T-SHAPED MODEL DESIGN FOR FURTHER EDUCATION IN BIM

Rainer Partl[1], Miya Sylvester[1], Franz Hengel[2] and Christian Heschl[1]
[1]University of Applied Sciences Burgenland, Pinkafeld, Austria
[2]AEE Institute for Sustainable Technologies, Gleisdorf, Austria

Abstract

The implementation rate of Building Information Modeling (BIM) in the construction industry remains low, especially in Small and Medium Enterprises (SMEs). Hence, many institutions offer BIM courses for further education focusing on civil engineering and architecture. However, professional on-the-job training for mechanical, electrical and plumbing (MEP) systems is rare. Therefore, a didactic concept is developed in the research project BIM4WARD based on the T-shaped model to train SMEs in simulation and BIM. The project aims to highlight the benefits and strategies of BIM applications in different project lifecycle phases by real use cases to establish knowledge transfer and digital skills.

Introduction

Integrating MEP systems is an essential factor for project success in complex buildings (Boktor et al., 2014) and ensure the thermal comfort quality in indoor environments (Larsen, 2011). Digitalization plays a central role in improving MEP installation productivity (Wu et al., 2022) and reducing energy consumption in residential and commercial buildings (IEA, 2017). BIM is a crucial technology that enables the digital transition in modern architecture, engineering, construction and operation (AECO). BIM adoption in the AECO is an essential factor in encouraging the digitalization process. (Casini, 2022)

Moreover, the BIM adoption rate depends on the company size. For instance, mainly large companies with more than 250 employees have more capacities for BIM implementation (Vidalakis et al., 2019) and generate benefits from using BIM very fast (Charef et al., 2019). In Europe, a rate of lower than 1% corresponds to large companies, which perform 21% of the economic value creation in the construction industry. On the other hand, most companies are composed of micro, small and medium-sized enterprises. More than 90% of SMEs have less than ten employees and provide 39% of economic value creation. (Casini, 2022) Vidalakis et al. (2019) pointed out that in the United Kingdom, the BIM adoption of SMEs is slow going forward in small steps though many SMEs are interested in digitalization and have a basic understanding of BIM-related concepts. This observation is similar to the findings of the recent report by the European Construction Sector Observatory for Austria (ECSO, 2021). The BIM adoption rate remains low. Only 20% of the SMEs in Austria are working with BIM.

However, there is a growing gap in BIM adoption between large companies and SMEs in Europe, leading to heterogenous maturity in the construction sector. Consequently, for BIM late-comers, the digital collaboration between Stakeholders will become challenging and affect the competitive power for cross-border projects. Furthermore, it has an impact on the economy of the European Union construction market. (Charef et al., 219) The most critical factors for BIM adoption are the high costs and the lack of personnel training skills for digital competence (Charef et al., 2019; Vidalakis et al., 2019; Tagliabue & Yitmen, 2022) Sategna et al. (2019) outlined that SMEs have a great potential to close the gap quickly by ad-hoc training, because they are flexible in changing their strategies in using digital technologies.

Many BIM courses are offered in the area of architecture, construction engineering and management at universities (Chihib et al., 2019) and tertiary education (Chegu Badrinath et al., 2016). The analysis of BIM training courses in Austria for further education reveals that on the job trainings for MEP engineering is rarely provided. Consequently, there is a need of implementation strategies for demonstrating the benefits of BIM in combination with digital technologies, especially for SMEs in the field of MEP. These findings are carried out in the research project BIM4WARD.

For this purpose, a concept for BIM training in further education is developed to provide SMEs in the MEP domain with digital technologies based on BIM. This paper presents the current status of SMEs in BIM4WARD and the design of the training concept based on the T-shaped model. Moreover, the content of the individual courses and the didactic concept are described. Finally, the presented approach and the results are interpreted in the discussion.

BIM status of SMEs

Overall, 12 institutions are members of the research project BIM4WARD. The University of Applied Sciences Burgenland and AEE Institute for Sustainable Technologies represent the academic institutions. The other ten project members are companies in the construction industry. Figure 1 shows the constitution of the companies and their sphere of practice. The predominant part of the enterprises is the MEP design and installation field, with five involved companies. Also, the next large group includes three consultants in building physics and energy consulting. One stakeholder in architecture and a client is vital for dealing with interdisciplinary issues in BIM. All the companies representing SMEs, 60% of which are small companies with less than 50 employees. The remaining 40% have less than 250 employees and correspond to medium-sized companies. An allocation of 20 people from each company is planned for the training modules.

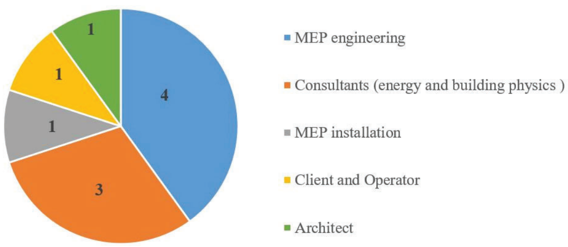

Figure 1: Constitution of the participating companies

All of the involved companies have a vested interest in BIM. Most of them are already using BIM, while others have planned to implement BIM in their enterprise in the near future. At the beginning of the project, a small survey questionnaire was prepared to outline the level of digital maturity and actual BIM usage at the company level. One question was presented to evaluate how the companies employ BIM practices. Furthermore, the application of further dimensions in BIM (4D, 5D), advanced technologies (e.g. reality capturing) and BIM-based energy simulation was part of the query. The results are shown in Figure 2. It shows that most SMEs use BIM in planning for dimensioning MEP systems and 3D modelling. Some of them use BIM for energy simulation and bidding and contract award from time to time. Only one company uses advanced technologies like laser scanning in practice. None of the companies is dealing with 4D BIM and hardly 5D BIM.

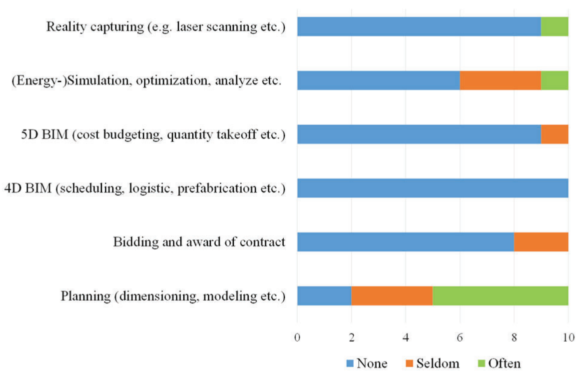

Figure 2: BIM applications and digital technologies used in practice

Another question was asking for their current software use. This question is important for academic institutions for developing BIM-based workflows and data transfer for use cases. In Figure 3 the results of this question are illustrated. A large number of 70% of the SMEs use software of Trimble (Nova), and nearly half of the companies use Autodesk (Revit). An interesting outcome of this survey is, that all companies in the MEP domain are using Trimble. Furthermore, two of the three consultants use this software tool. Another essential is that three of the five MEP companies also have Trimble Nova and Autodesk Revit. For 3D modelling, the consultants use different software tools like BricsCAD BIM or SketchUp. Most of the consultants use IDA ICE for energy simulation and one of the MEP planers. The Client and Operator utilize ArchiCAD software to collaborate on BIM projects.

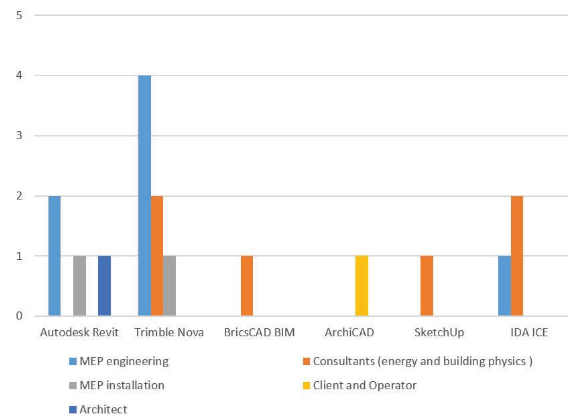

Figure 3: BIM Software usage in companies

In conclusion, the results show that the potential of a higher dimension of BIM and advanced technologies is currently not fully exploited. For that reason, it is important for the design of the educational concept to point out the benefits of advanced digital technologies and to create strategies for practical implementation.

BIM Education with T-shaped model

Finding an adequate mix of theory and practice for BIM teaching and learning is challenging in BIM education. (Puolitaival & Forsythe, 2016) Furthermore, it is an opportunity for innovation in education and a promising approach to restructuring traditional education models. (Saviano et al., 2016) For example, Martek et al. (2022) established a concept for education called the T-shaped BIM professionals. Many researchers in various domain disciplines refer to the T-shaped model for improving and attracting educational programs. Pedagogical approaches to BIM teaching and learning based on the T-shaped model in education are described in these publications.

The T-shaped model concept for BIM education is shown in Figure 4. It is inspired by the studies of Saviano et al. (2016) and Martek et al. (2022) and considers the typical characteristics of horizontal and vertical education pedagogy of the T-shaped form. The basic principle of choosing the T-shaped model is to follow an established standard in education. In this case, the Bloom Taxonomy fundamentals are integral to the T-shaped model. Another important aspect is to consider open BIM and buildingSMART standards for BIM certification (e.g. BIMcert foundation) and supporting information delivery methods like Use Case Management (UCM). In the following, the design of the T-shaped model for further education in BIM and MEP engineering is explained.

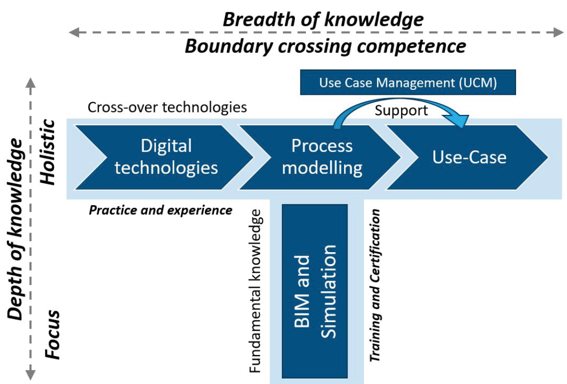

Figure 4: Concept of a T-shaped model for BIM and MEP

The vertical bar represents the depth of knowledge. Fundamental basics include BIM and Simulation topics related to MEP. Simulation methods are important for decision support throughout MEP systems in entire lifecycle. The focus is primary on energy simulation in combination with BIM models. Different workflows with the software tool IDA ICE, based on the import of Industry Foundation Classes (IFC), are exercised to optimize the energy performance on a digital prototype.

Furthermore, the simulation methodology is relevant for digital technologies e.g. MEP installation with 4D BIM or predictive maintenance in facility management. The BIM basics content refers to the curriculum of the international buildingSMART professional program according to the foundation level. Typical scope of the BIM basics are e.g. open data formats, BIM processes, terms and definitions etc. After course completion, the participants can take an exam for Professional Certification at the foundation level.

The horizontal bar represents the breadth of knowledge and comprises the acquired knowledge in BIM and simulation. An educational objective of the horizontal bar is to create and demonstrate the benefits of using digital technologies across different domains. Therefore, implementation strategies are developed and utilized with hands-on training in practical use cases. For this purpose, the horizontal bar is divided into three elements and comes up with a three steps approach that follows a sequential order. First, it starts with introducing digital technology, e.g. Laser scanning. The second step, process models are used to describe requirements and implementation workflows. For example, what are the requirements for using Laser scanning in terms of application possibilities, measurement accuracy, commercial software tools and platforms supporting the registration process etc. For referring to an established standard in BIM, the graphical language Business Process Model and Notation (BPMN) is used for describing these processes. The companies can use the process model as a workflow management guideline or compare their actual workflow. In the last step, the digital technology is tested on real use cases. Participants have the opportunity to come up with practical use cases for demonstration. For instance, if there is a need for reality capturing in an ongoing project, they can bring it into the project. The UCM methodology is a supporting instrument to transfer the developed process model into an actual application. Two use cases in this project are provided to the international UCM service platform to show best practice applications and make them accessible for other SMEs in this field. This final step enables the participants to reflect on their experiences as lessons learned and to evaluate if the introduced digital technology is relevant to their field of application.

This explained design of the T-shaped model is a generic approach for teaching skills in BIM and simulation. It is also transferable to other domain disciplines in construction. For instance, the vertical bar in structural engineering can include BIM and stress calculation by using computer modelling simulation methods. In the horizontal bar, camera drones with computer vision capability can be considered as digital technology. Furthermore, process models and UCM can support the use case of detecting cracks in concrete.

Modules and didactic utilization

Overview of the training modules and description

Based on the T-shaped model, ten training modules are developed for teaching SMEs in the BIM4WARD project. At the beginning of the project, each company was asked about their knowledge demands. This survey ensures that the needs of the involved SMEs are considered when developing the content of the modules. Furthermore, the content addresses specific and interesting topics in the entire lifecycle corresponding to the planning, construction and operating phase of buildings. The training modules deal with digital basics and advanced-level technologies. Digital basics focus on methods and technologies, which are widely used and established in practice. Advanced level technologies regarding promising technologies already offered, but due to their investing costs and complexity hardly used in the construction field.

According to the three primary project lifecycle phases in construction, the training schedule is divided into three semesters. Figure 5 illustrates an overview of the training modules in each semester and the module title. The academic institutions are preparing the content for the modules and act as training providers in this project. The workload and responsibilities between the academic institutions are shared and colour-coded marked for each module, as shown in Figure 5.

Another essential point is the integration of gamification strategies as an instrument in education. With gamification, a positive impact on motivation and learning outcomes is expected for the trained participants. Three modules consider playful learning approaches such as mini challenges or solution optimization.

After each semester, the participants experience is evaluated, and the expectation for the upcoming semester is documented. The evaluation process results are considered in the education plan, and the feedback will help to do revisions. In the following, the main aspects of each module are described.

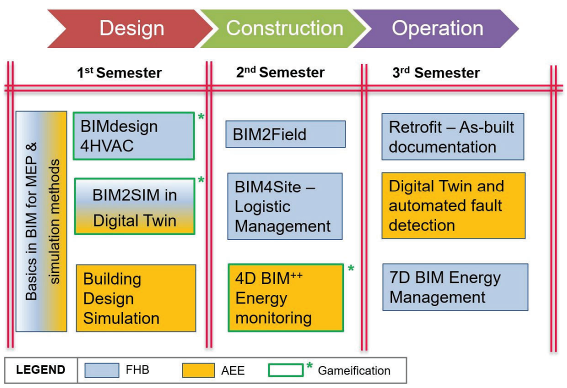

Figure 5: Overview of the training modules and module title

Most of the modules take part in the first semester, focus on topics related to the design phase. In the beginning, digital basics in BIM and simulation methods are taught, referring to the vertical bar of the T-shaped model. As a consequence, this is a compulsory module for all training participants. All the other modules outline advanced-level technologies and refer to the horizontal bar of the T-shaped model. In BIMdesign4HVAC the potential of parametric design approaches for optimizing the heating, ventilation and air conditioning systems (HVAC) are demonstrated. Energy performance simulations are realized in BIM2SIM with the software tool IDA ICE, based on open BIM workflows by using the IFC data format for data exchange. Furthermore, accurate energy monitoring data are taken for verification. This approach is regarding the distinct parts of a digital twin, where virtual models (e.g. BIM model) and physical objects (e.g. monitoring data) are connected. The subject matter of Building Design Simulation is BIM-based energy simulation in early design phases for decision support.

The central theme of the next semester is the realization and installation of MEP equipment. In order to improve the productivity of MEP installation in the field, the potential and benefits of the Internet of Things (IoT) technologies in combination with BIM are explained. For that reason, the module BIM2field addresses topics like modular prefabrication, lean to BIM approaches, scheduling of MEP installation (4D BIM) and real-time communication based on open BIM, e.g. Building Collaboration Format (BCF). Coordination and logistic management are a central part of BIM4Site. Various opportunities for progress monitoring with BIM and IoT devices are investigated, e.g. tracking and tracing based on Radio-Frequency Identification (RFID) sensors. Comparing Key Performance Indicators (KPI) from the BIM planning (e.g. building passports, heat and cooling load calculations etc.) with actual energy monitoring data is a central part of the module 4D BIM^{++} Energy monitoring. Therefore, linked data methods are tested in real use cases to merge KPIs from the heterogenous data source and get feedback of the current energy performance.

The last semester focuses on building operation and maintenance, representing the longest period in the project lifecycle of a building. Digitalizing facility management (FM) based on BIM and simulation enables resource efficiency in material use and energy consumption. Retrofit – As-built documentation – overviews reality-capturing methods with laser scanning to support the as-built documentation process in FM. Different scan-to-BIM technologies are tested in the field to capture information of MEP systems for FM application, e.g. location of MEP components. Real-time data transfer for automated fault detection and predictive maintenance based on the digital twin approach is a subject matter of the corresponding module title. In 7D BIM energy management, workflows for BIM-based energy management are developed with the training participants. The objective of this module is to link BIM models with tools for energy analysis.

Didactical concept by considering learning types

The constitution of the training participants in this project is heterogeneous. SMEs work in different domains (e.g. architecture, building physics, MEP) and act in different project lifecycle phases, e.g. planning, installation and maintenance. Furthermore, they serve in diverse roles in a construction project like, an investor, project leader, consultant, operator etc. Another important aspect is diversity related to age, practical experience, education and knowledge background in BIM and simulation. To deal with this initial situation, we refer to Kolb, A.D. (1981) for the didactical concept. He identified four basic learning styles in his publication and developed a four-stage learning model to consider individual learning characteristics. Figure 6 shows the learning model of the four learning style types according to Kolb, A.D. (1984).

Subsequently, it describes how the introduced design of the T-shaped model supports and ensures a positive impact on all the different learning styles.

The learning process starts with a virtual BIM model as an abstract concept of a building and its MEP systems. The BIM model provides the information for further applications in real use cases to realize active experimentation, e.g. case studies for energy simulation. It is the training participants task to find optimal conditions and limits. These activities should engage the converging learning type for solving problems and actively experimenting. Integrating digital technologies for IoT, laser scanning, fault detection etc., and testing it in practical use cases supports the concrete experience. These are practices which are preferred by the accommodator learning type.

For reflecting and observing results of simulations or discuss the usage of advanced technologies, workshops, and discussions are essential to all modules. Especially, the diverger learning type will derive benefits of that kind of teaching setting. Furthermore, the integration of extended reality applications will help this learning type to get a real feeling of using such technologies. The last-mentioned learning type, assimilator, will draw advantages of using process modeling to create guidelines and theories for using advanced technologies in his domain area.

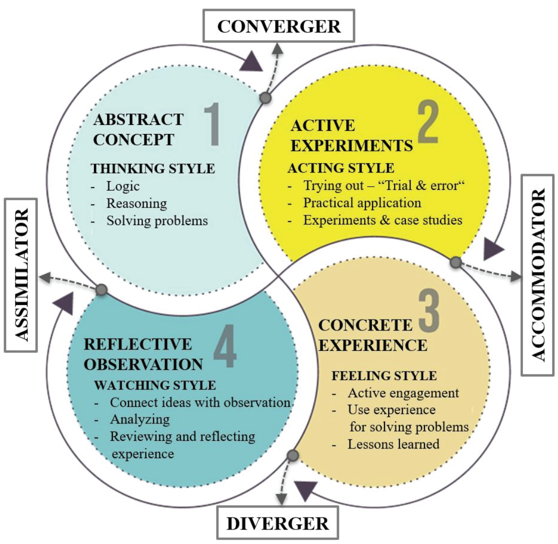

Figure 6: Characteristics of the four basic learning types

BIM plays a central role in the didactical concept in teaching and learning. The digital education environment is built on the principles of the BIM methodology. BIM4WARD is not training a special software tool for BIM. A required level of software knowledge can be assumed because the survey's results, in the beginning, showed that all participants use BIM tools. The main contribution of BIM4WARD is the SMEs training to establish BIM skills to improve digital competence. However, knowledge transfer is realized with lectures to give theoretical inputs. Also, interdisciplinary teamwork for exercising small project work corresponds to handling BIM projects and improves skills like information coordination and collaboration. Considering the SMEs job-related working load and limited time resources, some modules are exercised with blended-learning or hybrid-learning approaches to have more flexibility. Moreover, to make access to each module's content easier for the qualified participants.

A short description of the content gives the trainees a guideline for what they should prepare. Also, organizational aspects can be considered, like media for communication or relevant materials for teaching. Another advantage is that the companies get a preview of what to expect, and learning targets are the basics for the evaluation process. Furthermore, learning targets are defined for each training module to support the planning process for the academic institutions.

Discussion and future work

The survey results of BIM in practice showed that the involved SMEs want to use BIM in the near future or use BIM mainly for dimensioning and modelling. Hence, there is a basic understanding of working with BIM software tools and the predominant software used in BIM of MEP is Trimble Nova. This finding contrasts Boktor et al. (2014), who established that mainly Autodesk products, e.g. Revit MEP, dominate the market in the MEP sector. Hence, there is a big difference in software used in the MEP sector for BIM between European countries like Austria and North America, as mentioned in Boktor et al. (2014). An interesting finding of the survey is that most MEP companies have more than one software for BIM modelling. This factor suggests that these companies are prepared for various opportunities to handle BIM projects with different data formats. In the same way, investment cost for software infrastructure is rising, and employees are struggling with heterogenous software skills.

The low rate of utilizing advanced digital technologies or higher dimensions of BIM in the companies indicates the need to develop training concepts for further education to demonstrate benefits on practical use cases and create implementation strategies to support SMEs. This finding is similar to Vidalakis et al. (2019) and Wu et al. (2022), who especially distinguished productivity improvement with BIM in MEP. Therefore, the design of BIM education with a T-shaped model was presented to outline new approaches for attracting teaching and learning concepts in further education. The T-shaped model in this training concept for SMEs was chosen to gain interdisciplinary skills of BIM and simulation for stakeholders working in different engineering disciplines. Moreover, the individual training modules deal with interdisciplinary topics and the T-shaped model approach supports the achievement of the learning objectives due to previous findings in Van den Beemt et al. (2020) and Oskam (2009). Another reason is that the industry needs employees with T-shaped competence to have a broad understanding of different technologies (Conley et al., 2017). Furthermore, using the T-shaped model approach for BIM teaching confirms to previous papers (Turk & Istenič Starčič 2020; Martek et al., 2022). Alternative approaches of pedagogical concepts for BIM in higher education are Integrated Design and Delivery Solution (IDDS), the Technological Pedagogical Content Knowledge (TPACK) and Trinity of BIM (BIM3P) that are described in Hjelseth (2017).

However, BIM education is a well-documented topic as described in the BIM handbook (Sacks et al., 2018) or in the literature review paper of Chegu Badrinath et al.

(2016). Several studies, for instance Sacks & Pikas (2013) and Guo et al. (2022), analyzed the gap between BIM education and the industry requirements in practice and therefore, they suggested conceptual frameworks for BIM education. One of the gaps between universities and practice is the area of BIM processes related to information requirements exchange and to specify the level of details. (Sacks & Pikas, 2013) In BIM practice it is crucial to understand the processes and workflows (Sacks & Pikas, 2013; Hjelseth, 2017; Guo et al., 2022). A central part of the T-shaped model design in this work is the process modelling element in the horizontal bar to develop process maps for describing information flows between different stakeholders and defining requirements of using digital technologies in real use cases. Therefore, we use established standards in BIM like BPMN and UCM so that the involved participants become familiar with these process modelling techniques and may apply it in practice. Another gap is the difference of expectations between the taught BIM competencies and the requirements of the practitioners. (Sacks & Pikas, 2013; Guo et al., 2022) To close this gap, evaluation workshops are held at the end of each semester to get feedback of the participants and to make a workshop with them to describe their needs and expectations related to the modules of the next semester. With this proactive approach, the participants have the opportunity to bring their ideas and requirements into the teaching content of each module.

The research project BIM4WARD is an opportunity for academic institutions to test and evaluate this training concept before transferring it into the curriculum. On the other hand, the involved SMEs can improve their digital maturity level and analyze digital technologies in an educational environment. Moreover, the presented BIM education concept is a chance to promote MEP in BIM and international education standards.

In the next step, the T-shaped model and didactical concept is proved and tested in the first semester. A challenging task will be the digital competence evaluation of the participants. Therefore, we pay attention to various evaluation tools for analyzing the maturity level and benefits of BIM, which are reported in Kassem et al. (2020) and other approaches like the Unitec framework for professional knowledge evaluation mentioned in Puolitaival & Forsythe (2016).

Conclusion

This paper presented a BIM training concept for further education focusing on MEP and simulation methods. An insight into the current status of BIM usage and the level of digital maturity of SMEs in Austria was provided. The result outlined that SMEs in the MEP sector primarily work with Trimble Nova, and most SMEs have more than one BIM software tool. Moreover, this paper explained the design of the T-shaped model as a generic approach. The vertical bar deals with teaching skills in BIM and simulation. The teaching of BIM skills is the base for other digital technologies. Built on this basement, the horizontal bar part shows implementation strategies and benefits of digital technologies in practical use cases. The design considers open BIM standards and enables project participants' certification in the buildingSMART professional program. The teaching modules focus on promising advanced technologies in the construction industry throughout the entire project lifecycle.

Furthermore, gamification elements are integral to the didactical concept to increase learning outcomes and motivation. All these aspects should support and ensure a positive impact on all the different learning styles. However, providing attractive education concepts for further education is a critical factor for bridging the gap in the BIM adoption rate in the SME sector and improving digital competence.

Acknowledgements

The authors would like to thank the participating companies in the BIM4WARD project for answering the questionnaire and giving insight into their working practice with BIM. This work is carried out within the BIM4WARD project (FFG Grant No. FO999893653) funded in the program "Innovationscamps M", which is managed by the Austrian Research Promotion Agency (FFG) together with the Federal Ministry for Climate Action, Environment, Energy, Mobility, Innovation and Technology (BMK) and the Federal Ministry for Labour and Economy (BMAW).

References

Angel, L. W. (2011) HVAC Design Sourcebook. McGraw Hill.

Boktor, J., Hanna, A. & Menassa, C. C. (2014) State of practice of building information modeling in the mechanical construction industry. Journal of Management in Engineering, 30(1), pp.78-85.

Casini, M. (2022) Construction 4.0 advanced technology, tools and materials for the digital transformation of the construction industry. Duxfoird, Woodhead Publishing.

Charef, R., Emmitt, S., Alaka, H. & Fouchal, F. (2019) Building Information Modelling adoption in the European Union: An overview. Journal of Building Engineering, 25, p.100777.

Chegu Badrinath, A., Chang, Y. T. & Hsieh, S. H. (2016) A review of tertiary BIM education for advanced engineering communication with visualization. Visualization in Engineering, 4(1), pp.1-17.

Chihib, M., Salmerón-Manzano, E., Novas, N. & Manzano-Agugliaro, F. (2019) Bibliometric maps of BIM and BIM in universities: A comparative analysis. Sustainability, 11(16), 4398.

Conley, S. N., Foley, R. W., Gorman, M. E., Denham, J., & Coleman, K. (2017) Acquisition of T-shaped expertise: an exploratory study. Social Epistemology, 31(2), pp.165-183.

Guo, B. H., Gonzalez, V. A., Puolitaival, T., Enegbuma, W., & Zou, Y. (2022) Bridging the gap between building information modelling education and practice: a competency-based education perspective. International Journal of Construction Management, pp.1-12.

Hjelseth, E. (2017) Building Information Modeling (BIM) in higher education based on pedagogical concepts and standardised methods. International Journal of 3-D Information Modeling (IJ3DIM), 6(1), pp.35-50.

ECSO (2021) European Construction Sector Observatory, Country profile Austria

IEA (2017) Digitalisation and Energy. Technology report. International Energy Agency. Paris

Kassem, M., Li, J., Kumar, B., Malleson, A., Gibbs, D. J., Kelly, G., & Watson, R. (2020) Building information modelling: evaluating tools for maturity and benefits measurement. Centre for Digital Built Britain: London, UK, 184.

Kolb, D.A. (1981) Learning styles and disciplinary differences. In: A. W. Chickering, The Modern American College, San Francisco, Jossey-Bass, pp.232-255.

Martek, I., Wu, W., Oraee, M. & Hosseini, M.R. (2022) Educating the 'T-'shaped' BIM professional: Lessons from academia. In: M.R. Hosseini, F. Khosrowshahi, A.A. Aibinu and S. Abrishami, eds., BIM Teaching and Learning Handbook Implementation for Students and Educators. New York, Routledge, pp.247–261.

Oskam, I. F. (2009) T-shaped engineers for interdisciplinary innovation: an attractive perspective for young people as well as a must for innovative organisations. In: 37th Annual Conference–Attracting students in Engineering, Rotterdam, The Netherlands, Vol. 14, pp.1-10.

Puolitaival, T. & Forsythe, P. (2016) Practical challenges of BIM education. Structural Survey, 34(4/5), pp.351–366.

Sacks, R. & Pikas, E. (2013) Building information modeling education for construction engineering and management. I: Industry requirements, state of the art, and gap analysis. Journal of Construction Engineering and Management, 139(11), 04013016.

Sacks, R., Eastman, C., Lee, G. & Teicholz, P. (2018) BIM handbook: a guide to building information modeling for owners, designers, engineers, contractors, and facility managers. Hoboken, New Jersey, John Wiley & Sons.

Sategna, L. G., Meinero, D. & Volontà, M. (2019) Digitalising the Construction Sector, Unlocking the potential of data with a value chain approach. Committee for European Construction Equipment.

Saviano, M., Polese, F., Caputo, F. & Walletzký, L. (2016) A T-shaped model for rethinking higher education programs. In: Proceedings of 19th Toulon-Verona Conference "Excellence in Services", University of Huelva, Spain, pp.425–440.

Tagliabue, L.C. & Yitmen, I. (2022) Special Issue Cognitive Buildings. Applied Sciences, 12, 2460Vidalakis, C., Abanda, F. H., & Oti, A. H. (2019) BIM adoption and implementation: focusing on SMEs. Construction Innovation, 20, pp.128-147.

Turk, Ž., & Istenič Starčič, A. (2020) Toward deep impacts of BIM on education. Frontiers of Engineering Management, 7(1), pp.81-88.

Van den Beemt, A., MacLeod, M., Van der Veen, J., Van de Ven, A., Van Baalen, S., Klaassen, R., & Boon, M. (2020) Interdisciplinary engineering education: A review of vision, teaching, and support. Journal of engineering education, 109(3), pp.508-555.

Wu, Q., Chen, L., Shi, P., Wang, W. & Xu, S. (2022) Identifying Impact Factors of MEP Installation Productivity: An Empirical Study. Buildings, 12, 565.