes which is an AR implication. Students generated QR codes via Flowcode.

2.5. Survey

The survey was conducted on 8 questions (Table 1). The survey was aimed to measure the level of reaching the main learning outcomes of the course as well as revealing students' perspectives on the digitalization approach in the construction management course. The total number of students was 10 who completed the course in the 2021–2022 fall term in the Department of Architecture at Beykoz University. The respondents' age varied from 21 to 23, consisting of 7 females and 3 males. Any private personal data belonging to the respondents was not collected. The students previously took prerequisite construction courses. The survey was conducted in February 2022 through Qualtrics which is a web-based program. A five-point Likert scale was used for survey responses, as follow: Strongly Disagree = 1, Disagree = 2, Undecided = 3, Agree = 4 and Strongly Agree = 5. Thus, the ordinal scale was used to measure the responses. Microsoft Excel was used to evaluate the results of the survey statistically in terms of frequency and percentage.

Table 1. Survey questions.

Question Number	Question
1	I can make connections between 2D-3D-4D-5D thanks to the BIM.
2	I can understand the requirements of preparing schedule.
3	I can demonstrate relations between construction process and work breakdown structure thanks to the 4D simulation that I have created in Bexel Manager.
4	I can manage obtaining and organizing quantity information from BIM model.
5	I can conduct cost estimations through BIM software.
6	4D-5D BIM and simulations increased my understanding on construction management.
7	I can use Revit –as a BIM tool- efficiently.
8	I can use Bexel Manager –as a BIM tool- efficiently.

3. RESULTS AND DISCUSSION

3.1. Application of the Framework: Student Works

The 2D stage involved layout design and decisions about building materials, elements, and systems. Analyses that were conducted in the previous 1D stage were inputs for 2D. Research about similar functioned buildings, building materials, and systems was compiled by the students. Students were assigned material decisions and designed building elements in Revit (Figure 2).

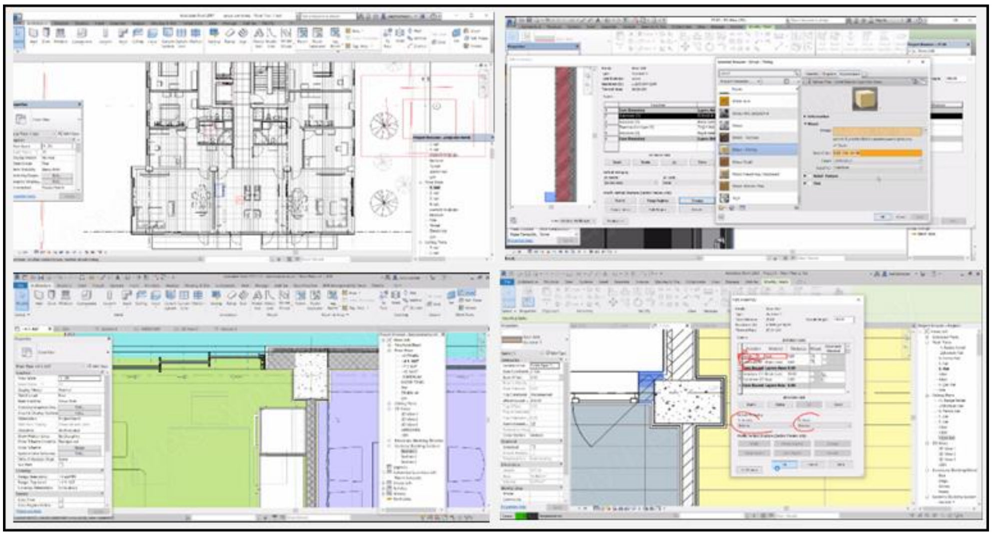


Figure 2. Deliverables of 2D BIM

According to the proposed 4D-5D BIM Framework, 2D and 3D stages were interrelated to each other where a continuous feedback loop occurred. Therefore, 2D and 3D drawing sets were generated simultaneously by Revit. 3D deliverables can be seen in Figure 3. To examine and review construction details and systems comprehensively, SimLab software -as a VR application- was used because of its advantages such as simulating real-time material information and environmental conditions. Besides, SimLab provided a walkthrough simulation that extends the perception of the students.

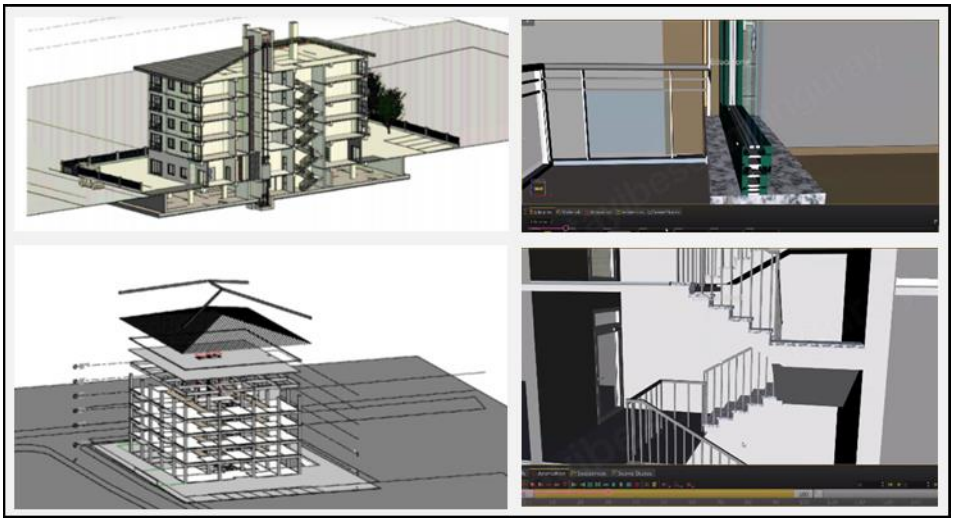


Figure 3. Deliverables of 3D BIM

On the other hand, students were guided to produce a wide range of representation techniques, such as section perspectives, axonometric views, and exploded perspectives through Revit. which helped students to realize extensively building elements and systems. In addition, students were flexible to experience changes in different dimensions that activated the self-checking mechanism and resulted in improvement in the students' 3D perception. Besides, these representations supported students to recognize work items and sequences, which they will need in the 4D stage to organize WBS.

Deliverables of 4D BIM illustrated in Figure 4. Firstly, students prepared WBS according to the instructors’ lectures. While defining the WBS, they brainstormed and organized work items and sequences of these. Bexel Manager was used to generate 4D BIM requirements together with its capability to simulate the construction process visually. Students linked their Revit BIM Models to Bexel Manager and defined selection sets. Selection sets were categorized accordingly being structural or non-structural. Each category was elaborated with work items. The structural selection set of the building was composed RC raft foundation, RC columns and shear walls, beams, slabs and a timber structured roof. Non-structural selection set involved external and internal walls, windows and doors, circulation system elements, insulations, plasterworks and all finish work. Durations of each work items were assigned. Video simulation supported students to correct their works as a self-checking mechanism. while examining the schedule simultaneously.

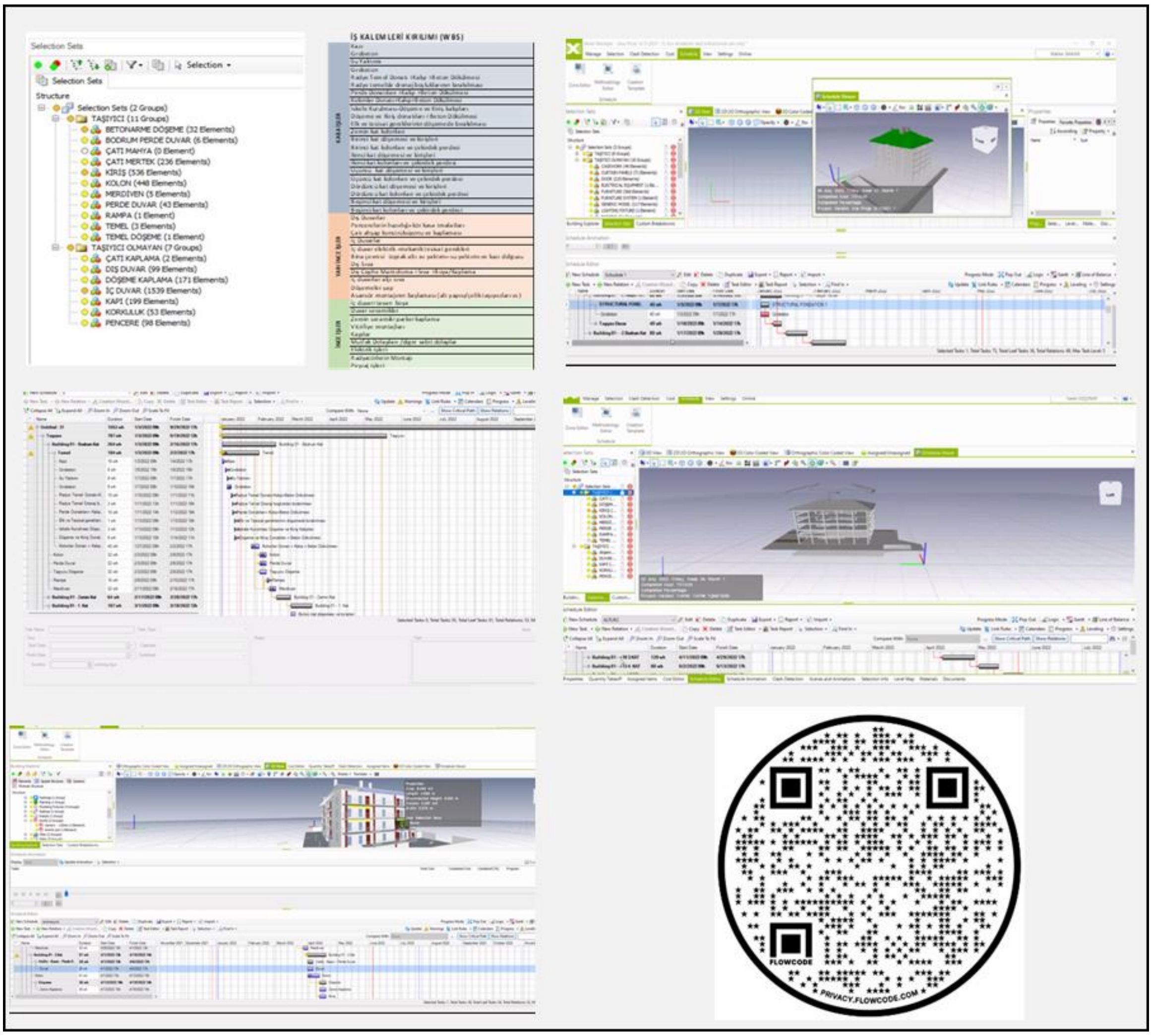
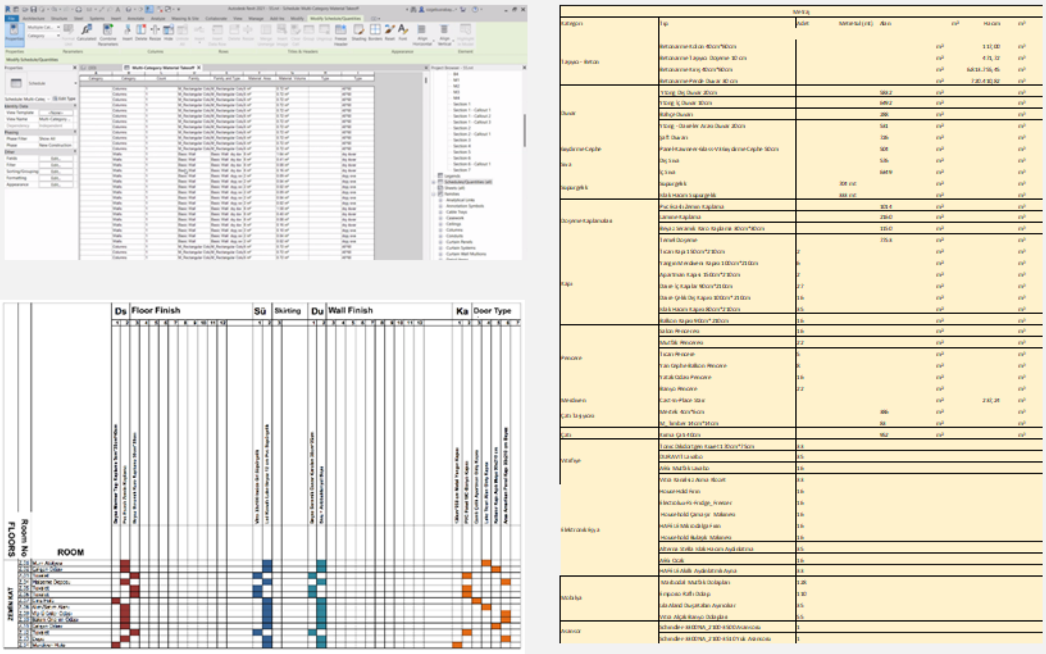


Figure 4. Deliverables of 4D BIM

Also, errors and clashes in the schedule were detected easily thanks to the video simulation. In addition, instructors gave revisions weekly. Additionally, the relation between these work items were defined finish to start. The schedule was represented with a Gantt chart and construction process was shown as a video animation. As an example, the video animation of a student could be seen from the QR Code (Figure 4). This representation technique gave the advantage of being able to see the video

As a component of 5D BIM, quantity list, room list and cost estimation were generated by the students through Revit and Microsoft Excel (Figure 5). Students got quantity and room list data from Revit. Then, they organized these files in Microsoft Excel, as the data from Revit was raw. Students had to filter proper units and quantities given by Revit. Instructors guided students to apply true unit forms for each material. For example, m3 for concrete, m2 for ceramics, count for doors. Unit-price method was used to generate cost estimation. Unit-price data was obtained from government agency annual report (URL-1) and then applied on quantity list. Besides, students were able to calculate quantity and cost estimation for each building subsystems such as structure system, wall system.



CATEGORY	TYPE	number	meter	squaremeter	m^2	volume	m^3	Unit Cost (TL)
RC Concrete Load Bearing Structure	RC Column 40cm*60cm					117,00	m^3	495
	RC Slab10 cm					471,72	m^3	495
	RC Beam 40cm*60cm					6.813.755,45	m^3	495
	RC Shear Wall 30 cm					720.410,82	m^3	495
					Total Quantity	7.534.754,99	m^3	
					Total Cost	**3.729.703.720,05**	**TL**	
Wall	Aerated Concrete Block- -20cm			6363	m^2			76,4
	Aerated Concrete Block- -10cm			6492	m^2			38,2
			Total Quantity	12.855,00	m^2			
			Total Cost	**734.127,60**	**TL**			

Figure 5. Deliverables of 5D BIM

3.2. Survey Results

Survey results are shown in Figure 6 and Table 2. All of the students completed the survey and answered the all 8 questions. The survey results were analysed in terms of frequency (Figure 6), percentage, mean value and standard deviation. The assessment of the survey responses highlight that all students recognize the benefits of the applied framework. In total, 100% of the responses of questions 1–3 and 6 is “Strongly Agree” and “Agree”. This is considered as evidence that students able to make connection between 2D-3D-4D-5D, understand schedule requirements and demonstrate relations between WBS and video simulation via Bexel Manager, increase in understanding various dimensions of BIM. Question 4 examines the preparation of the quantity list from BIM model and 30% of the students answered “Strongly Agree” and 60% of the students answered, “Agree”. In addition, 50% of the students answered “Agree” and 10% of the students answered, “Strongly agree” for the question number 5 which focused on cost estimation. Question number 7 is about Revit maturity level, 90% of the students, 60% “Agree” and 30 “Strongly Agree”, identified themselves as efficient users of Revit, only 10% (1 student) could not define the level of Revit usage and answered as “Undecided”. For the question number 8, 80% of the students agreed on using Bexel Manager efficiently.

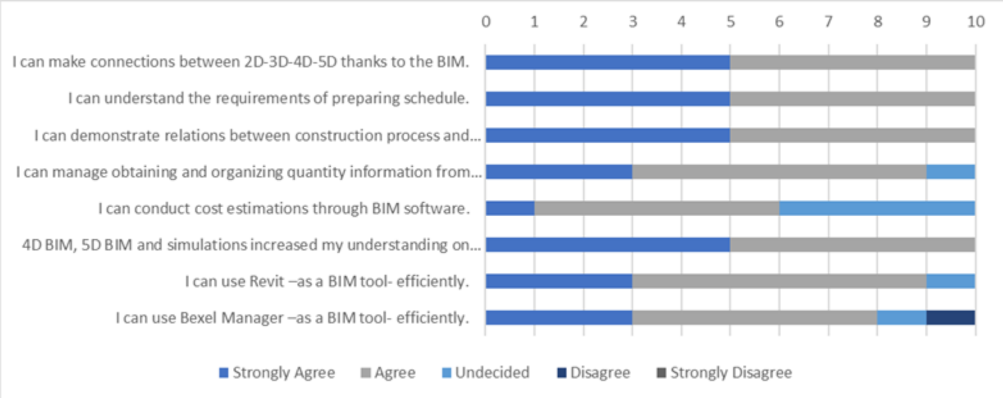


Figure 6. Survey responses distributions: frequency

In addition, statistical analysis including mean and standard deviation are shown in Table 2. According to Table 2, the mean values of 1-3 and 6 questions are 1,5 which means the students agree on the usefulness of the 4D-5D BIM framework to extend their understanding. Also, standard deviation of these questions is 0,5 which means there is not a significant difference in students' attitudes. Mean value of 4 and 7 is 1,8 and standard deviation is 0,6. This result shows the consistency as these two questions are related to each other. For the question number 5, mean value is 2,4 and standard deviation is 0,66. Even though, question number 5 has the highest mean value, standard deviation is not that high because responses varied between 3 options. However, question number 8 has the highest value of standard deviation -0,89- as the responses divided into 4 options with a mean value of 2. In general, students were agreed on advantages of the framework. These results particularly emphasize that construction management and economics course through 4D-5D BIM framework enhance students' understanding on cost and time management of a building construction.

Table 2. Survey responses statistical analysis

No	QUESTIONS	Strongly Agree (%)	Agree (%)	Undecided (%)	Disagree (%)	Strongly Disagree (%)	Mean	Standard Deviation
1	I can make connections between 2D-3D-4D-5D thanks to the BIM.	50	50	0	0	0	1,5	0,50
2	I can understand the requirements of preparing schedule.	50	50	0	0	0	1,5	0,50
3	I can demonstrate relations between construction process and work breakdown structure thanks to the 4D simulation that I have created in Bexel Manager.	50	50	0	0	0	1,5	0,50
4	I can manage obtaining and organizing quantity information from BIM model.	30	60	10	0	0	1,8	0,60
5	I can conduct cost estimations through BIM software.	10	50	40	0	0	2,4	0,66
6	4D BIM, 5D BIM and simulations increased my understanding on construction management.	50	50	0	0	0	1,5	0,50
7	I can use Revit –as a BIM tool- efficiently.	30	60	10	0	0	1,8	0,60
8	I can use Bexel Manager –as a BIM tool- efficiently.	30	50	10	10	0	2	0,89

Different dimensions of BIM and their applications are major topics as components of Construction 4.0. In this regard, 4D and 5D BIM have been used in project planning and bring some significant benefits for the entire lifecycle such as communication and collaboration among participants, visualizing and monitoring the whole schedule, simulating construction process and obtain a realistic cost estimation. In the AEC industry, 4D and 5D BIM approach are started to use commonly. However, the architecture education in undergraduate level has not reached the maturity level of the industry in terms of digitalization. Even though in design subjects, there are some examples in computational design, BIM, VR or related topics, in construction management courses these adaptations are very limited. Pioneering academic institutions such as Harvard, MIT, ETH Zurich and ITKE Stuttgart have particular investigations about adopting digitalization methodology in some architectural courses (Koc et al., 2020) However, there is an emerging need to adopt industry's requirements and way of thinking on the curricula in the era of Construction 4.0. Actually, this is directed by the rapid transforming process AEC industry. The necessity of reconsideration of curricula in terms of digitalization is also emphasized in the studies of Mayouf (2019) and Koc et al. (2020). In this regard, this study both suggested and applied a 4D-5D BIM framework with a digitalization approach on a construction management course. Moreover, the applied framework extended and transformed the theoretical course into a project-based course which enables students to be active learners and be qualified graduates for the industry. Furthermore, the framework was highly accepted and considered beneficial by the students according to the survey results.

For future directions, 6D and 7D BIM could be implemented on the proposed framework. According to Eastman et al. (2010), 6D refers to facility management and 7D refers to sustainability. This extension is also aligned with future directions BIM to nD. To have a more comprehensive and holistic perspective on the building life-cycle, to integrate operation and maintenance, facility management could be considered. Life cycle assessment could be designed with BIM adaptation. As Chan (2014, pp. 37-39) mentioned BIM provides better project lifecycle management, sustainable design, alternative solutions, visualization of the construction process, and safety management. On the other hand, sustainability is the major future objective of the whole industries including AEC. Concerning this, an adaptation of 7D BIM, including material information and energy assessments could be employed in sustainability-related courses in architecture education.

4. CONCLUSIONS AND RECOMMENDATIONS

Construction 4.0 has brought new technologies into the AEC industry and changed the way of doing it in different phases. nD BIM, AR, and VR are one of these technologies which are expanding their borders in the industry. As a result of this transformation, construction management becomes crucial to obtaining building projects considering time, cost, and quality requirements. Thus, there is a significant need for qualified professionals, and architecture education should respond to this urgent necessity. Aiming to adopt a digital approach to the construction management undergraduate course in architecture, a 4D-5D BIM-related framework was developed and applied in this study.

Key implications of the novel framework can be listed as: performing 4D visualization of construction, perform automated generation of construction tasks, monitoring and visualizing the construction process and detecting clashes. In addition, reaching more accurate quantity list and cost estimation are additional practical implications. These implications have helped to obtain learning outcomes effectively. This is also supported by conducted survey. According to the survey responds, 100% of the students agree on the benefits and usefulness of the framework.

The major future research directions can be involved adopting facility management and sustainability as 6D and 7D respectively. Besides the academia, the industry can also use the proposed framework.

AUTHOR CONTRIBUTIONS

Tayibe Seyman Güray: Designing the research, writing and reviewing the manuscript. **Burcu Kısmet**: Data collecting and analyzing, writing and reviewing the manuscript.

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The authors declare no conflict of interest

ETHICS COMMITTEE APPROVAL

This study does not require any ethics committee approval.

REFERENCES

Abanda, F. H., Tah, J. H. M., & Cheung, F. K. T. (2017). BIM in Off-site Manufacturing for Buildings. *Journal of Building Engineering*, 14(October), 89–102.

Abbas A., Din Z. U., & Farooqui R. (2016). Integration of BIM in Construction Management Education: An Overview of Pakistani Engineering Universities, *Procedia Engineering*, 145, 151-157. https://doi.org/10.1016/j.proeng.2016.04.034

Ahmed S.M., Yaris C., Farooqui R. U., & Saqib M. (2014). Key Attributes and Skills for Curriculum Improvement for Undergraduate Construction Management Programs, *International Journal of Construction Education and Research*, 10:4, 240-254. DOI: 10.1080/15578771.2014.900833

Alizadehsalehi, S., Hadavi, A., & Huang, J.C. (2020). From BIM to extended reality in AEC industry. *Automation in Construction*, 16. https://doi.org/10.1016/j.autcon.2020.103254

Assaf, S.A., & Al-Hejji, S. (2006). Causes of delay in large construction projects. *International Journal of Project Management*, 24(4), 349-357.

Bloom, B. S., Engelhart, M. D., Furst, E. J., Hill, W. H., & Krathwohl, D. R. (1956). Handbook I: cognitive domain. *New York: David McKay*.

Bryde, D., Broquetas, M., & Volm, J.M. (2013). The project benefits of building information modelling (BIM). *International Journal of Project Management*, 31(7), 971-980.

Chan, C.T.W. (2014). Barriers of implementing BIM in construction industry from the designers' perspective, A Hong Kong Experience. *Journal of System and Management Sciences*, 4 (2), 24-40.

Charlesraj, V.P.C., & Dinesh, T. (2020). *Status of 4D BIM Implementation in Indian Construction*. 37th International Symposium on Automation and Robotics in Construction (ISARC 2020).

Cheng, J. C. A., & Ma, L. Y. (2013). A BIM-Based System for Demolition and Renovation Waste Estimation and Planning. *Waste Management*, 33(6), 1539–1551.

Crowther, J., & Ajayi, S. O. (2021). Impacts of 4D BIM on construction project performance. *International Journal of Construction Management*, *21*(7), 724-737.

Davidson, A. (2009). A Study of the Deployment and Impact of Building Information Modelling Software in the Construction Industry.

Diaz, P. M. (2016). Analysis of benefits, advantages and challenges of building information modelling in construction industry. *Journal of Advances in Civil Engineering*, *2*(2), 1-11. https://doi.org/10.18831/djcivil.org/2016021001

Ding, L., Zhou, Y., & Akinci, B. (2014). Building Information Modeling (BIM) application framework: The process of expanding from 3D to computable nD, *Automation in Construction*, 46, 82-93. https://doi.org/10.1016/j.autcon.2014.04.009

Duit, R. (1996). The constructivist view in science education–what it has to offer and what should not be expected from it. *Investigaçôes em ensino de ciências*, *1*(1), 40-75.

ECSO (2021). Digitalisation in the Construction Sector Analytical Report, European Construction Sector Observatory, available at: https://ec.europa.eu/docsroom/documents/45547 (last accessed 21.02.2022).

Eastman, C. M., Eastman, C., Teicholz, P., Sacks, R., & Liston, K. (2011). *BIM handbook: A guide to building information modeling for owners, managers, designers, engineers and contractors*. John Wiley & Sons.

Elbeltagi, M. (2016). *Construction Site Layout Planning: Identifying, Sizing and Locating Temporary Facilities on Construction Sites*, Lambert Academic Publishing.

Evans, M., Farrell, P., Elbeltagi, E., & Dion, H. (2021). Barriers to integrating lean construction and integrated project delivery (IPD) on construction mega projects towards the global integrated delivery (GID) in multinational organisations: lean IPD&GID transformative initiatives. *Journal of Engineering, Design and Technology*, Vol. ahead-of-print No. ahead-of-print. https://doi.org/10.1108/JEDT-02-2021-0070

García de Soto, B., Agustí-Juan, I., Joss, S., & Hunhevicz, J. (2019). Implications of construction 4.0 to the workforce and organizational structures, *International Journal of Construction Management*, 1 (1), 1-13.

Hadavi, P. & Tavakolan, M. (2018). *4D modeling and BIM-based Project planning using constraint-based simulation for implementation in Iran considering an actual case study*. Construction Research Congress, CRC 2018, 542–551.

Hall, D., Algiers, A., Lehtinen, T., Levitt, R. E., Li, C., & Padachuri, P. (2014). *The Role of Integrated Project Delivery Elements in Adoption of Integral Innovations*. EPOC 2014 Conference, (July), 1–20.

Howell, G. & Lichtig, W. (2008). Lean Construction Opportunities Ideas Practices. Speech presented to the Cascadia LCI "Introduction to Lean Design" Workshop. Seattle, Washington. https://leanconstruction.org/uploads/wp/media/docs/Lean_Construction_Opportunities_Ideas_Practices-Deans_Speech_in_Seattle_r1.pdf (last accessed 20.06.2022)

Ikerd, P.E.W. (2013). Who's Using BIM? Trends and drivers affecting structural engineers, http://www.tpm.com/component/content/article/1-latest-news/ 620-whos-using-bim (last accessed 21.02.2022).

Jung, Y., & Joo, M. (2011). Building information modelling (BIM) framework for practical implementation, *Automation in Construction*, 20, 126-133.

Kim, J., & Irizarry, J. (2021). Evaluating the Use of Augmented Reality Technology to Improve Construction Management Student's Spatial Skills, *International Journal of Construction Education and Research*, 17:2, 99-116. DOI: 10.1080/15578771.2020.1717680

Koc, E., Pantazis, E., Soibelman, L., & Gerber, D. (2020). Emerging trends and research directions. *Construction 4.0*, 460-476. doi: 10.1201/9780429398100-23

Kurt, S. (2011). Use of constructivist approach in architectural education. *Procedia Social and Behavioral Sciences*, *15*, 3980-3988. https://doi.org/10.1016/j.sbspro.2011.04.402

Liu, M. (2013). *The application of BIM and IPD in public design and construction* (Doctoral dissertation, Polytechnic Institute of New York University). http://160.75.22.2/docview/1284156646?accountid=11638

Lu, W., Lai, C. C., & Tse, T. (2018). *BIM and Big Data for Construction Cost Management*. Routledge.

Mayouf, M., Gerges, M., & Cox S. (2019). 5D BIM: an investigation into the integration of quantity surveyors within the BIM process, *Journal of Engineering, Design and Technology*, 17 (3), 537-553. doi: 10.1108/JEDT-05-2018-0080.

Messner, J. I., & Horman, M. (2003). Using advanced visualization tools to improve construction education. In *Proceedings of CONVR 2003 conference*,145-155.

Moses, T., Heesom, D., & Oloke, D. (2020). Implementing 5D BIM on construction projects: contractor perspectives from the UK construction sector, *Journal of Engineering, Design and Technology*, 18(6), 1867-1888. doi: 10.1108/JEDT-01-2020-00

Oesterreich, T.D., & Teuteberg, F. (2016). Understanding the implications of digitisation and automation in the context of Industry 4.0: a triangulation approach and elements of a research agenda for the construction industry, *Computers in Industry*, 83,121-139.

Osunsanmi, T., Aigbavboa, C.O., Oke, A.E., & Liphadzi, M. (2020). Appraisal of stakeholders' willingness to adopt construction 4.0 technologies for construction projects, *Built Environment Project and Asset Management*, 10 (4), 23-34.

Osunsanmi, T.O., Aigbavboa, C.O., Thwala, W.D.D., & Molusiwa, R. (2022). Modelling construction 4.0 as a vaccine for ensuring construction supply chain resilience amid COVID-19 pandemic , *Journal of Engineering, Design and Technology*, 20 (1), 132-158. https://doi.org/10.1108/JEDT-07-2021-0384

Pan, W., Ilhan, B., & Bock, T. (2018). Process Information Modelling (PIM) Concept for on-site construction management: Hong Kong case. *Periodica Polytechnica Architecture*, 49 (2), 165-175, doi: 10.3311/PPar.12691

Pittard, S., & Sell, P. (2017). *BIM and quantity surveying*. Routledge.

Sampaio, A. Z. (2018). Enhancing BIM methodology with VR technology. *State of the Art Virtual Reality and Augmented Reality Knowhow*, 59-79.

Sawhney, A., Riley, M. & Irizarry, J. (2020). Construction 4.0: An Innovation Platform for the Built Environment, Routledge. ISBN 9780367027308.

Shaqour, E.N. (2022). The role of implementing BIM applications in enhancing project management knowledge areas in Egypt. *Ain Shams Engineering Journal*, 13(1), ISSN 2090-4479, https://doi.org/10.1016/j.asej.2021.05.023

Smith, P. (2014). BIM & the 5D Project Cost Manager. Procedia - Social and Behavioral Sciences, 119, 475 – 484.

Xu, J. (2017). Research on application of BIM 5D technology in central grand project. *Procedia engineering*, *174*, 600-610. https://doi.org/10.1016/j.proeng.2017.01.194

Wang, Q., Guo, Z., Mintah, K., Li, Q., Mei, T., & Li, P. (2019). Cell-based transport path obstruction detection approach for 4D BIM construction planning. *Journal of Construction Engineering and Management*, *145*(3), 04018141.

Wong, J., Wang, X., Li, H., & Chan, G. (2014). A review of cloud-based BIM technology in the construction sector. *Journal of information technology in construction*, *19*, 281-291.

URL-1: AIA California Council (2010). Integrated project delivery steering committee and AIA national integrated practice discussion group. Integrated Project Delivery: Case Studies, www.ipd-ca.net (last accessed 18.02.2022)

URL-2: https://webdosya.csb.gov.tr/db/yfk/icerikler//bf-2022-turkce-20220119085513.pdf (last access date:18.02.2022).