New Approaches in Civil Engineering Education

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Abstract

The spread of the digital transformation, which started with Industry 3.0, along with the developing technology, has affected the construction and education sectors as well as different professions and industry groups. It is seen that the use of technologies such as building information modeling (BIM), cyber-physical systems (CPS), laser scanners, virtual reality, augmented reality and artificial intelligence has increased with Construction 4.0, especially in the design and construction management stages. It is inevitable that students, who are in these technological and digital transformations, need different methods in terms of perceiving information compared to other generations. While traditional methods are effective for the Y generation and the old, traditional methods lose their effect in the Z and future generations. This situation necessitated a change in education methods and revealed the concept of Education 4.0. In this study, new methods used in civil engineering education, especially in the last 10 years, were investigated. The results obtained from the use of the methods found as a result of the research in civil engineering education, and the advantages and disadvantages of these methods were examined.

Keywords: *civil engineering education, education 4.0, educational technology, industry 4.0.*

Introduction

Industry 4.0, which first came to exist in 2011, is a new industrial revolution based on robotics, the internet of things (IoT), real-world virtualization, big data storage, nanotechnology, energy storage and artificial intelligence (Mogoş et al., 2018; Esmer & Alan 2019). Technologies brought by the Industry 4.0 revolution have revealed many 4.0 concepts such as marketing, logistics, health, management, construction and education (Schircks et al., 2017). Each of these concepts refers to digital transformation and technological progress in its own field. With construction 4.0, it is seen that the use of technologies such as building information modeling (BIM), cyber-physical systems (CPS), laser scanners, virtual reality (VR), augmented reality (AR) and artificial intelligence (AI) has increased, especially in the project designing and monitoring stages. The size and complexity of the construction projects built with these technologies cause the need for technical personnel who can adapt to the developing technology. This situation makes it inevitable to use the developing technology in engineering education. In order to train qualified personnel in the field of civil engineering, as in every field, there is a need for a project-based, life-long learning, developmental, innovative, technology and internet-using education system. Nowadays, the education system that aims to meet this need is called Education 4.0.

Education 4.0 has nine goals besides integrating high technology and digital data into education (Fisk, 2017):

- To ensure that education is not limited to classrooms and learning anywhere and asynchronously.
- To enable the student to choose the appropriate tools and programs for learning.
- To provide education with a personalized curriculum according to the student's abilities.
- To enable the student to learn by herself/himself, to gain independence in learning, and to ensure that the teacher takes a guiding role in the learning process.
- To ensure that practical training is included in the curriculum, to provide opportunities for students such as internships and industry cooperation projects.
- To provide project-based thinking, learning and working principle.
- To provide students with organizational, collaboration and time management skills.
- Determining student and sector needs in education.
- Using assessment methods such as data interpretation, questioning and answering instead of traditional exams.

It is also seen that the technological and methodological goals of Education 4.0 are compatible with the learning style of the Z generation living with technology. Young people (Generation Z), who grew up with technology, have difficulties in adapting to classical materials and techniques. Generation Z youth focus on first-hand access to information (Kuleto et al., 2021). Therefore, this generation of young people prefers web, computer, phone, tablet, etc. environments to access information, unlike the classical library environment. Educating civil engineering students with an appropriate pedagogical and technological approach will increase the capacity of universities to train engineers at a professional level. In addition, it is foreseen that students will gain a systematic perspective, lifelong learning, intergenerational experience exchange, interdisciplinary cooperation, and increase the entrepreneurship and innovation culture of students (Samaka & Ally, 2016). Due to the aforementioned reasons, it is thought that the blackboard and chalk system should be abandoned in universities, technological developments should be followed and Education 4.0 should be integrated into university education (Almeida & Simoes, 2019; Boz, 2019).

This study is aimed to investigate new methods and technologies used in civil engineering education that emerged with Industry and Education 4.0. For this purpose, new technologies used in civil engineering education have been obtained by researching studies in the literature in recent years. The results obtained from the use of the new methods found in civil engineering education, and the advantages and disadvantages of these methods were examined.

Methodology

Since the mention of Industry 4.0 in 2011, it is seen that studies related to educational technologies have increased in the literature. In this study, the keywords "Engineering Education" and "Education Technologies" were used to search for new technological approaches. The related studies conducted in the last 10 years were searched in the databases of “Scopus”, “Google Scholar” and “Thesis Center” with the determined keywords. In the investigations, seven technologies have been identified. These are “Audio-Visual Materials”, “3D Printers”, “BIM”, “Games and Animations”, “VR”, “AR” and “Mixed Reality (MR)”. Then, the usage of these technologies in "Civil Engineering Education" was searched in the same databases. In the following stages of the study, these technologies are examined in detail. The research methodology is given in Figure 1.

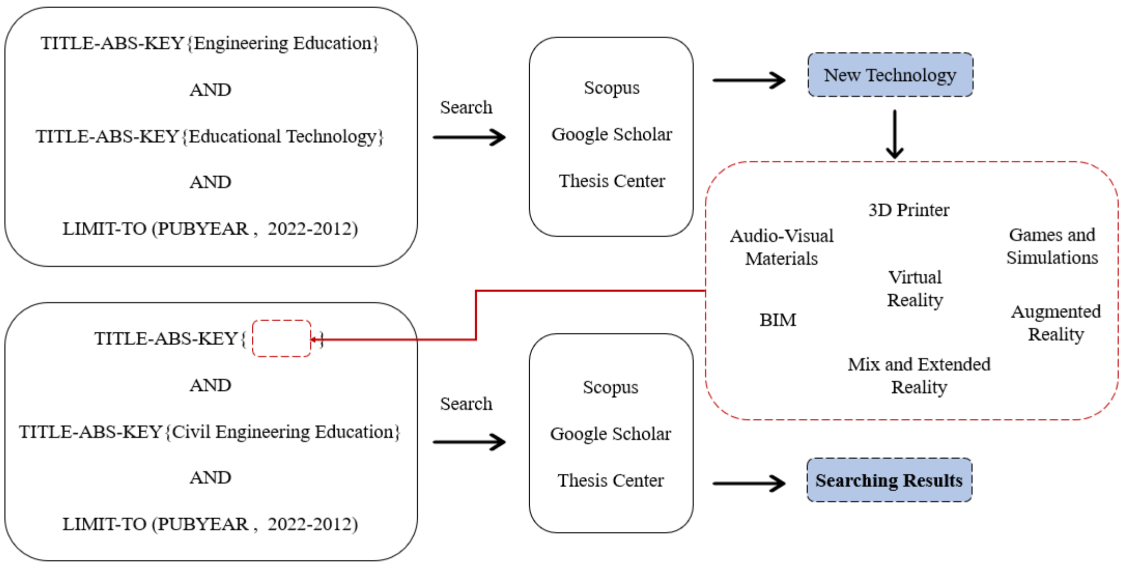

Figure 1: Research methodology.

In this study, a systematic literature review such as meta-analysis, bibliometric analysis, and statistical analysis of publications was not carried out. By using these keywords, new technologies were tried to be determined and these approaches' usage in civil engineering education was investigated.

Audio-Visual Materials

The invention and use of audio-visual materials, which were used before Industry 4.0, have changed considerably until today. The high quality of audio-visual materials used these days (videos, animations, simulations, animated presentations, audio slides, etc.) and their easy accessibility (mobile phone, television, computer, tablet, etc.) have greatly increased the use of these materials. The widespread usage and increasing speed of the Internet, the satisfactory video quality and the easy sharing of videos in the digital environment have made videos, one of the audio-visual materials, quite successful in education. The videos, which are used frequently during the Covid-19 pandemic period, have made a great contribution to the continuation of education regardless of place and time (Liu, 2021).

In the literature, it is seen that videos also contribute to the spreading of educational services, increase the quality of education, ensure memorability and attract the attention of students in education (Stefanova, 2014). In addition, the benefits of videos are stated as saving the time and cost of teaching the subjects, showing the details to the students by zooming the image in professional fields and providing practical education more easily (Boz & Toğan, 2021). It is also emphasized that audio-visual materials allow students to learn the subjects faster than written texts and to concentrate on the subject by stopping their education whenever they want (Kay, 2012). It has been demonstrated through surveys, observations and experiments that educational documentaries or practice videos about subjects that cannot be shown directly in the lessons are useful in education (Bétrancourt & Benetos, 2018) and that course materials supported by real-life pictures, simulations, animations and interactive narrations provide advanced benefits in education (Bikçe et al., 2011).

Bauer et al. (2021) stated that the necessity of using technology in civil engineering education is more understood in the Covid-19 period. In order to support distance education, the team of professors has prepared comprehensive training videos on environmental, geotechnical, transportation and structural engineering issues. They stated that the students who were educated with videos found it interesting and that the videos helped the students to understand the course content.

Boz (2019) argued in their study that practical training is necessary for civil engineering students to fulfill their professional responsibilities well after graduation, but internships, which cover a large part of applied education, cannot fully accomplish this task. For this reason, they explained the production of stone walls, which is in the professional practice of civil engineers, to civil engineering students using audio-visual materials. The videos include the designing phase of the stone wall, the technical terms in the projects and the real video on site under construction (Figure 2). As a result of the study, they determined that audio-visual materials can be used especially in practice training.

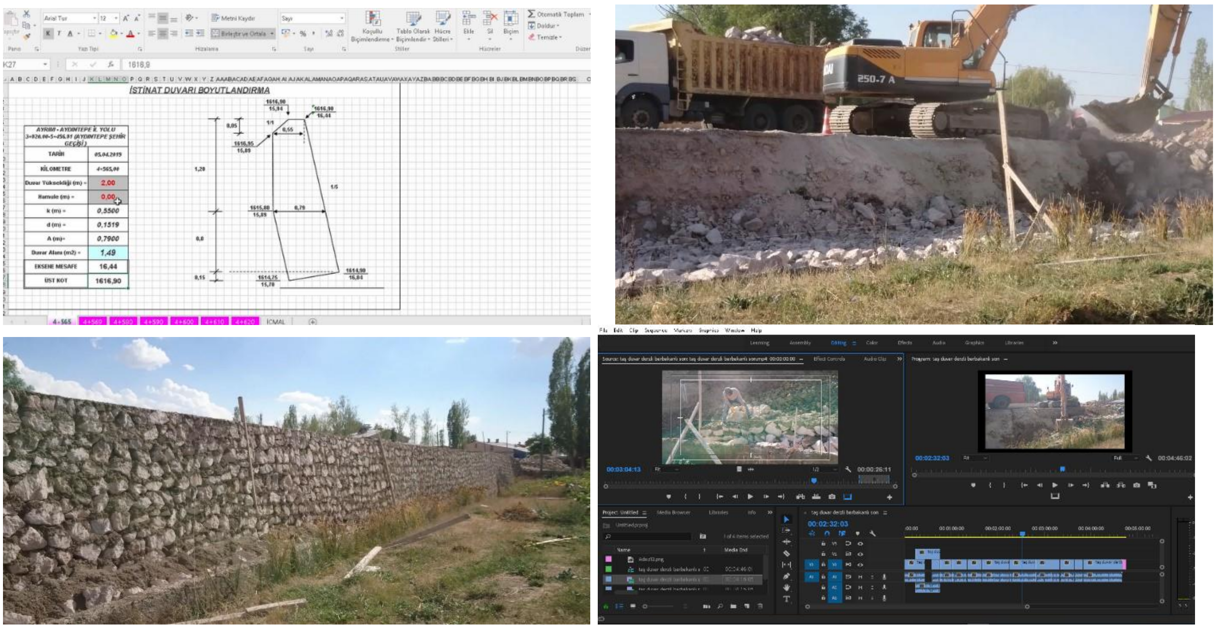

Figure 2: Stone wall video (Boz & Toğan, 2021).

Stefanova (2014) divided engineering students taking electronic measurement courses into two groups. They taught the lesson to one of the groups using audio-visual materials and the other group with traditional methods, and as a result of the study, it was determined that the students who were educated with audio-visual materials learned the lesson better.

3D Printers

3D printers, which became widespread with Industry 4.0, have managed to become a trend in the field of prefabricated manufacturing with their contributions to speed, design possibilities, economy and engineering. Today, it is used in many areas other than manufacturing and it has different usage areas day by day. It is thought that small-sized 3D printers, which can also produce 3D course materials, will create significant changes to engineering education (Kökhan & Özcan, 2018).

3D printers, which can be used in the education of fields such as architecture, art, biology, chemistry, geology and construction, are seen as an important tool for increasing creativity in mechanical and technical courses. With the effective use of this technology in the educational environment, students can quickly see their designs in 3D, improve their perspective vision skills (Lantada et al., 2010), find the opportunity to create physical objects (Syed, 2012) and learn by showing more interest in the lessons and having fun (Schelly et al., 2015).

While Tehrani et al. (2017) taught civil engineering students the working principles and necessary programs of 3D printers to make multidisciplinary designs, Katrenicova et al. (2020) used 3D printers in education to increase the geometric perceptions of civil engineering students. In addition, Kazemiroodsani and Kamat (2021) used 3D printers to better understand the land conditions and cut/fill works in the road project design in the civil engineering transportation department.

Building Information Modeling (BIM)

BIM is the process of producing digital models for the design, construction and operation of projects and using these models throughout the project lifecycle (McGraw Hill, 2009). This process includes stages such as static, architectural, machine and energy elements of the building can be modeled in three dimensions (3D), creating planning and scheduling documents and showing the construction phases. BIM is also becoming a new generation learning method in terms of pedagogy, thanks to the ability to see two-dimensional building components in 3D and the simulation features. From another perspective, BIM technology can provide an environment for students who have not seen the construction phase of a building to think and practice all building processes and behaviors close to digital and physical reality. Owing to these advantages of BIM, it is seen in the literature that BIM is used especially in architecture and civil engineering education (Bozoglu, 2016; Sampaio, 2018; Pomares Torres et al., 2017).

Meterelliyoz and Özener (2017) developed the operation of the Construction Technology course by using BIM technology. As a result of the case study, they have identified positive changes in the improvement of students' knowledge levels and also the design and development of building elements.

Lassen et al. (2018), in the Introduction to Civil Engineering course at Akershus University in Oslo, gave the students the task of designing a two-story wooden structure in the BIM-based Autodesk Revit program. As a result of the task, the students reported that they understood the design, implementation and construction details better. In addition, students have gained collaborative working experience. As a result of the study, it was determined that BIM supports students in understanding professional civil engineering. In Figure 3, there are images from the models created in the study.

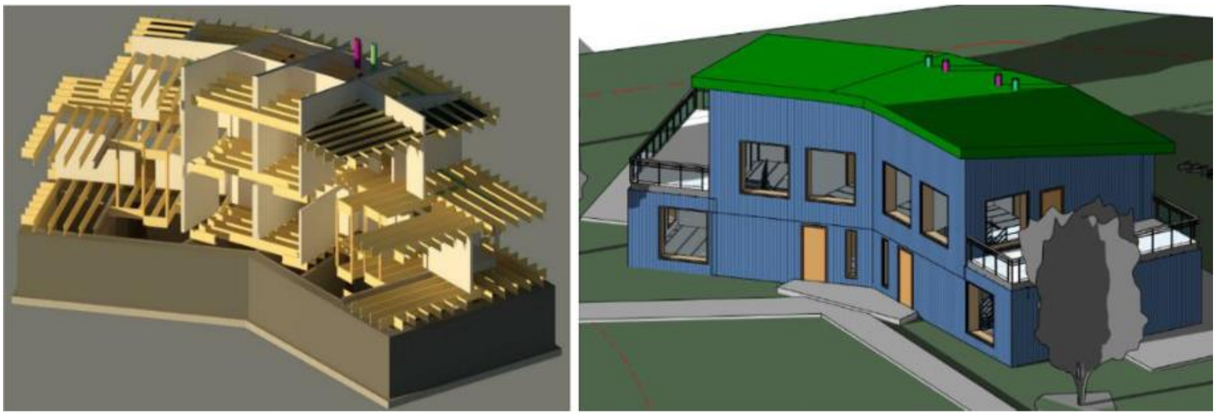

Figure 3: Images from the study (Lassen et al., 2018).

Games and Simulations

It is getting harder and harder to motivate Z generation students in the classroom with traditional methods for a long time. This generation, growing with technology, is looking for a more flexible and interactive educational environment (Proserpio & Gioia, 2007). It is thought that digital tools such as games and simulations will meet this need (Poole et al., 2014). Game-based learning, which is one of the new generations learning methods, creates high motivation and habits in individuals (Huang & Soman, 2013). In game-based learning, features such as virtual rewards, achievement badges and displaying students' success rankings according to various characteristics increase participation in education, create competition and improve learning (Alanne, 2016). It is also mentioned in the literature studies that the fun learning brought by games and simulations is better understood than the lessons presented as text or oral presentation (Chen & Wu, 2015). It is seen that the advantages of digital game-based education increase with the rise in the frequency of use of devices such as computers, tablets and phones (Sera & Wheeler, 2017). While this method provides the opportunity to present information without requiring a large investment, it also relieves students of the obligation to devote intensive time to classes (Kapp, 2012).

Fatahi and Khabbaz (2015) used a computer game to teach civil engineering undergraduate students about soil behavior. In the study, it was observed that game-based learning contributed to students' information gathering methods, creative thinking, problem-solving and lifelong learning skills. In addition, a fun competitive and collaborative learning environment was provided in the course, and students' motivation and critical thinking skills increased.

Sousa (2020) organized suitable games for two civil engineering courses and added them to the course curriculum. In the study, it was seen that game-based learning contributed to the student's learning of transportation costs and construction terms. However, it was also stated that a lack of seriousness in the lesson may occur in game-based learning.

Zechner and Ebner (2011) applied the game-based learning method in the civil engineering structural analysis course. 159 students used the games and as a result, they found that the learning outcomes of the students who used the application increased. Although the learning outcomes of the students who played the game increased compared to those who did not, there was no difference between the students who played the game more and those who played less.

Virtual Reality

VR is a technology that allows a person to observe or do events in a virtual environment that may occur in the real world by isolating them from the real environment. This technology, which has a slow spread rate due to the expensive required equipment and the difficulty of preparing materials, has started to be used in fields such as health, engineering, military, automotive and tourism in recent years. It is thought that VR technology, which is preferred for personnel training in many areas that may pose a danger to humans and the environment, can make it possible to learn subjects and concepts that are difficult to understand at other levels of education in a more interesting, memorable and effective. Especially in civil engineering education, it is thought that the opportunity to gain experience without going to the construction site and the ability to visualize and interact with the 3D materials in the theoretical courses will both contribute to the practical training of the students and contribute to a better understanding of the theoretical knowledge and increase the academic success of the students.

VR applications are becoming more popular daily with developing technologies and various field-specific VR applications and simulators are being developed. The integration of VR into education has increased the potential of students to access education (Balak, 2019; Kılıç, 2020). Piovesan et al. (2012) stated that 3D virtual learning environments can improve spatial knowledge, facilitate impossible or impractical experiential learning, enable the transfer of knowledge and skills learned in virtual environments to real situations, and increase learning motivation and participation. Mikropoulos and Natsis (2011) stated that VR makes it easier to understand the basis of a subject, can transform intangible ideas into tangible representations, and offer users more situations than they can normally experience. Çoruh (2011) investigated the effect of using VR applications as a learning model in Art History courses in Fine Arts and Architecture Faculties on student achievement. At the end of the study, it was stated that the majority of the students were in favor of the use of VR applications and technologies both as a learning model and as a complementary element in Art History courses.

Sampaio et al. (2010) pointed out that VR technology can be used as a complement to 3D modeling in civil engineering vocational education and practice. They emphasized that the VR models developed for the construction process can provide a visual simulation of the physical progress of each type of work, can help to examine the necessary equipment and learn information about the operation in the field, and can evaluate the knowledge gained by the students in their professional practices.

Özel (2019) created a VR application to measure the ability of construction workers to recognize hazards at construction sites. The dangers that the workers may encounter in real life were placed in the application and the workers were expected to walk around the virtual construction site and detect the dangers by wearing VR glasses. Thanks to this training, workers experienced dangerous behaviors and substances without going to the real construction site. An example of a virtual construction site is shown in Figure 4.

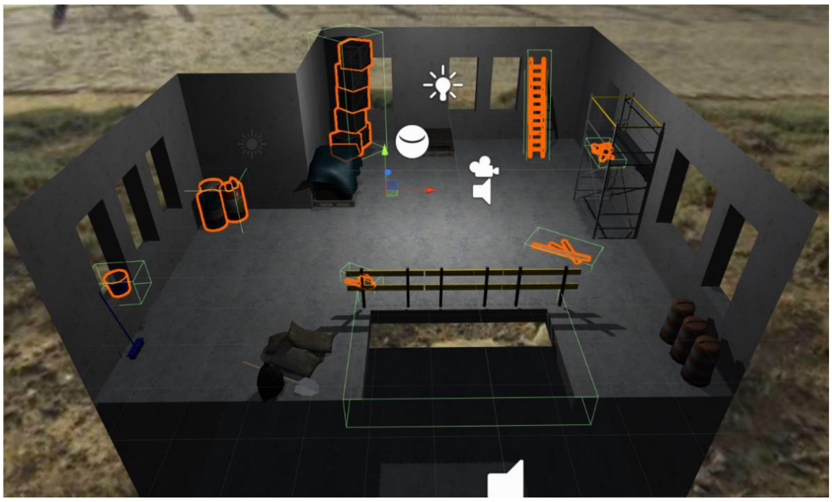

Figure 4: Virtual construction site environment with various dangers (Private, 2019).

İçten (2021) designed an educational virtual environment so that pedestrians and driver candidates can learn traffic rules in a virtual environment based on real traffic rules. It has been argued that VR can be a solution tool in eliminating the problems that pedestrians and driver candidates will encounter in traffic, with the training in this application in which natural hand movements are followed and vehicles move. Figure 5 demonstrates the images of the designed program and its use.

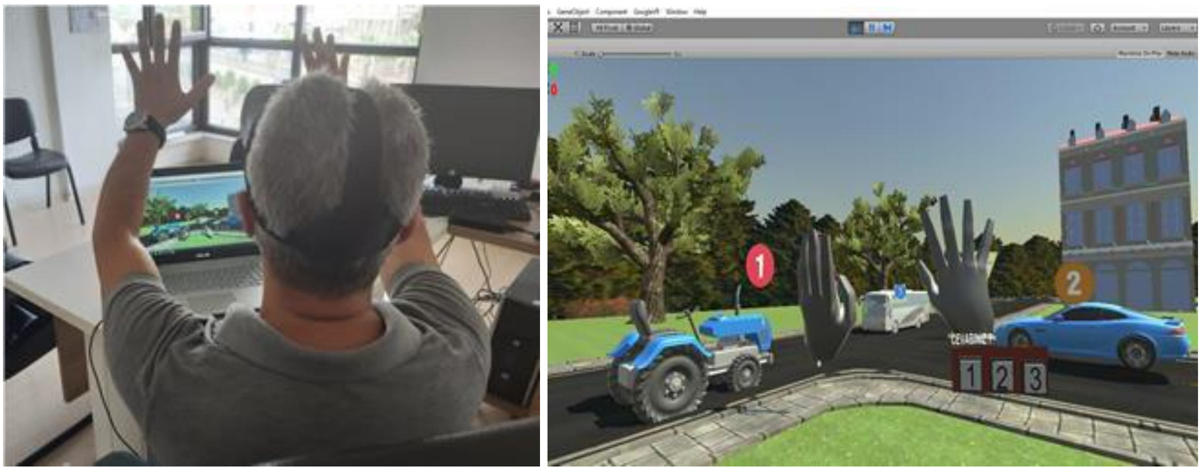

Figure 5: Interactive 3D virtual environment (İçten, 2021).

Kılıç (2020) mentioned that students have difficulty in understanding application issues such as finishing structure details, material, space and object scale in lessons. As a solution proposal to this problem, a VR application teaching model with an immersive effect and representing a virtual construction site, has been developed to be used in interior architecture education. In this study, the author revealed that VR application has an effect on accelerating the interior architecture teaching process and increasing the quality of teaching. The designed VR application is shown in Figure 6.

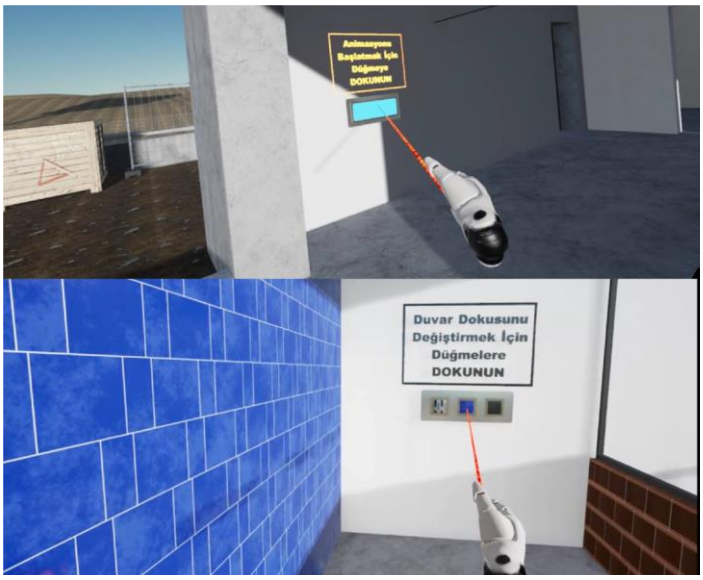

Figure 6: Interior architecture virtual training application (Kılıç, 2020).

In the above-mentioned studies, it has been determined that VR technology, adapted from real life, mainly helps students to understand and learn the information better because it opens new ways for learning and offers an interesting method.

Augmented Reality

The general purpose of AR and VR is to strengthen, support and enrich reality by providing information that people cannot see but can imagine under normal conditions. However, AR does not create a completely artificial environment, unlike VR. With the AR glasses, opportunities such as viewing the situations of objects in different environments, the details of machine parts and the process-result steps of the construction work guides are provided. These possibilities have made AR a new technology that can be used both in the sector and in education (Albahbah et al., 2021).

Nesterov et al. (2017) claim that AR is replacing expensive laboratory equipment and that students' interest level has increased due to the interaction of these technologies with students. Somyürek (2014) expresses some of the usage areas of AR for educational purposes as adding a 3D to 2D books, training on cognitive and psychomotor maintenance/repair tasks, and providing information/skills about tools and materials in engineering education. Balak and Kısa (2016) investigated the use of AR technology with smartphones in technical drawing education and emphasized that AR has critical importance for engineering students in the technical drawing course. Li et al. (2017), on the other hand, state that visualizing accurately and effectively using an AR platform for analysis and simulations involving engineering data types reduces false learning and interpretation.

Theodossiou et al. (2018) developed an AR application for hydrology education in civil engineering. Thanks to the application, the students gained the ability to better understand the effects of floods and structures on the flow regime, rainfall intensity and evaporationtranspiration. Louis and Lather (2020) used an AR to teach excavation planning. As a result of this study, it has been suggested that AR virtual spaces can support planning and managing large-scale construction projects. It is also mentioned that the application can be used by excavation construction teams and professional engineers. Also, Waters et al. (2021) created an AR application for the Foundations, Soil Mechanics, Hydraulics and Hydrology courses in the civil engineering undergraduate curriculum of Villanova University. For the planning and implementation of these modules, faculty members from more than one discipline (geotechnical, water resources and structural engineering) worked in the department. It is aimed to support education with 3D materials for other courses at the university, as positive feedback is received on the 3D visualization and application skills of the students who use these modules.

Mix and Extended Reality

Nowadays, it is seen that the concept of MR is used as a term that covers both VR and AR applications (Sherman & Craig, 2018). The MR concept, which uses wearable technology instead of hand-held devices, provides the opportunity to interact with virtual objects in the real world (Künüçen & Samur, 2021). While the user is experiencing MR with these devices, they can interact with virtual menus or objects with their hands without the need for any additional device and can be more involved in the experience process than the classical AR concept (Langstone, 2021). Extended reality (XR) is a concept that brings all other realities together. With XR, which is less common in the literature, people will be able to feel as if they are anywhere in the world thanks to wearable technologies (Künüçen & Samur, 2021). These technologies require expensive equipment and are more complex technology than AR and VR, therefore, the possibility of using these technologies in civil engineering education reduces.

Discussion

Civil engineering education should not be limited to subjects such as the response of load-bearing elements under various loads and various environmental conditions, how the bearing elements are designed, and how the materials that make up the structural elements are produced. Civil engineering is a generally field-studied profession. When the theoretical knowledge taught in universities cannot be combined with field studies, the efficiency of the students' vocational education decreases. Civil engineers taking responsibility in many areas such as bridges, roads, tunnels, industrial structures, prefabricated structures, infrastructure works, dams and ports in their working life, cannot gain the necessary experience with traditional education methods. When it comes to the training of field applications, the use of current technologies is of great importance. It is much more practical and faster than traditional methods for students to learn, manage and develop the design processes and construction stages by using technology.

Within the scope of this study have been researched new technologies that can contribute to applications such as internships, technical trips and laboratories used in civil engineering practice education. Audio-visual materials, 3D printers, games, simulations, BIM, VR, AR and MR are some of these technologies. Audio-visual materials are very useful in providing asynchronous learning, transferring the experience acquisition that takes a long time to the student in a short time and in showing the construction stages. However, audio-visual materials have some disadvantages such that they cannot be filmed under all conditions, some dangerous works cannot be recorded on video recordings, and the students feel a lack of perception of reality in animations. Although 3D printers increase imagination, design skills and perspective vision, the inadequacy of 3D design elements in crowded classrooms is one of its disadvantages. Although games are very advantageous in providing fun learning and keeping information in mind, the lack of seriousness while playing games in the classroom is one of the difficulties brought by this technology. Interdisciplinary BIM studies contribute to the collaborative learning of students, to have knowledge about design and development of building elements, and to examine the details of design and construction stages. The environment provided by VR technology to students and the opportunity to interact with objects can offer students unlimited experience, especially in practice training. The cost of the design of VR environments and the used materials slows the spread of this technology. AR technology, which can be easily accessed by tablets and phones used today, can be used in education with simple coding and 3D models. MR is a mixture of VR and AR technology. Similar to VR, it requires expensive equipment.

Conclusion

The expectation of Industry 4.0 and Education 4.0 is to train human power integrated with technology. In order to fulfill these expectations, new technologies should be integrated into education. For this purpose, educational technologies that can be used in civil engineering education, together with their advantages and disadvantages, are examined. It has been shown with examples from Turkey and the world that these technologies can be integrated into civil engineering education. It is thought that the technologies mentioned in the study, in addition to traditional methods, will contribute to the training of qualified and technology-skilled civil engineers with application knowledge. Nowadays, when the virtual classroom and Metaverse have become widespread, it is obvious that traditional methods are insufficient.

Future studies can investigate different new technologies that can be found by systematic literature review. Educational approaches other than engineering education can also be included in these studies. In addition, new pedagogical approaches used for the Z generation can also be explored for engineering education.

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