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TEACHING BIM:
A COMPARISON BETWEEN ACTUAL AND FUTURE PERSPECTIVES

Caterina Morganti[1], Ugo Maria Coraglia[1], Marco Alvise Bragadin[1], Dominique Rissolo[2], Emlyn Witt[3] and Kalle Kähkönen[4]
[1]Alma Mater Studiorum University of Bologna, Bologna, ITALY
[2]Cultural Heritage Engineering Initiative Qualcomm Institute, University of California, San Diego, CA, USA
[3]Department of Civil Engineering and Architecture, Tallinn University of Technology, Tallinn, ESTONIA
[4]Laboratory of Civil Engineering, Tampere University of Technology, Tampere, FINLAND
caterina.morganti4@unibo.it

Abstract

Building Information Modeling BIM in AEC education is a promising teaching strategy. The aim of the European project BENEDICT is to analyze teaching approaches to Building Information Modeling (BIM) for the construction industry. The goal of this research is therefore to perform an exhaustive analysis on the methods of transmission of BIM awareness and education in some American universities with the aim of comparing them with the BENEDICT approach developed in Italian, Estonian and Finnish Universities. Therefore, a teaching plan that aims to standardize and unify relevant teaching programs, tools and methods is developed, tackling existing skill gaps and mismatches between academia and industry.

Introduction

The concept and use of Building Information Modeling (BIM) is currently a popular design and control tool used extensively in the construction industry, in Italy, in Finland, in Estonia, in USA, and worldwide. BIM is a holistic process of creating and managing information for construction. It is a set of technologies, processes and policies that enables multiple stakeholders to collaboratively design, construct and operate a Facility in virtual space (ISO 19650-part).

Existing BIM tools make it possible to develop building and infrastructure designs, plan construction work and support building management activity, digitally, centrally, and collaboratively (Becerik-Gerber et al., 2012).

The power of BIM tools to create parametric models with information regarding not only geometry and spatial relationships, but also the properties of applied materials, geographic data, cost estimating, documentation classification, and certificates, makes the use of BIM the key tool for exploring innovative work procedures. In the construction industry, BIM has helped to decrease design errors and discrepancies between the design and the built construction, thus reducing errors in cost estimates (Arashpour et al., 2017).

Although Finland was the first country to systematically introduce the use of Building Information Modeling, the first country to develop the tools for its implementation was the United States. Actually, understanding the U.S. experience in the field can give us some important insights concerning BIM oriented teaching implementation and consequently figure out how to best structure a BIM enabled learning platform (BLE).

To support an integrated design workflow, it is certainly necessary to have common working standards, such as the open Industry Foundation Class (IFC) standard, to overcome software interoperability problems (Plume et al., 2007). Over time, the construction industry has experienced quickly evolving technology, supported by continuous advances, improvements, and enhancements (Abdirad et al., 2016).

A key aspect, the main subject of the study under analysis, is that related to training future professionals within academia. BIM training programs, found in undergraduate courses in architecture and construction and civil engineering, play an important role in educational institutions (figure 1) (Shen et al., 2012), because they prepare a new generation of graduate professionals that are ready to work in the construction industry with a new ability to manage collaborative and interdisciplinary software.

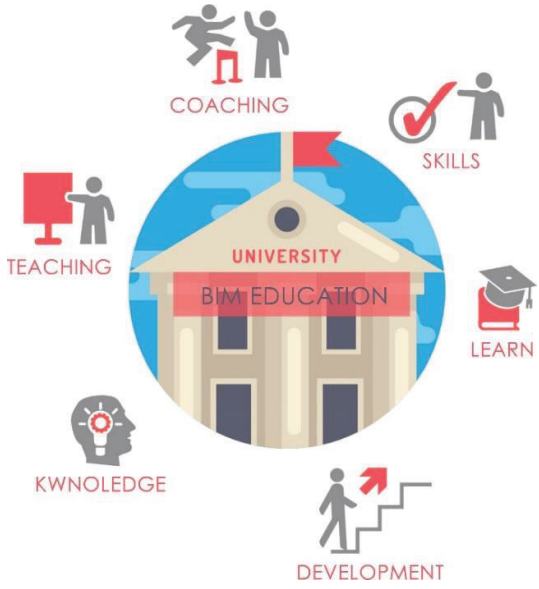

Figure 1: University and BIM Education

The research focused on the topic of BIM teaching in the university. The research aimed to analyze different courses related to the teaching of BIM in order to prepare useful materials for BIM education that can be uploaded to an open-access platform, created within the "BENEDICT" project. Therefore, the research questions under the present research work is “How BIM is being taught in the U.S., and how this experience can be used in the Benedict project?”

The BIM-enabled Learning Environment for Digital Construction (BENEDICT) project aims to capitalize on the emerging possibilities of BIM to improve the education of REC professionals by developing an innovative, BIM-enabled learning environment that offers more realistic, engaging, and integrated learning experiences.

The project will result in the development of the BLE as an open online learning platform with initial learning resources and demonstration materials. In the long term, BLE is seen as a tool that can be used to improve education, training, and continuous professional development of personnel throughout the REC value chain in the European Union and in other countries.

Methodology and research development

Literature review

For the development of the research, a literature review of texts in the field of academic education on BIM was initially conducted. Papers with keywords such as "BIM education", "BIM curriculum", "BIM course", and "visualization in engineering education" in publications from 2012 to the present day were analyzed.

The analysis was used to organize qualitative data related to BIM into similar groups of conceptual categories in order to analyze trends in current academic research on BIM education (Berwald, 2008). The study reviewed and analyzed 60 publications related to BIM education from 2012 to the present from authors in 20 countries, by searching the keywords in different web platforms (google scholar, science direct and scopus).

The seminal work of Dossick et al. indicated a variety of BIM specific content and general topics, an appropriate level of course work related to each topic and the type of education needed (Dossick et al., 2014). The literature review process on global trends in BIM education research led to the identification of six conceptual categories:

- identifying BIM needs in tertiary educational institutions;
- identify essential BIM skills for BIM education;
- develop BIM educational frameworks;
- develop BIM curricula;
- experiment with BIM courses;
- develop strategies to overcome BIM educational problems.

These categories show that researchers and educators in the BIM field have addressed related questions on:

a. "why" we need BIM education;
b. "what" to teach in academic BIM education;
c. "how" to develop academic BIM education on the different levels.

U.S. BIM-related courses

In the United States, there are several undergraduate programs with BIM-related courses at many different levels, the main ones include "Civil Engineering", "Architecture", "Architectural Engineering", "Construction Engineering", and "Construction Management". Almost 120 universities in the United States are fully accredited to provide degree programs that offer BIM courses as part of the curriculum, the following table shows some examples (courses updated to the academic year 2022/2023) (figure 2). With the exception of the Georgia Institute of Technology, which has been conducting research on BIM since the early 1990s, most U.S. universities have been introducing BIM since the 2000s (Sabongi, 2009). In 2003, BIM was introduced into undergraduate and graduate programs at the University of Minnesota and at California State University, where specific BIM courses have been taught since 2004. The University of Nevada began introducing BIM in 2005, while the University of Pennsylvania first introduced the Integrated Design Studio using BIM in 2006 (Shenton et al., 2014). In the same year, the University of Utah began a process of remodeling its curriculum by including teachings on BIM. Since 2006, other schools have begun offering BIM-specific courses, such as the New Jersey Institute of Technology and Brigham Young University.

In 2007, Auburn University began an experimental study on teaching BIM. At the same time, at the University of Wyoming, students in engineering courses collaboratively developed a complex project using BIM tools.

Since 2010, many other universities have started integrating their course disciplines with BIM and experimenting with distance learning.

To date, universities such as the University of Pennsylvania, the Georgia Institute of Technology, the University of Southern California, Montana State University, the University of Wyoming, and the University of California system are identified as leaders in BIM education. Through a literature review and an analysis of the web pages of the different universities, it was possible to identify almost 120 universities having the presence of BIM-related courses in their curricula. Two of the authors of the research work under this paper were involved into BIM - related research and teaching activities at the University of California, San Diego, (UCSD) therefore this case of UCSD has been focused.

In the specific case of the UCSD, within the Jacobs School of Engineering in the undergraduate course in Structural Engineering there is a mandatory course *SE Graphical Communication for Engineering Design*, this course is mandatory for students and involves teaching computer graphics (CAD software) the creation of 2D and 3D models and BIM design is introduced.

There are also optional supplementary courses at the University of California, San Diego called "Extension courses", specifically the educational proposal at UCSD includes three:

- Revit I: Introduction. This course involves the student starting a project, editing elements, and presenting models. By the end of this Revit training course, students will have built a BIM project from the scratch and will present multiple views of the model.
- Revit II: Intermediate. Topics in this course include constructing building components within the Revit environment, using the family editor to create 2D and 3D components, refining graphics, and adding building documentation. Upon successful completion of this intermediate-level Revit training course, students will be able to develop a BIM model independently and understand how to organize it as an integrated, interoperable set of construction documents.
- Revit III: Advanced. The course involves modeling an existing building and the creation of a model with a two-story expansion of that building model. Students will learn the creation of demolition plans to accommodate new construction and rendering of the final model. Upon completion of the course, students will be able to develop a BIM model independently and understand how to organize it for later development into a set of integrated, interoperable construction documents.

University name	State	Course Code	Course name
Massachusetts Institute of Technology	Massachusetts	4.567/4.507	Introduction to Building Information Modeling in Architectural Design
Stanford University	California	CEE220A	Building Information Modeling Workshop
Stanford University	California	CEE220B	Advanced Building Modeling Workshop
Harvard University	Massachusetts	SCI-06331-00	Building Information Models
UCLA - University of California, Los Angeles	California	C&EE X 489.16	Introduction to Building Information Modeling (BIM) (Extension course)
UCB - University of California, Berkeley	California	CIV ENG X494	Introduction to BIM: Virtual Design and Construction Technology (Extension course)
UCSD - University of California, San Diego	California	ARCH-40009	Revit I: Introduction
UCSD - University of California, San Diego	California	ARCH-40010	Revit II: Intermediate
UCSD - University of California, San Diego	California	ARCH-40011	Revit III: Advanced
Yale University	Connecticut	1019c	Intro to Revit
Georgia Institute of Technology	Georgia	ARCH 6503	Building Information Modeling - Concepts and Applications
University of Pennsylvania	Pennsylvania	ARCH 4310	Construction I
University of Southern California	California	CM 470	Building Information Modeling and Integrated Practice
Purdue University	Indiana	CGT 26000	Introduction To Modeling For BIM
Purdue University	Indiana	CGT 46000	Building Information Modeling for Commercial Construction
Arizona State University	Arizona	REV100	Building Information Modeling (BIM) Certificate Program

Figure 2: BIM courses in American universities (academic year 2022/2023)

This study categorized American academic BIM experiences into three categories: "single-course"; "interdisciplinary" and "distance collaboration" (figure 3).

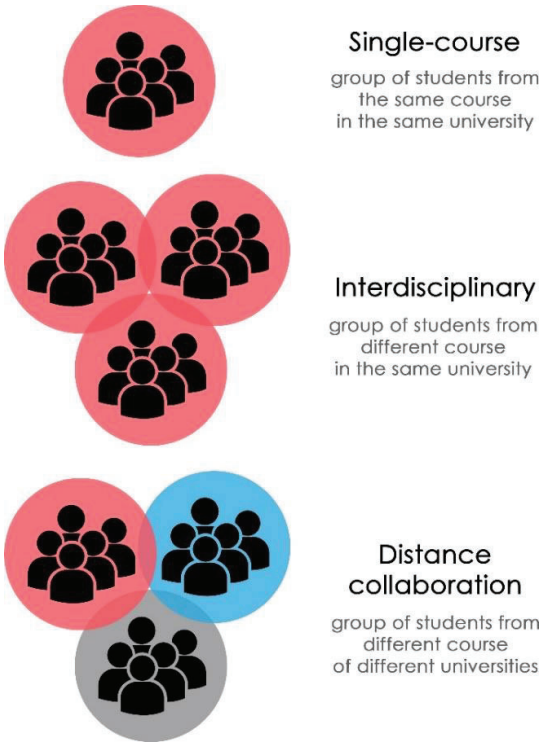

Figure 3: Categories of BIM experiences

Single-course: this category includes universities that have introduced BIM, but in only one discipline (Zhao et al., 2015). These courses teach the use of BIM software and the creation, development, and analysis of the models themselves. They also plan to simulate real collaboration, but with students in the same course (Taylor et al., 2007).
Interdisciplinary: this category includes universities that teach BIM concepts by simulating real collaboration with students from different courses at the same university. Examples of interdisciplinary courses can be found at the University of Pennsylvania, Oklahoma University, Auburn University, Georgia Institute of Technology, and the University of Maryland. These are examples of universities that currently integrate two- and three-course programs in which students develop collaborative projects using BIM software (Gier, 2015).
Distance collaboration: this category includes universities that teach BIM subjects by simulating real collaboration with students from different universities who are expected to collaborate in an interoperable way. An example of this experience is provided by the collaboration between the University of Nebraska-Lincoln, Montana State University, and the University of Wyoming.
By examining the state of the art of teaching techniques and courses delivered in U.S. universities on BIM, it was possible to analyze existing BIM-related teaching approaches and needs and propose BIM-based solutions to deliver university courses in the AEC sector, particularly addressing the objectives of the BENEDICT project.
The BENEDICT project, BIM-Enabled Learning Environment for Digital Construction, is an Erasmus+ strategic partnership between the Department of Civil Engineering and Architecture at Tallinn University of Technology (Estonia), the Civil Engineering Unit of Tampere University (Finland) and the Department of Architecture at the University of Bologna (Italy). The BENEDICT project deals with how to teach courses at university level with BIM Building Information Modelling tools, in particular through the use of an IT platform for BIM models.

BENEDICT project

The fundamental needs of Architecture, Engineering and Construction (AEC) students concerning Building Information Modeling involve the design, development and implementation of various building and management systems, for instance Architectural system; Structural system; Mechanical/Electrical/Plumbing systems, Construction and Project management systems. The needs of students and teachers consists in having the availability of data, reports, pieces of information, BIM objects and models concerning architecture and engineering systems. Therefore, a BIM-based learning system needs to be implemented in a virtual platform where BIM workflows can be performed.
The BENEDICT project provides a learning environment, a web-based platform where teaching and learning activities can be performed.
This platform is termed BIM-Enabled Learning Environment, BLE. As indicated by the literature review, the BLE platform can deliver three different categories of BIM experiences (figure 3).

The BLE Platform

The BLE is an open, online platform that enables web-based education and supports distance learning which, e.g., under pandemic conditions, helps address learning continuity needs (Boeykens et al., 2013).
The design, data formats, protocols, functionalities and IT-solution which constitute a common, open learning environment which can act as a repository of learning materials and which host the open learning resources and pilot modules developed as part of the BENEDICT project (Olowa et al., 2022). The resultant BLE platform is the infrastructure for having a systemic solution for BIM-enabled learning.
This refers here to unfolding the possible avenues for education and training where Building Information Modeling (BIM) and its results are utilized in a pervasive manner for the learning benefits of new and existing professionals (Rüütmann et al., 2022).
The BLE platform integrates BIM technologies and their learning with traditional design and engineering studies rather than having separate modules and courses for learning BIM skills (Kiviniemi, 2013).
Additionally continuing education is relevant here for updating the skills of experienced professionals (Nielsen

et al., 2009). The BLE platform is presented via its three educational dimensions: spectrum, modes, and extent.

The educational spectrum presents the various contextual dimensions that are covered by the BLE platform (Wu et al.,2013). Those are:

1. Building modeling and production of good quality models that are useful in different phases of construction projects. This covers different design and engineering disciplines (e.g., architecture and geotechnical, structural and building services engineering). Various BIM analyses, such as visualizations/VR/AR experiments for end users and clients, structural optimization, sustainability and energy efficiency analyses, are in a growing manner an inbuilt feature of modeling itself.
2. The use of resultant building models for numerous tasks and needs in construction operations (e.g., quantity take-off, cost estimating, scheduling, procurement, and supply management).
3. The interplay and its processes for having effective collaboration between different parties in a BIM intensive construction operation.

The educational modes present the main pedagogical solutions that are present in the BLE platform:

1. Demonstrational teaching via E-learning and/or Open Course Ware (OCW) lessons. Educational packages for independent studies.
2. Learning by doing. Interactive learning according to a systematic study program where instructors and students are linked to each other in a consistent manner for follow-up studies, providing reflections and feedback.
3. Collaborative learning by project work. Students are together experiencing a simulated construction project and work in such an environment. This is seen as most advanced educational form where students rather than as a stand-alone exercise can experience the dynamics and complexity of BIM intensive construction projects. These courses can particularly enhance knowledge and competence on project work practices, collaboration with different parties, design meetings, dialogue, and problem-solving skills. The educational extent presents the main ways how the BLE platform is entering the built environment profession: 1. Academic BIM studies: for different degree programmes (BSc., MSc.) in a single university or for having joint educational courses/modules between universities. 2. Continuing education: for universities or other educational and training institutions organising studies on topical matters of interest to professionals.

With its IT-SOLUTION the BLE platform:

1. Open learning environment for BIM-enabled education: solutions are to be open and software vendor independent, and they are to be available for the use of educational and training institutions throughout the Real Estate and Construction (REC) sector. The building models used will be according to open BIM standard and principles; these models shall be available in a standard interoperable format (ifc).
2. Repository of building models and relating learning resources (these will be developed as Intellectual Output O3). This includes presentation of educational pilot modules (developed as Intellectual Output O4) and their use.
3. Available online via Internet.

The materials produced will be available on the open access web platform, which can be accessed at https://www.bim-enabled-learning.com/ble/course/. The platform is still in development and all BENEDICT project partners, will upload the materials produced in their home language and/or in English. Following are some preview images of the platform (figure 4, figure 5, figure 6, figure 7, figure 8). The BLE platform has a dashboard page where all the items are addressed: the coureses and the data repository (figure 5). There three pilot courses addressing different topics of construction management, design management (figure 6), risk management (figure 7) and time management (figure 8). These three sections allow teachers and students to share open learning resources and learners' output.

Figure 4: Students testing the BLE platform

Figure 5: BLE platform preview - Dashboard

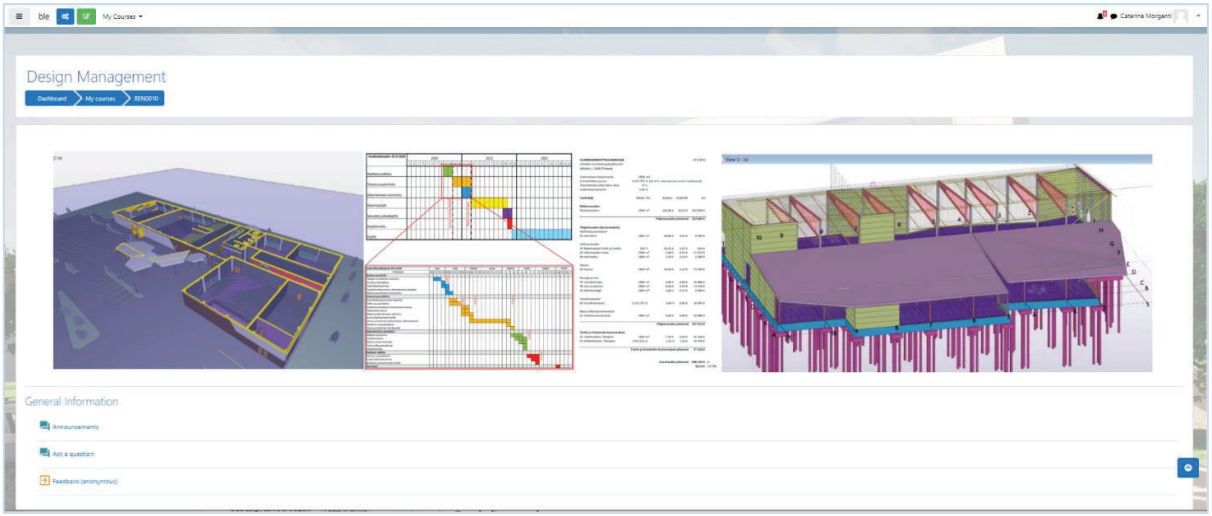

Figure 6: BLE platform preview - section Design Management

Figure 7: BLE platform preview - section Risk Management

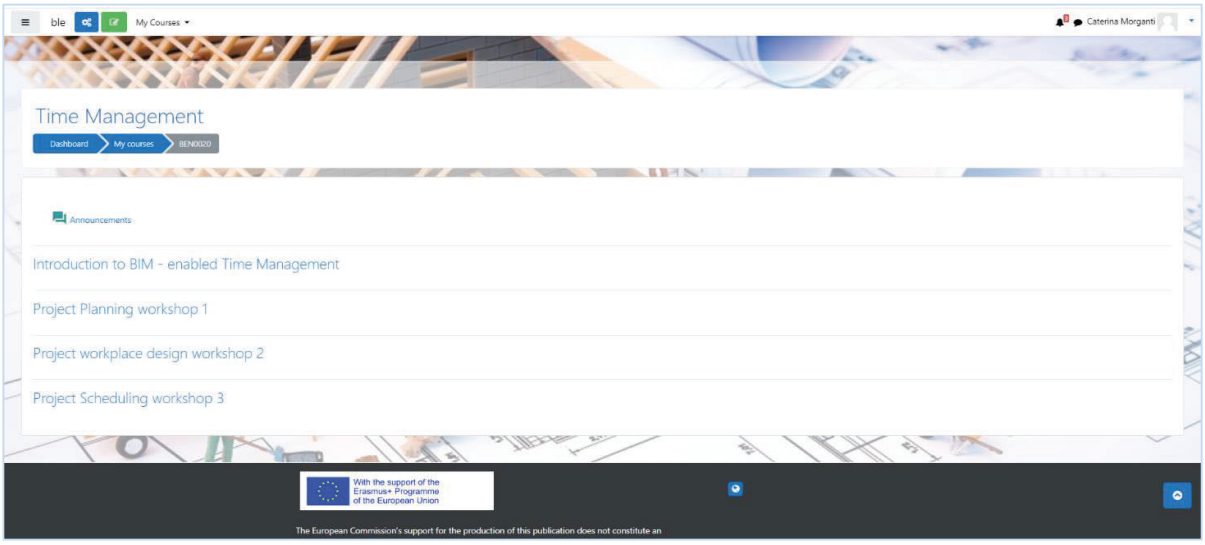

Figure 8: BLE platform preview - section Time Management

Conclusions

BIM education and awareness/assumption have different levels of implementation around the world. The study and examination done on the U.S. case studies help to provide greater knowledge of the subject and more tools for the purpose of creating the teaching platform object of study.

The studies conducted indicate that educators face many challenges regarding the incorporation of BIM into the curriculum, mainly concerning educators' knowledge/skills and available resources, both financial and physical.

The educational approach to teaching BIM can be integrated into the construction curriculum as a learning tool in the training of new professions.

However, this teaching approach must be easily replicable in any degree program, as the new engineering, architecture, and design community will increasingly find diverse professionals who will, however, need to use common design and working tools.

By creating searchable and updatable materials on an open access platform and interactive features for using it, the proposed BIM teaching approach should help students achieve a deeper understanding of the subject of BIM.

BLE platform can be useful to connect academia and industry because it creates the virtual environment where BIM models can be stored and shared and thus giving the opportunity to train a new digital generation of professional engineers and architects. Therefore, the answers to the research questions are the following.

"How is BIM taught in the United States?" BIM is taught by addressing appropriate levels of students in higher education programs, specific content and topics, and different types of instruction. The teaching of BIM in the U.S., unlike what is often happening in European universities, aims to increase the interdisciplinary use of this tool while enhancing the collaboration aspect among students.

"How can this experience be used in the Benedict project?" The U.S. experience, which goes back at least 20 years, can be used as a guide in implementing the specific features of the BLE, BIM-Enabled Learning Environment. It is possible to learn from the U.S. teaching experiences how to improve the degree of interoperability, interconnection, and collaboration of students as they approach learning the BIM workflow.

Research limitations concerns the availability of BIM-oriented courses in the U.S., as only the ones of UCSD could have been gathered directly, because of the experience of the authors. Future work will be aimed at developing teaching/learning workflow processes of the pilot courses implemented within the BENEDICT project.

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References

Abdirad, H., Dossick, C., S. (2016) BIM curriculum design in architecture, engineering, and construction education: A systematic review. J. Inf. Technol. Constr. (ITcon), 21, pp. 250-271.

Arashpour, M., Aranda-Mena, G. (2017) Curriculum renewal in architecture, engineering, and construction education: Visualizing building information modeling via augmented reality. In: Proceedings of the ISEC 2017 - 9th International Structural Engineering and Construction Conference: Resilient Structures and

Sustainable Construction, Valencia, Spain, ISEC Press: Fargo, ND, USA.

Becerik-Gerber B., Ku, K. and Jazizadeh F. (2012) BIM-Enabled Virtual and Collaborative Construction Engineering and Management, Journal of Professional Issues in Engineering Education and Practice, Vol. 138, No. 3, 234–245.

Berwald, S. (2008) From CAD to BIM: The Experience of Architectural Education with Building Information Modeling. In: AEI 2008: Building Integration Solutions, 2008, Denver, USA.

Boeykens, S., De Somer, P., Klein, R., Saey, R. (2013) Experiencing BIM Collaboration in Education. In: Proceedings of the 31st International Conference on Education and Research in Computer Aided Architectural Design in Europe (eCAADe), Delft, The Netherlands.

Dossick, C., S., Lee, N., Foleyk, S. (2014) Building Information Modeling in Graduate Construction Engineering and Management Education. In: Proceedings of the Computing in Civil and Building Engineering, Orlando, FL, USA, American Society of Civil Engineers: Reston, VA, USA, pp. 2176-2183.

Gier, D., M. (2015) Integrating building information modeling (BIM) into core courses within a curriculum: a case study. International Journal of Engineering Research and General Science, Vol. 3 No. 1, pp. 528-543.

ISO Technical Committee ISO/TC59/SC13. (2018) Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM) – Information management using building information modelling part1 concepts and principles ISO 19650-1: 2018

Kiviniemi, A. (2013) Challenges and opportunities in the BIM education - how to include BIM in the future curricula of AEC professionals. BIM Academic Workshop 2013, Düsseldorf.

Nielsen, D., Fleming, M., Kumarasuriyar, A. (2009) An innovative learning model for teaching architectural technology using Building Information Modeling: a Queensland university of technology perspective. In: CIB IDS, First International Conference on Improving Construction and use Through Integrated Design Solution.

Olowa, T., Witt, E., Morganti, C., Teittinen, T., Lill, I. (2022) Defining a BIM - Enabled Learning Environment - An Adaptive Structuration Theory Perspective. BUILDINGS, 12, pp. 1 - 19.

Plume, J., Mitchell, J. (2007) Collaborative design using a shared IFC building model-Learning from experience. Automation in Construction, Amsterdam, 16, pp. 28-36.

Rüütmann, T., Witt, E., Olowa, T., Puolitaival, T., Bragadin, M., Evaluation of immersive project-based learning experiences (2022). In: 18th CDIO International Conference Proceedings, pp. 313 - 323.

Sabongi, F., J. (2009) The integration of BIM in the undergraduate curriculum: an analysis of undergraduate courses. Proceedings of the 45th ASC Annual Conference, Gainesville, Florida.

Shenton, H., W., III, Conte, P., R., Bonzella, J. (2014) A first course in BIM for civil engineering majors. In Proceedings of the Structures Congress, Boston, MA, USA, pp. 1097-1105.

Taylor, M., J., Liu, J., Hein, M., F. (2007). Integration of Building Information Modeling (BIM) into an ACCE Accredit Construction Management Curriculum.

Zhao, D., McCoy, A., P., Bulbul, T., Fiori, C., Nikkhoo, P. (2015) Building Collaborative Construction Skills through BIM-integrated Learning Environment. Int. J. Constr. Educ. Res., 11, pp. 97-120.

Shen, Z., Jiang, L., Grosskopf, K., Berryman, C. (2012) Creating 3D web-based game environment using BIM models for virtual on-site visiting of building HVAC systems. In: Proceedings of the Construction Research Congress, West Lafayette, IN, USA.

Wu, W., Issa, R., R., A. (2013) BIM education for new career options: an initial investigation. BIM Education Symposium - Building Innovation 2013, National Institute of Building Science Annual Conference, Washington DC.