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ACQUIRING DIGITAL COMPETENCES FOR CONSTRUCTION PROJECT MANAGEMENT

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Abstract

The construction industry is currently undergoing a profound transformation in project management, led by the integration of Building Information Modeling (BIM) and Industry 4.0. BIM is central to modern construction project management and is at the heart of this change. Slovenian universities have adapted civil engineering curricula to equip students with essential digital skills. The paper describes in detail the experience in teaching BIM and advanced technologies, and thus describes the objectives of the subject, competences acquired, teaching methods and outcomes. The article emphasizes the importance of cutting-edge training and looks at BIM-based and Industry 4.0 courses. By integrating advanced methods into civil engineering education, graduates will be equipped with the digital skills they need for their future careers.

Introduction

Project management is a scientific discipline that is present in all sectors of the economy. Over the last decade, this field has changed rapidly due to the development of advanced technologies. In the construction industry, however, the situation is unfortunately not yet as advanced in terms of the introduction of digitalization (Manyika et al., 2015). Therefore, current efforts are focused on research and examples of best practice, emphasizing a responsible and lifelong approach to the planning and execution of construction projects. At the forefront of these efforts is the implementation of advanced technologies and methods (Xavier and Jacob, 2018). A major challenge is the transformation of traditional business models, shifting from material-centric to information- and digital-centric products, data-driven approaches and intellectual business models (Klinc and Turk, 2019). In general, this means the digitalization of business in the construction sector.

The introduction of Industry 4.0 principles, technologies and methods is enabling transformative advances in the construction industry today. To close the digitalization gap and drive the construction industry forward, it must keep pace with the trends of Industry 4.0 (Klinc and Turk, 2019). The latest research findings highlight trends such as Building Information Modeling (BIM), robotics, project management, advanced materials, offsite construction, occupational safety, monitoring, green building, 3D printing and networked construction sites (“Top 10 Industry 4.0 Trends in 2024 | StartUs Insights,” n.d.). These innovations are recognized in both academic and professional circles (Hasan and Sacks, 2021).

The construction sector faces numerous challenges in the digital transformation of management processes. Modern and advanced technologies are gradually being integrated into the entire project life cycle, from planning to execution and post-occupancy. It is crucial that future and current engineers acquire digital skills.

Due to the rapid adoption of BIM, many construction management (CM) and civil engineering programs have added BIM courses to the curriculum or are integrating BIM topics into various courses. According to 2013 data, 54% of construction programs had included BIM courses in their curricula, and 52% of BIM materials were embedded in traditional courses (Wu and Issa, 2014). In the USA, for example, in 2022/23 there are almost 120 universities that are fully accredited and offer degree programs that offer BIM courses as part of the curriculum (Morganti et al., 2023).

Studies dealing with the use of BIM in higher education (Wang et al., 2020) provide a comprehensive review of the current state of BIM education literature and list important journals and conference proceedings in which research on BIM education is published. An analysis of the bibliometric study in the Scopus database was performed (Chihib et al., 2019). For the citations »BIM in University« it was found that the development of publications in the period from 2003 to 2018 is relatively weak compared to BIM worldwide (only 6.4% of articles refer to BIM in universities); the distribution by country and institution shows that the most productive institutions are the USA, the UK and China (46% of all articles).

Many studies that investigated pedagogical strategies for BIM courses show that the two main teaching approaches are team-based learning and project-based learning, for ACE students (Anderson et al., 2020; Jin et al., 2018; Olowa et al., 2022) and for CEM students (Wang et al., 2022; Zhang et al., 2018). Some studies also propose the T-shaped model as a concept for BIM education (Partl et al., 2023).

Two Slovenian faculties that train civil engineers have also recognized the importance of incorporating modern content into the study process and have successfully integrated it by active learning methods (Lassen et al., 2018).

At the Faculty of Civil Engineering, Transportation Engineering, and Architecture (FGPA), University of Maribor (“UM FGPA-a. 2023,” n.d.), six undergraduate programs, four postgraduate programs and three doctoral programs are offered in the field of the built environment. The undergraduate and postgraduate programs in civil engineering and industrial engineering, which are crucial for the development of the construction sector, are

gradually introducing the principles of BIM approach and Industry 4.0. In this, introduction of Industry 4.0 methods is particularly important for the business and project management aspects of construction projects.

At the Faculty of Civil Engineering and Geodesy of the University of Ljubljana, BIM-related content has been part of the study process since 2008 (Šuman et al., 2023). After 2010, the first courses dealing exclusively with modelling and processes within the BIM approach were accredited. The faculty incorporates the topics of digitization and automation into various courses in the different degree programs. Teaching is implemented with integrated problem-based learning (Computer Integrated Construction degree course, 2nd degree) and a workshop approach, which is primarily used in the undergraduate degree courses. Since the 2019/20, the faculty has also been introducing the international Master's degree course BIM A+ (BIM A+, n.d.).

This paper aims to provide an overview of the formal and nonformal acquisition of digital competences in the field of construction management at the FGPA of the University of Maribor. It describes how students acquire digital competences during the learning process, especially in subjects based on the BIM approach and Construction 4.0 technologies. Informal methods for acquiring digital skills are also outlined. The paper concludes with insights into lifelong learning, including a brief description of the buildingSMART Professional Certification Program ("buildingSMART Professional Certification," n.d.) and the presentation of the Platform 5.0 project as part of the Recovery and Resilience Plan (RRP) ("University of Maribor, Pilotni projekti NOO - UM.si," n.d.), which aims to train workers in the field of digitalization and acquire micro-certificates. In this paper, experiences from teaching digital skills acquisition in construction management are shared with the international community and discussions and suggestions for improvement are encouraged.

Formal acquisition of digital competences through the study process

At the FGPA of the University of Maribor, the importance of introducing methods and technologies for digitalization and automation was already recognized in the 1990s, initially within the framework of the Chair of Construction Informatics. With the development of ICT methods and applications, the importance of their use expanded to other areas within the AEC. Significant benefits were recognised in construction management, which led to the integration of digitalization content into the courses offered by the Chair of Construction Management, Technology and Economics. These topics have been gradually introduced over the last 10 years and are taught by competent teachers who keep up to date with the latest trends and research findings. Digitalization is integrated in most professional subjects and in all elective subjects of the 3rd doctoral level.

Since the 2015/16 academic year, the FGPA UM has been offering a BIM (Building Information Modeling) subject at 2nd level. This subject introduces the general concept of BIM, its role and technologies. Specifically for the area of construction management, methods and tools of digitization are used as a basis for construction processes in further courses at the Chair of Construction Management, Technology and Economics e.g. Project management in construction, which is carried out in final year master students with a background in civil and industrial engineering. In addition to BIM-based content, topics relating to Industry 4.0 methods and technologies have increasingly been covered in recent years. Therefore, in the past two years, the chair offers electives such as Computer modeling of construction objects in the 1st level of study as well as BIM approach in operational construction in the 2nd level. In addition, most of the chair's courses cover topics related to digitization and automation, for example in Safety at construction work, Spatial arrangement and advance planning, Maintenance and rehabilitation of structures and Rehabilitation of civil engineering structures. Figure 1 shows the scheme of courses and degrees related to BIM and Industry 4.0 at FGPA UM. All courses, with the exception of the general BIM course, which is a stand-alone course, benefit from the approach of implementing BIM into existing courses (Ghanem, 2022) and include basic and advanced BIM applications. Electives are labelled (e) and courses in the module are labelled (m).

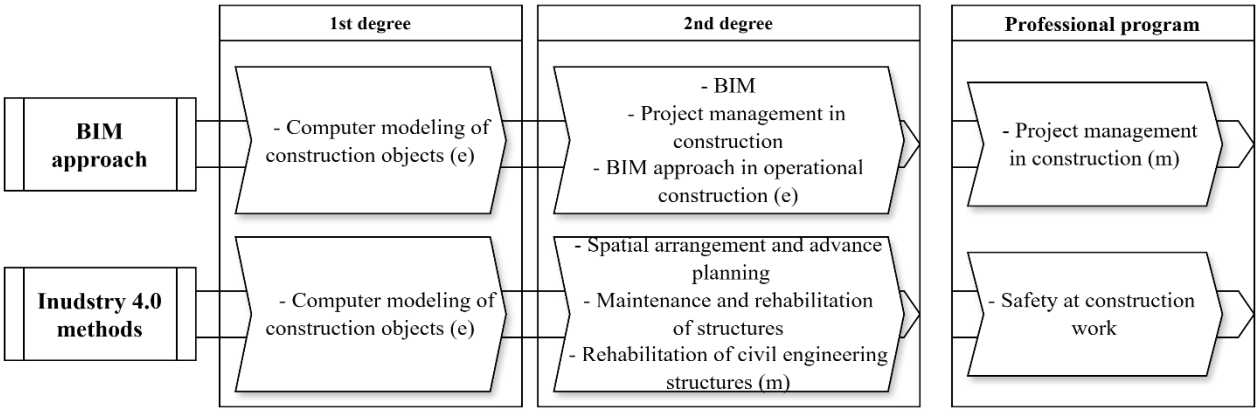


Figure 1: Scheme of courses and degrees with topics on BIM and Industry 4.0

Members of the chair also supervise student theses on digitalization topics. Through courses and theses, students acquire advanced digital skills, roughly divided into a) BIM-supported learning processes, b) learning processes with Industry 4.0 methods and technologies and c) theses on digitization in construction. The following sections present the FGPA's efforts to integrate BIM-based and Industry 4.0 topics into the curricula of the 1st and 2nd degree programs.

Integrating the BIM-based approach

The integration of the BIM-based approach into the study process has been underway at FGPA for many years. The first working example of BIM was introduced specifically for the management of construction projects in the 2015/16 academic year. These concepts were integrated into the subject Project management in construction in the 2nd degree program, which is offered jointly in two study programs: Civil Engineering and Industrial Engineering. This year, a 4D and 5D BIM model for a garage building in Skopje was created as a working example. In following years, the students expanded their knowledge by creating 4D and 5D BIM models for various building construction projects, including a school sports hall, a single-family house with associated infrastructure, a commercial office building, a two-family house, an apartment building, a single-family house with outdoor area and a high-bay warehouse. Since the 2019/20, this approach has also been used at the 1st degree professional study program Civil Engineering, subject of the Operational construction module.

Project work with students on the Project management in construction course follows a structured procedure: students first familiarize themselves with a basic 3D BIM model for a real object and learn about the importance of 3D model information and its application. They then extend the basic model to 4D (construction schedule) and 5D (construction costs) BIM models. Theoretical knowledge about higher BIM dimension levels, i.e. 4D, 5D and 6D BIM models, is taught in lectures. The project work itself is carried out through tutorials and computer-based tasks, with groups of up to three students working together. Selected software tools, including the modules of the Trimble Vico Office™ software ("Vico Office," n.d.), the local tool 4BUILD for cost estimation and MS Project ("Project Management Software | Microsoft Project," n.d.) for scheduling, are used to create 4D and 5D BIM models. A more detailed description and a diagram of the BIM creation process during the study at the FGPA of the University of Maribor can be found in the articles in (Pučko et al., 2019; Pučko and Šuman, 2024).

In the 2022/2023 academic year, the students created a highly detailed BIM model for a single-family house that encompasses both the 4D and 5D dimensions. The input data came from a conceptual design that was developed using Allplan BIM software. The original 3D BIM model was previously created and served as an input model for working with students. Figure 2 shows the 3D BIM model of the single-family house and illustrates the level of detail achieved in this comprehensive BIM model.

Figure 2: 3D BIM model of a single-family house

The Vico Office software was used to create the 4D and 5D BIM models, which does not allow direct import from the Allplan program. This led to particular challenges when using the basic 3D BIM model, which had to be converted via the IFC format. Despite these challenges, this was an additional learning opportunity for the students to effectively customize the 3D BIM model and familiarize themselves with the IFC format. For this reason, the subsequent detailed work focused exclusively on the basement of the building.

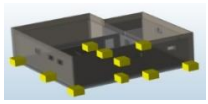
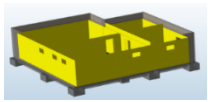
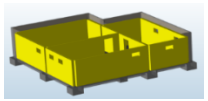
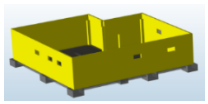
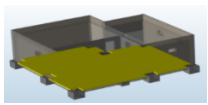
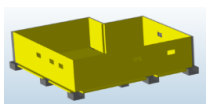
The creation of 4D and 5D BIM models was carried out in groups of two students each, so that a total of six groups were formed. Each group was assigned a specific set of building elements, which are listed in Table 1. First, the groups thoroughly analyzed the elements assigned to them, taking into account dimensions, material, technology, quantity, etc. They collected input data important for estimating unit costs and scheduling, including market prices for materials, equipment and machinery, as well as average wages and standards for labor.

A 5D BIM model was then created using the Cost Planner module. This software offers a significant advantage as it enables the direct and bidirectional linking of cost information with the 3D BIM model elements. This means that every change to the geometry of the 3D BIM model automatically updates the associated costs. The activities and their sequence were then defined as the basis for planning the construction work.

The software facilitates time analysis by creating a 4D BIM model in the Task Manager module. When analysing time, the elements of the 3D BIM model are directly linked to the activities in the schedule. This approach takes into account the links between the activities and the allocated resources and provides a comprehensive understanding of the time aspects of the project.

Table 1: Students group number, assigned project tasks and visualization of building elements

#	The topic of the project task	Visualization (set in Vico Office)

1	001 Reinforced concrete point foundations 010 Reinforced concrete stair foundation	
2	007 Drywall walls 017 Plastering of reinforced concrete basement walls	
3	008 Reinforced concrete basement walls	
4	009 Reinforced concrete columns-ties 015 Facade	
5	004 Reinforced concrete base plate	
6	003 Gravel filling 005 Waterproofing 006 Thermal insulation XPS 016 Facade waterproofing	

In December 2023, a final presentation of the groups' project work took place at the faculty. Each group presented the 4D and 5D BIMs they had created (Figure 3). At the end, the overall result for the execution of the basement was also presented to the students as a comprehensive 3D, 4D and 5D BIM model (Figure 4). A simulation of the construction process was also created by the course teacher. This representation of common 4D and 5D BIM models gives students an insight into the overall cost estimate and schedule.

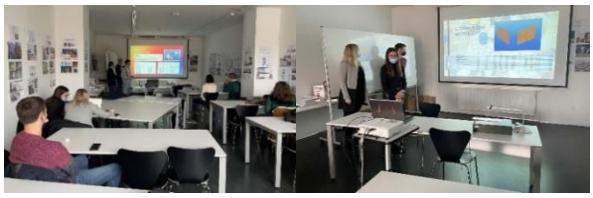


Figure 3: Final presentation of project work

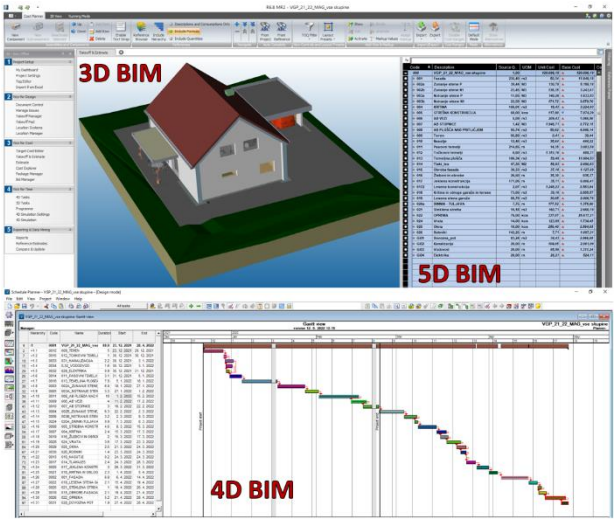


Figure 4: Comprehensive 3D, 4D and 5D BIM model

Integrating methods and technologies of Construction 4.0

Although there is no uniform definition for Construction 4.0, as can be seen from the literature review (Forcael et al., 2020; Jazzar et al., 2020; Perrier et al., 2020), it can be summarized that there is a consensus that the introduction of Construction 4.0 will not only change the construction process, but also the organizational and project structures, transforming the dispersed construction industry into an integrated industry. Individual disruptive technologies that are increasingly being used in the construction industry stand out. In recent years, students have become familiar with the theoretical starting points of Construction 4.0 and acquired individual knowledge and practical skills. For example, in numerous subjects, both in the 1st and 2nd levels of study, digital content is obtained using the technology of data acquisition of the environment using a 3D laser scanner. This technology is used in the following subjects Safety at construction work (1st degree), Spatial arrangement and advance planning (2nd degree), and Maintenance and rehabilitation of structures (2nd degree). The use of a 3D laser scanner is possible for a variety of purposes, such as capturing the as-built condition of the environment, ensuring site safety, determining work progress and creating a 4D as-built BIM model, etc. As part of the subjects listed, students are shown how to use a 3D laser scanner and the method of collecting point cloud data. Figure 5 shows the point cloud data acquired by the students for the selected site as part of the Spatial arrangement and advanced planning course on 2nd degree of study program Industrial Engineering.

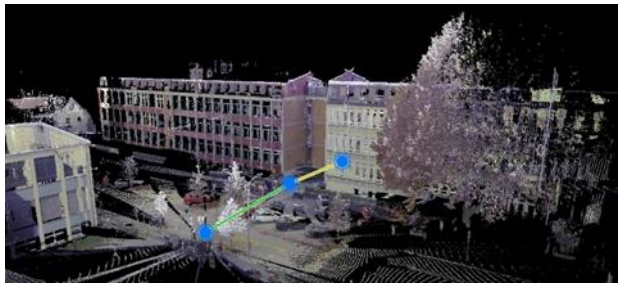


Figure 5: Acquired point cloud data by the students

Students also gain from the modern digital content of Industry 4.0 through advanced augmented reality technologies. With these methods, they acquire knowledge and skills to connect a real environment with digital elements that enable a 1:1 visualization of the built environment. This technology is still relatively new in the construction sector and therefore only a few applications can currently be demonstrated in practice. However, we believe that this technology has great potential and it is expected that further innovations will be developed in the coming years. Figure 6 shows an example of the use of advanced mixed reality in Spatial arrangement and advanced planning course on 2nd degree of study program Industrial Engineering in the 2022/23 academic year.

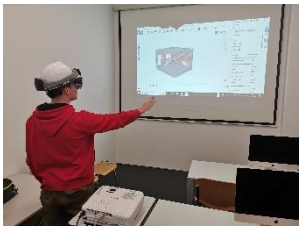


Figure 6: Use of advanced mixed reality during the study process

Nonformal acquisition of digital competences

Many other nonformal learning activities on the topic of digitalization and automation in the construction industry are also carried out at the FGPA. These activities include student participation in various professional events, conferences, trade fairs, excursions, and site visits.

In terms of student participation in various events such as conferences and trade fairs, we would like to highlight a 2-day professional excursion in 2018 with the participation of 50 students at the BIM WORLD Munich Congress (Figure 7-a) (Pučko et al., 2019). In 2023, a visit to the 33rd International Fair for Construction (MEGRA) in Slovenia was organized for students ("Megra 2023," n.d.), where the students took part in an event entitled An educational day in the Slovenian construction industry. Presentations of the latest digital technologies were held at the thematic lectures ("Chamber of Commerce and Industry of Slovenia," n.d.).

In addition, the students took part in an open day in May 2023 at the invitation of the Protim Ržišnik Perc design office. They were introduced to the latest software for working in the BIM environment, as used in the office's design practice (Figure 7-b) ("UM FGPA-b. 2023.," n.d.).

In 2023, various excursions were organised for students with visits to construction sites where the BIM approach was used for detailed design and during construction. We visited the following construction sites with the students, among others Second track Divača-Koper railway line (Figure 7-c) ("UM FGPA-c. 2023.," n.d.) and short visits to construction site Center Rotovž in Maribor (Figure 7-d) ("UM FGPA-d. 2023.," n.d.).

(a)

(b)

(c)

(d)

Figure 7: a) BIM WORLD Munich Congress, b) open day of the project bureau Protim, c) Construction site Second track Divača-Koper railway and d) Construction site Center Rotovž Maribor

All these activities help students to broaden their horizons and gain a closer insight into how modern techniques and methods are applied in the construction process.

Activities of lifelong learning at FGPA

Lifelong learning for working graduates on the topic of acquiring digital competences has been implemented at the FGPA since 2022. This involves running the Fundamentals of BIM course, which is offered under the auspices of the bSI Professional Certification Program ("buildingSMART Professional Certification," n.d.). After completing the course, participants can take an exam to obtain a certificate for basic BIM knowledge, the so-called buildingSMART Professional Certificate, which internationally certifies that professionals are highly qualified and recognisably trained in digital working methods. FGPA is designated as the official training center for the implementation of this program. Civil engineers, architects, electrical engineers and some students (civil engineering and architecture) have successfully completed the course so far.

From July 2022, a pilot project introducing advances digital technologies is also being implemented at the FGPA. The project is being implemented as part of the Recovery and Resilience Plan (RRP) ("University of Maribor, Pilotni projekti NOO - UM.si," n.d.). The University of Maribor is carrying out a total of 23 such pilot projects, which are intended to enable a green and resilient transition to Society 5.0. At the FGPA, the project is called Platforma 5.0 FGPA. The aim of the platform is to identify the knowledge and skills required to promote sustainable development and digitization in study programs over a period of three years. One of the aims of the project is also to create modules for lifelong learning for professionals who will acquire micro-certificates after completing the courses. At the same time, digital technologies for informatization of education will be recognized and implemented, including BIM-

based and Industry 4.0 content. Upon completion of the project, the study programs will be aligned with the needs of the economy and society, and students will acquire digital skills and competencies for the green transition and digitization in addition to the competencies dictated by the labor market.

Lessons learned

Each academic year, FGPA UM conducts a course evaluation survey to evaluate the teacher's grade point average and student workload. In the 2022/23 academic year, teachers grades for courses with a BIM approach and Industry 4.0 content were above average at 1.66 (grade range from -2.00 to +2.00). In general, no 1-year or 2-year deviations were identified in terms of student workload. The deviation was only found in the subject Computer modeling of construction objects (+-20%), where students felt that there were too many lectures and tutorials, but students had more independent work. The course was run for the first time this academic year and the results of the survey provide a good basis for the direction of the work in the future.

During several years of running courses on the integration of BIM and two years of implementing Industry 4.0 methods in existing courses, we have come to the following conclusions:

- Working with the BIM approach enables students to better understand the entire construction process, in particular the specific integration and upgrade of 4D BIM (time planning techniques) and 5D BIM (cost estimation approaches)
- The use of interdisciplinary teamwork helps students to develop their collaboration and problem-solving skills and increase student engagement to achieve better results.
- Teachers who actively implement project- and team-based learning together with their students generally ensure a higher quality of teaching.

Based on the knowledge gained, organizational and structural changes are planned:

- A new computer classroom should be set up for practical exercises, equipped with high-quality computers (for conducting BIM courses, modeling and simulation) and the necessary equipment for 3D printing, VR/AR/MR equipment and robots in the construction industry (Industry 4.0).
- As part of the renovation of study programs at the 1st level, a stand-alone BIM course should be introduced to teach the BIM concept and specific modeling skills. The course could replace the current CAD course or be offered as an elective.
- BIM software training should be offered to students and teachers, preferably in collaboration with local industry, to give students hands-on experience.
- Collaboration between teachers on BIM and Industry 4.0 courses should be encouraged and their education made possible.

Conclusions

Despite the rapid development of Industry 4.0 methods, the construction industry is lagging far behind other sectors in terms of digitalization and automation. Project management in the construction industry has changed significantly with the introduction of modern tools, which requires rapid adaptation of learning processes and the integration of BIM and Industry 4.0 into university curricula. This paper outlines the approach taken at the FGPA of the University of Maribor to teach formal and acquiring nonformal digital competences, with a focus on BIM and advanced technologies of Construction 4.0. The emphasis is on providing a comprehensive understanding of BIM principles, mastery of the software and practical application through project work. Nonformal learning, including conferences, trades, and site visits, plays a crucial role in students' education, especially in the context of the accelerating global digital transformation. The implementation of lifelong learning at FGPA through courses such as Fundamentals of BIM and the FGPA Platform 5.0 project ensures continuous education and professional buildingSMART certification for students and professionals alike.

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