Building Information Modelling - the Quest for Simplicity Within Complexity

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There is a common expectation of technology to better help us manage the complexity of life and to simplify our daily tasks. However, these developments also raise a question of whether design technologies encourage complexity at the expense of simplicity in the design process. Does computation cause complexity? Or does it enable simplicity? This paper aims to answer these key questions, posed as the main focus of the eCAADe 2016 Conference, by confronting different approaches to teaching Building Information Modelling (BIM) in schools of Architecture. The scope of the paper is based on both the author’s knowledge of recent BIM implementations in the academic curricula and experiments conducted at Lodz University of Technology. Necessary prerequisites enabling understanding the complex knowledge are discussed. What is more, the scheme for the integrated BIM pedagogy is proposed.

Keywords: Building Information Modelling, BIM, semantic model, information visualization, integrated design

INTRODUCTION

We often expect a technology to better help us manage the complexity of life and to simplify our daily tasks. However, these developments also raise a series of questions of whether design technologies encourage complexity at the expense of simplicity in the design process. Does computation cause complexity? Or does it enable simplicity? [1] There is no doubt such defined problematics require manifold analysis. To answer these questions and workout a clear statement the paper will focus on Building Information Modelling as a key area in a design process.

It is observed new digital technologies influence design methods and offer exciting opportunities for architectural design. Recent developments in computer technologies and digital design tools enable us to address complex situations in architectural environments. On the one hand the more advanced technological support may evoke more challenging tasks; on the other hand the tasks may provoke technological growth and development. It is observed lately such intricate methods have been gradually involved in the processes of building design, construction and maintenance. The most meaningful is Building Information Modelling.

As Building Information Modelling is high on agenda nowadays and influences the workflow in architectural design practice and industry, it is timely to confront and discuss the topic. There are many initiatives in Europe in the subject area, consolidating regional BIM clusters, proposing EU funded projects and other activities the author has been involved.
BIM has also become a very widely discussed research topic, what can be proved by the presence of the theme at conferences such as CAAD Futures, ACADIA, SIGRADI, CAADRIA and eCAADe. A variety of related papers can be given as examples: from the focus on BIM in education (Vinšová et al. 2014) and a novel approach to combine BIM and VR (Kieferle and Woessner 2015), through the application of BIM in digital reconstructions of heritage objects (Boeykens et al. 2012), to programming for the enrichment of BIM capabilities (Sharif and Gentry 2015). What is more, there are many other conferences and symposia focusing on BIM entirely, gathering people from academia and practice with an ample industry involvement.

WHAT IS BIM NOWADAYS?
Building Information Modelling has become a common concept and the term has been already adopted to everyday language. To some extent, this common use is often exaggerated and excessively applied to 3D modelling or even CAAD drawings. Therefore, it is timely to recap what BIM actually stands for.

There is a number of definitions of Building Information Modelling, however, all of them point out the same core characteristics. Thus, BIM can be understood as a concept, an approach, a process, a methodology, a knowledge-base for project information, a technology or a set of tools essential to embed all necessary data about designed object in an integrated way. The richness and complexity of the output are strongly related to the scope and level of information possible to read or retrieve from the semantic model. This semantic model is the key to comprehend the idea of BIM, though it does not mean it encompasses the entire definition. One of the definitions states the following: "Building Information Modelling (BIM) is a collaborative way of working, underpinned by the digital technologies which unlock more efficient methods of designing, creating and maintaining our assets" [2]. Besides, it is worth mentioning here, that BIM is not IFC. The latter stands for Industry Foundation Classes and it is a platform neutral, open file format specification. It is registered by ISO, and it is an official International Standard. It is a commonly used collaboration format in Building Information Modelling based projects. To sum up, IFC is an open format for data exchange, particularly intended to describe building and construction industry data.

To conclude, the mostly agreed definition nowadays is to interpret BIM as a process involving the generation and management of digital representations of physical and functional characteristics of places, while building information models (BIMs) mean files which can be exchanged or networked to support decision-making about a place.

A PLACE FOR BIM IN ACADEMIC CURRICULA
BIM has been receiving an increasing attention in the architecture, engineering and construction industry. Due to official regulations concerning the compulsory use of BIM in practice and being adopted in more and more countries, there is an urgent necessity to adapt the curricula in Architecture studies to the demanding market.

Actually, there is an ongoing discussion on the best suited place in academic curricula for implementing BIM concept and methodology. On the one hand, in some institutions BIM is taught as early as in the first semester of Bachelor studies (Vinšová et al. 2015). On the other hand, there are arguments to let students mature for learning such complex tools, and as a result, BIM is introduced at fourth of five years of studies (Magdy M. Ibrahim 2014).

The author’s personal experience in teaching BIM goes back to the 90s of the twentieth century. Experiments and didactics were based on the industry first BIM software for architects. However, it was not defined BIM at that time but was named "Virtual Building Modelling in 1:1". By adding the scale 1:1, it was emphasized it would reflect the real size of a designed building.

There is no doubt the evolution of IT in general, and to point out more specifically, of CAAD software
in architectural design domain have been progressing significantly since that time. That is why the revision questions arise: Does the use of complex design methods offer simplicity to the design process itself? Is it possible to design complexity with simple methods? Or, in other words, to process complex tasks with simple tools?

In order to answer the above questions and to discuss a place for BIM in academic curricula, two cases of BIM courses conducted at Lodz University of Technology have been described, analysed and compared. Generally, these two courses are delivered at two bachelor study programmes which have been expected to be similar, however, some key differences appeared. The study programmes discussed in the paper are as follows: Architecture and Architecture Engineering. Both of them are eight semesters long, and BIM is taught at the same semester, viz. the third semester of studies. A scope of the two courses and the learning outcomes have been planned the same, and the main goal is to teach BIM and how to apply it in the design process. The classes start with an introduction to the BIM concept, then a set of exercises is prepared to allow students learn chosen software supporting a design process enriched by information about a building. Finally, a design task is provided to recap knowledge and to practice newly developed skills. The theme is adjusted to the level of third semester students’ capacity, so in a case of Architecture study programme, it is a family house at a given real location, while students of Architecture Engineering are asked to design a summer cottage on a chosen plot. The task is not a concept design only. The basic requirement is, however, to decide on building construction and materials, to estimate the thickness and the skins of external walls, a roof, slabs, fundaments. Apart from geometry and structure the environment and climate issues are taken into account and as a result, such information is embedded in the virtual model of designed building. There are some limitations planned a priori. Hence both study programmes are leading to qualifications in architecture, these basic BIM courses represent the approach to teaching architecture design studio. What is more, as it is the early stage of education (the third semester of bachelor programme) proposed tasks should not be too complex. The idea is to provide simple steps to achieve a complex result. Nevertheless, such courses require a set of prerequisites to enable students proceed with the tasks and develop new skills. What was surprising, the BIM courses revealed a huge gap between the two study programmes. While students of Architecture were able to meet the requirements, students of Architecture Engineering suffered from the lack of basic knowledge on building structures. Therefore, at the beginning the latter group was not able to proceed with preparation of an informative virtual model. So, the classes had to be reconfigured to help students achieve learning outcomes at the end of the semester. This situation provoked undertaking an investigation on differences in curricula. Both study programmes are relatively new, so such experience may lead to valuable conclusions and improvements of the curricula. For the purpose of the investigation a comparison of pre-selected courses assumed to be prerequisites has been prepared (see Figure 1). Each course has been described concisely in the following paragraphs to picture the problem. The brief is based on the official description of courses published online [3] and [4].

BIM prerequisites at Architecture study programme
Semester 1:

General Building I. Students are acquainted with the principles of technical drawing and basics of building engineering. They are also familiarised with various construction types as well as typical solutions for basic building elements (wall, roof, beam, slab). Students are expected to apply their knowledge throughout small projects such as a modular co-ordination of the plan and a design of external walls for a single family house. (lectures and tutorials)

Building Materials. The aim of this course is to provide students with information on basic building
materials (brick, wood, concrete, stone, glass, etc.), their properties and applications. Some processes, which take place in the building materials (heat transfer, moisture transport, hardening), are explained. The appropriate use (structure, insulation, finishing) of various materials is discussed. Potential risks and dangers as well as methods of their mitigation are outlined. (lectures and lab)

**Introduction to Architectural Design.** The course aims at introducing basics of the designing process and its principles. A particular attention is given to stimulating architectural design thinking, creativity and responsiveness. Design exercises are focused on solving simple problems requiring small scale interventions. Students are expected to achieve skills crucial for architectural profession - analysis of given information and site; design representation with drawings and models. Principles of professional ethic (respect, dependability and responsibility) are also outlined. (lectures and studio)

**Semester 2:**

**General Building II.** Further information on building methods is provided, including principles of load bearing; foundation types; principles of thermal insulation; stairs design. Students learn how to design various roof types and a ribbed ceiling slab. Additionally, they are to present a written report from their visit to the Building Industry Exhibition. (lectures and tutorials)

**Computer Aided Design Studio I.** The aim of

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**Figure 1**
Comparision of prerequisites of two BIM courses.
the course is to develop spatial cognition and to provide an introduction to computer aided design as a basic tool in engineering practice. Learning outcomes include precise digital drafting, basic 3D modelling and designing in the virtual environment. Students should be able to create 2D architectural drawings. They are also expected to perform a concept design of a simple architectural form in a chosen software. (lab)

**Introduction to Architectural Design II.** The course includes three small-scale projects: 1. an object in open landscape (for example, a rest stop along a highway); 2. a similar facility in an urban setting (for example, an entry to a botanic garden); 3. a more complex design (for example, a holiday bungalow). Students are expected to focus on interrelation between human being, architecture and environment (setting). At the end of the course they should be able to merge functionally uncomplicated architectural forms into groups. (lectures and studio)

**Semester 3:**

**Building Physics.** Students are provided with the theoretical and practical knowledge of basic concepts and problems concerning heat and mass exchange in a building shell, sound propagation, moisture exchange, energy balance of a habitable building, which are necessary for proper architectural design process. Students are also familiarised with solar energy issues and their application including passive and active systems and their efficiency. At the end of the course they should be able to assess the effect of a building modification and estimate the basic heat and energy characteristics of building elements. (lectures and tutorials)

**General Building III.** The course extends students’ knowledge on technical and structural issues related to architectural design. Topics include foundation methods and depths; water drainage systems; windows, doors, gates types, constructions, methods of fitting and sealing; flooring and floors; wall plastering and painting. The Polish Building Code is also discussed. A documentation of a single-family house is to be compiled by each student by the end of the semester. (lectures and tutorials)

**Timber Structures.** The course is envisaged as an introduction to the basic properties of wood and wood-based materials. Traditional and contemporary structural solutions are described. The issues related to proper maintenance and exploitation of a timber construction are also explained. Students apply the knowledge throughout designing a beam-column structure, a roof structure, and a glued-laminated wood girder. (lectures and tutorials)

**Building Installations.** The course consists of two parts. The first part aims at acquainting students with the basics of designing hot and cold water systems; fire-extinguishing water installations; domestic and rainwater sewage systems in a building and its surroundings. The second part focuses on the construction and design of simple central heating systems, mechanical ventilation systems and a variety of heat sources. Both parts include lectures and a design studio. Students are expected to apply knowledge to design installation systems in a given multifamily house (a cold and hot water supply, an internal sewage system, sanitary and rainfall installation connected to the municipal sewage systems). Then they focus on a design of a central heating or mechanical ventilation in a single-family building. (lectures and tutorials)

**Integrated Architectural Design.** Throughout this course students learn the basic principles of architectural design of housing. During the lectures they are provided with theoretical and practical information concerning a design task - a small complex of single-family houses (at least three buildings) with the emphasis on the urban context and functional solutions (proper orientation, proportion and functional relationships, etc.); the appropriate structural system and building materials should be also taken into consideration. (lectures and studio)

**Computer Aided Design Studio II.** The aim of the course is to provide an introduction to BIM applications, to develop practical skills in creating information models of architectural objects and project documentation based on the models and to learn es-
sential visualization techniques. On successful completion of the course students should be able to apply BIM concept to architectural design tasks. This includes preparing a comprehensive documentation of architectural design based on the model information as well as creating sets of detailed data on the architectural objects based on the spatial BIM model. (lab)

**BIM prerequisites at Architecture Engineering study programme**

**Semester 1:**

Building Materials. The aim of this course is to provide students with information on basic building materials (brick, wood, concrete, stone, glass, bituminous adhesives, mineral binders, etc.), their properties and applications. Some processes, which take place in the building materials (heat transfer, moisture transport, hardening) are explained. The appropriate use (structure, insulation, finishing) of various materials is discussed. Potential risks and dangers as well as methods of their mitigation are outlined. (lectures and lab)

Fundamentals of Civil Engineering. The course covers an introduction to the principal building elements, structural systems and traditional technologies including ventilation, exhaust and smoke ducts. The problem of loads is emphasised. Students are expected to make calculations for determining the value of loads, including an impact of functional arrangement and climatic conditions. This project is to be done for a given rib-and-slab floor. (lectures and tutorials)

Introduction to Architectural Design and Ergonomics. The course focuses on the basic knowledge of architectural design ideas and principles. Students should learn the rules of architectural drawing, methods of presenting and discussing architectural issues. To achieve basic understanding they are expected to prepare a presentation on a modern/contemporary well known architect. The final assessment is a design of a small building (expo pavilion, summer house, etc.). (tutorials and studio)

**Semester 2:**

Architectural Design Studio I. The main goal of the course is to familiarise students with a design process of residential buildings and complexes. The course is based on a design process starting with a wide range of analysis of existing exterior site conditions, through the formulation of architectural forms using adequate materials, to finding optimal architectural solutions. The design studio is enhanced with lectures expanding on associated issues, such as the impact of the building on the user, functional layout and interrelations between building and its surrounding, residential buildings typology, etc. (lectures and studio)

Computer Methods in Architecture I. The aim of the course is to develop spatial cognition and to provide an introduction to computer aided design as a basic tool in engineering practice. Learning outcomes include precise digital drafting, basic 3D modelling and designing in the virtual environment. Students should be able to create 2D architectural drawings. They are also expected to perform a concept design of a simple architectural form in a chosen software. (lab)

**Semester 3:**

Building Physics and Acoustic. Students are provided with the theoretical and practical knowledge of basic concepts and problems concerning heat and mass exchange in a building shell, sound propagation, moisture exchange, energy balance of a habitable building, which are necessary for proper architectural design including lighting and acoustics. Methods of numerical analysis of heat flow including 2D and 3D modelling are outlined. Students are also familiarised with solar energy issues and their application including passive and active systems and their efficiency. At the end of the course they should be able to assess the effect of a building modification and estimate the basic heat and energy characteristics of building elements. Students are expected to conduct calculations concerning heat exchange, energy balance, and reverberation time for selected rooms. (lectures and tutorials)

Concrete Technology. The course aims to famil-
iarize students with the technology of cement concrete including issues related to properties of concrete and the requirements, concrete classification, normalization and classes, components of concrete mixtures, their workability, placing and curing. Methods of concrete testing are also outlined. (lectures and lab)

Building Installations. Students are introduced to the classification-related terminology, designing, operations, setting up and exploitation of typical sanitation systems and district heating. Tutorials include assessment of the influence of particular installations on hygiene and sanitation safety, the acoustics-related comfort and fire hazard, people, buildings and the surrounding. In addition, students are expected to design a simple central or water heating installation, based on legal requirements and principles of technical knowledge. (tutorials and studio)

Architectural Design Studio II. During this course students are acquainted with the architectural design of small commercial buildings (a hotel, a kindergarten, local bus/railway station, etc.) in an urban context. Lectures provide information not only on the issues related to the design task (e.g. hotel structure & programme; vertical communication in building), but also on various concepts behind the modern and contemporary architecture, such as: "less is more", "we do not create art we solve problems", "less is bore" and many other. (lectures and studio)

Computer Methods in Architecture II. The aim of the course is to provide an introduction to BIM applications, to develop practical skills in creating information models of architectural objects and project documentation based on the models and to learn essential visualization techniques. On successful completion of the course students should be able to apply BIM concept to architectural design tasks, and in particular to prepare a comprehensive documentation of architectural design based on the model information, as well as to create sets of detailed data of the architectural objects based on the spatial BIM model. (lab)

OBSERVATIONS AND CONCLUSIONS

The following deliberation presents the perspective of teaching computer aided architectural design and being situated in predefined settings. The main motive to undertake the above search was the observation that students of two courses of study, viz. Architecture and Architecture Engineering, taking part in BIM courses had differential background knowledge. It is worth mentioning here, that it was intended these two courses should differ in the language of instruction only. The Architecture course is taught in Polish, whereas the Architecture Engineering course is delivered in English. Nevertheless, there are diverse names of particular courses, the overall learning outcomes are the same. Both courses consist of eight semesters, both are concluded by final bachelor diploma projects and both promote engineers in architecture. What is more, the two study programmes are relatively new, so such investigation may reveal the most emergent conflicts, lead to valuable conclusions, and in consequence, improvements of the curricula.

The examination of the courses, presumed to be prerequisites to teaching BIM, have helped to understand differences in the learning progress. Through the analysis of students' earlier learning outcomes and prerequisites, and moreover, by an observation of diversified knowledge it was possible to denominate key problems. First of all, as the lack of coherence in students' knowledge emerged very early at the "Computer Methods in Architecture II" course, it was possible to adapt the course to students needs while keeping the goal and project tasks unchanged. Thus, it can be considered as an emergent reaction to the situation. Secondly, a study of complementary courses was undertaken. The primary impression while reading the courses catalogues was rather not unexpected. The courses looked alike and distinguished tiny differences were not supposed to be the reason of the problem. However, after several discussions with students and observations of their state of knowledge, it became perfectly obvious the prerequisite courses were not the same.
The courses for Architecture Engineering students focused more on civil engineering tasks and calculations while students of Architecture learnt more about building structures with the capacity essential for architects. Additionally, students of Architecture benefited more since the "Computer Aided Design Studio II" course became complementary to other courses provided at the third semester, viz. Integrated Architectural Design, General Building III, Building Installations, Building Physics and Timber Structures. It was the initiative beyond the stiff catalogue courses' descriptions. As a result, the design studio project benefited from the associated courses and students performed better understanding of complex knowledge. What is more, they were able to develop also technical skills and apply them in their final projects.

The observations allow to draw some conclusions. First of all, BIM is not suitable for the first semester or even the second semester students since it requires a set of prerequisites not possible to apprehend in such a short time. Secondly, to understand BIM basics it is essential to learn building structures first. Until then we may speak about two dimensional drafting or three dimensional modelling, but it is not equal to building information modelling, however, often mistaken even by the teachers. Another conclusion is that BIM courses should be provided on several levels of education and should start as a course dedicated to certain study programme, for example for architecture students, civil engineering students, environmental engineering students, etc. The BIM course described earlier would stand for the basic, introductory one. Then, an advanced course should be proposed enabling working in multidisciplinary teams and offering a simulation of the real problems to be solved in a co-operative way. It is worth mentioning here, that among many definitions, finally BIM is about working together.

To sum up, there is no doubt BIM process is com-
plex and multifaceted, however through carefully designed curriculum it is possible to make such complex knowledge and practical skills simple to acquire.

FURTHER PLANS
Hence BIM is high on agenda and it is a real need to prepare students to meet the growing challenges of industry and technology, a new concept of interdisciplinary design process simulation course based on BIM has been proposed. It is planned to continue the idea of teaching by "simple steps towards complex results".

The idea coincides with a new programme of undergraduate studies "Control Systems Of Intelligent Buildings" launched at the Faculty of Electrical, Electronic, Computer and Control Engineering at Lodz University of Technology. The curriculum has been developed in co-operation with other faculties, among them the Faculty of Civil Engineering, Architecture and Environmental Engineering. The new concept for advanced BIM course would include an integrated design studio merging students from both faculties and four courses of study (see Figure 2). They would form interdisciplinary teams gathering representatives from different fields of studies, principal to challenge intelligent buildings design. So, students of architecture, civil engineering, environmental engineering (building installations) and control systems of intelligent buildings would work together to bring a project to fruition: from the initial concept to the 'in use' phase [5]. Participation of students and tutors of versatile backgrounds and knowledge would stimulate exchange and, what is more, simulate a design process as close as possible to the reality. The latter would be achieved through the involvement of extramural stakeholders from the AEC industry. It is necessary to stress, this sector is very active in the adoption of Information and Communication Technologies. Therefore, Integrated Project Delivery (IPD) is highly on demand. It is an emerging process framework bringing together people, systems, business structures and practices to keep information flowing smoothly towards integrated architectural, structural, environmental and ICT solutions. To sum up, the aim of this newly proposed course is to provide a scenario for a simulation of a complex design process and preparing students to meet the AEC industry expectations. To achieve such complex goal, it will be necessary to involve an innovative teaching methods based on Design Thinking and Problem Based Learning (Kepczynska-Walczak 2016).

FINAL REMARKS
The plethora of new possibilities generates challenges in education. They are assumed not to provoke replacements but rather extensions to the old and tested methods. Furthermore, taking into account also the tendencies on the market, it is possible to draw some conclusions on how the design education should be developed in the near future. Therefore, the proposed scenarios would be worth considering in a broader discussion.

The impact of industry on academia is increasing, so it is worth considering how these two may benefit from each other. It refers directly to the concept of research by design (Verbeke 2013; Herneoja et al. 2015) perfectly reflecting research activities conducted in / with and through practice.

There is no doubt BIM belongs to highly complex concepts, though learning it can be a simple and successful process. Besides the factors described earlier, the success depends on how carefully and explicitly BIM course is planned and delivered. It is worth mentioning here the author’s approach towards discussing BIM in the context of Complexity & Simplicity has been formulated from the perspective of computer aided architectural design education.

The author believes the paper will contribute to better understanding of BIM concept, to teaching methodologies development, to a discussion on updating the academic curricula and strengthening the BIM idea in a design studio context. It is time for BIM - complex in its nature - to simply immerse in academia!
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