

Teaching building construction design using BIM: the benefits and difficulties

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ABSTRACT: Architecture academics have found themselves at a watershed moment for the technology of design. This concerns how to master the new digital professional toolset. The era of *flat* design in 2D has passed, and a new era of coherent and parameterised 3D+ (4D, 5D) design in an object environment has begun. This has come about so quickly that universities have found themselves unprepared. An urgent requalification of didactic staff is required, as is the introduction of significant changes to curricula with design using the building information modelling (BIM) standard. In this article is described the author's experience in introducing the BIM standard as part of the building construction teaching module dealing with the preparation of architectural and construction documentation. As well, BIM was used for the preparation of building surveys.

INTRODUCTION

The *ArchiCAD Winter School - 2018*, which took place in March in Tarvisio, Italy included a BIM (building information modelling) design workshop. An interesting experiment was performed with participants: to compare a design developed in a traditional manner with a design developed as a virtual BIM model. The participants were divided into three-person teams, viz. manager, architect and contractor.

In the first part of the exercise, each team was given a box of wooden blocks in different shapes and colours, as well as traditional design documentation of a spatial structure composed of the blocks. This included a floor plan, longitudinal and transverse cross-sections, and four elevation views. The task was to achieve the quickest possible construction of a structure in accordance with the documentation; the allocation of duties in line with the roles assigned within each team. The average task completion time was about 15 minutes. Only one of the participating teams performed the task without error. However, this came at the cost of completing the task in the longest time. Figure 1 below shows the structures built of wooden blocks.

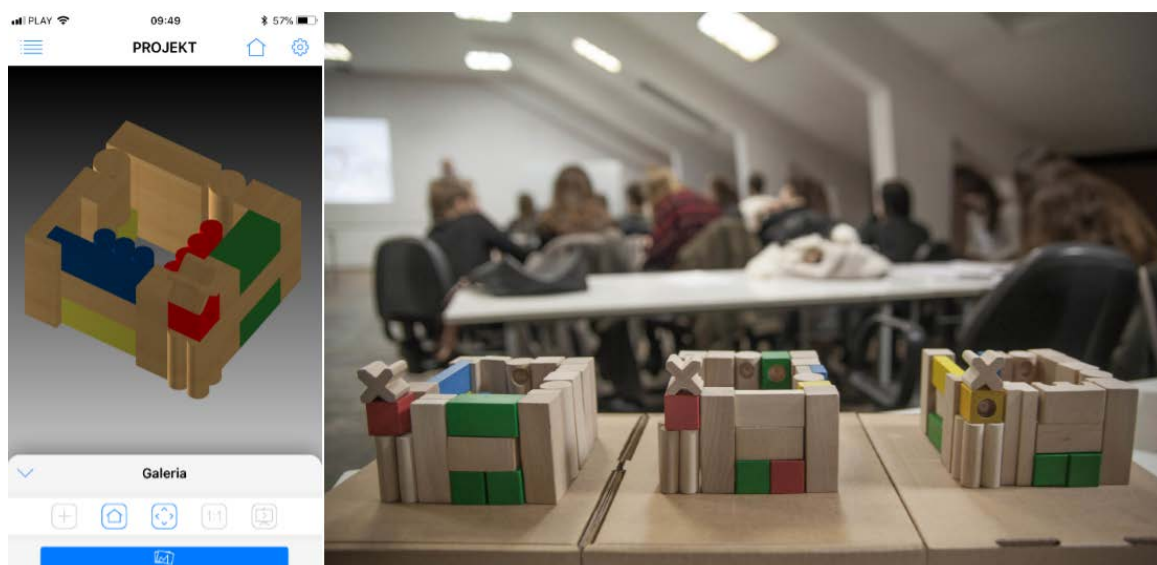


Figure 1: 3D design using the BimX program and the finished structures made out of wooden blocks.

In the second part, the participants were given a design of a different structure with a similar level of complexity, but prepared as a virtual model using the BimX program. The model of the structure was sent to each team's mobile device, e.g. iPad or iPhone. The model could be easily rotated, tilted and zoomed in 3D space.

Furthermore, each of the blocks comprising the model could be selected on a touchscreen and highlighted. All the teams completed the task in a time of about five minutes. Furthermore, all of the structures were constructed without error. The results of the experiments were quite a surprise, notwithstanding that all of the participants had a positive attitude toward BIM technology.

IMPLEMENTING BIM IN THE BUILDING CONSTRUCTION MODULE

The projects prepared by architecture students in the building construction teaching module are partial designs, which constitute successive parts of typical architectural technical documentation [1]. They focus on successive components of design documentation, such as foundation design; the design of a repeatable storey; designs of floor slabs and stairs; a doors and windows schedule; a roof truss design and a flat roof design.

In a standard curriculum each design project is prepared as traditional, two-dimensional architectural technical documentation in the form of two-dimensional floor plans, cross-sections and details. Furthermore, the projects are drawn by hand, using technical pens, during the first two semesters. It is only during the third and fourth semesters that students are allowed to use 2D CAD-type software. After finishing the building construction module, students have the ability to prepare full architectural technical design documentation.

However, this documentation is prepared to the traditional 2D CAD standard. The curriculum does not feature the preparation of architectural technical design documentation to the BIM standard. In order to prepare for bridging this gap in education, one of the module groups was assigned an expanded pilot curriculum in 2017, featuring the preparation of architectural technical documentation to the BIM standard, using ArchiCAD software.

In Table 1 is a list of the benefits and design problems that were observed during the implementation of BIM technology in the building construction teaching module during successive design projects covering distinct parts of architectural and technical design documentation. Provided in Figure 2 and Figure 3 are examples of some of the issues raised in Table 1.

Table 1: Design benefits and problems in the implementation of BIM technology in the building construction module.

Benefits	Difficulties
a) Design of a repeatable storey in a multi-family residential building	
<ul style="list-style-type: none"> • Quick drafting with the use of axes, thanks to all of the previously designed layered partitions (external walls, load-bearing walls, partition walls, inter-storey floor slabs with floor layers, etc). • Automatic generation of joints between layered structures (e.g. a floor slab with a floor automatically joins with an external wall in a correct manner). • Automatic placement of windows and doors along with their dimensions and the possibility of quick editing. • Interactive dimensioning (automatic updating after making changes to the size of a window, etc). • An automatic tool for the calculation and design of stairs, along with structure type selection. 	<ul style="list-style-type: none"> • The graphical representation of a 3D model on 2D floor plans and cross-sections requires preparing initial definitions that are compliant with current drafting standards for 2D drawings. • The automatic joining of walls and floor slabs requires the definition of so-called priorities for each construction material in such a manner that, for instance, the structural material will <i>cut away</i> the insulation and finish at the site of the joint. • One problem that affected practically all students to varying degrees was modelling a project in such a manner that the automatically generated 2D floor plans and cross-sections would not require correcting using drafting tools (line, hatch, etc) performed not on the model itself, but on the 2D sheets meant for printing.
b) Design of a building's foundations and footings	
<ul style="list-style-type: none"> • The elimination of errors, thanks to a 3D model. • The possibility of quickly modelling complicated and interconnected elements, such as excavations, wall footings, perimeter drains and gravel beds around a building using the <i>complex profile</i> tool. • The ability to quickly model the elements of a design that are highly complicated in terms of their geometry, such as the escarpments of excavations and access roads on a slope. 	<ul style="list-style-type: none"> • An unconventional graphical representation of the foundation floor plan - the plan of the footing with walls without doors and windows by the program does not exist on the floor plan of the model. • Elements, such as floor plans of stepped wall footings in buildings located on a slope require intervention using drafting tools. • Side views of wall footings require the placement of <i>patches</i> with appropriate views taken from the cross-section.

Benefits	Difficulties
c) Floor slab design	
<ul style="list-style-type: none"> • Making design work more quickly after defining the elements of a floor slab system as 3D model library elements. • The virtual model makes it possible to create automatically generated and error-free 2D cross-sections through any location. 	<ul style="list-style-type: none"> • The transformation of a literal view of user-defined axes of floor beams. • The graphical representation of elements, such as separation beams on the floor plan.
d) Roof truss and roof surface design	
<ul style="list-style-type: none"> • Intuitive creation of a virtual model with the option of automatically generating even the most complicated roof plan geometry. • The automatic generation of any desired cross-sections from a 3D model. • Easy and intuitive elimination of spatial collisions. • Automatic scheduling of roof truss elements (profile lengths, cross-sections, volume, etc). 	<ul style="list-style-type: none"> • The graphical representation of roof trusses on floor plans requires the introduction of simplifications (e.g. rafters shown only using dashed lines), while floor plans are generated in a literal and complete manner from the 3D model, which causes the drawing to become crowded and reduces its legibility. • The roof surfaces must be supplemented by a separately modelled roof truss. • Difficulties in modelling strategies in the case of thermal insulation between rafters, and then along the horizontal collar beams, leaving an uninsulated attic above the collar beams. • Difficulties in modelling strategies concerning overhangs at the point of contact with gables.
e) Flat roof design	
<ul style="list-style-type: none"> • Easy and intuitive elimination of spatial collisions. • Thanks to dedicated tools, such as <i>truss maker</i>, it is possible to quickly model spatially complex trusses. • The ability to use responsive library objects, such as trapezoidal metal sheets with changeable parameters, such as the height and width, greatly speeds up the work. 	<ul style="list-style-type: none"> • The adoption of an appropriate strategy and tool selection for the modelling of a virtual building, e.g. the incline layers in a non-ventilated flat roof can be modelled using different tools (such as roof surfaces, complex profiles).
f) Complete technical design of a single-family house and interior arrangement	
<ul style="list-style-type: none"> • Site development schedule, floor area schedules, window and door schedules, roof truss element schedules, furniture schedules, etc. are automatically generated and updated when corrections are made. • All changes introduced when making corrections are automatically remodelled on the associated drawings (e.g. window dimensions changed on a floor plan are automatically corrected on cross-sections, elevations and perspective views). • The ability to filter drafting layers (e.g. on a floor plan meant for the developer there will be furnishings and functional descriptions, while on a plan for the contractor there will be dimensions, floor area schedules and other technical information). • Insolation analyses, thermal bridge analyses, etc. 	<ul style="list-style-type: none"> • Correcting graphical display settings is time-consuming, thus it is recommended to prepare a starting file with the desired graphical layout preset - with default settings for dimensioning graphics, various descriptions, the graphical representation of various elements, a set of <i>favourite</i> library objects (e.g. typical doors and windows), etc. • The greatest difficulty is associated with the modelling of atypical technological joints, in which an optimal strategy of selecting modelling tools needs to be adopted. • It appears necessary to implement projects that need to be developed as a part of a team, divided into <i>teamwork</i> modules, into the curriculum.

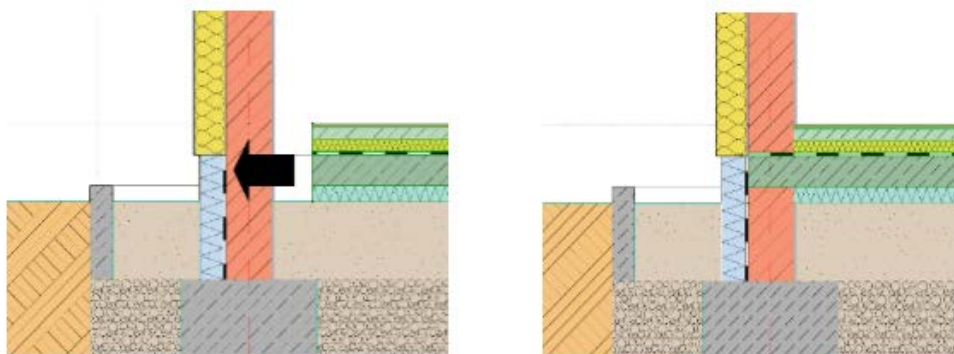


Figure 2: The automatic joining of walls and floor slabs requires defining so-called priorities for each construction material.

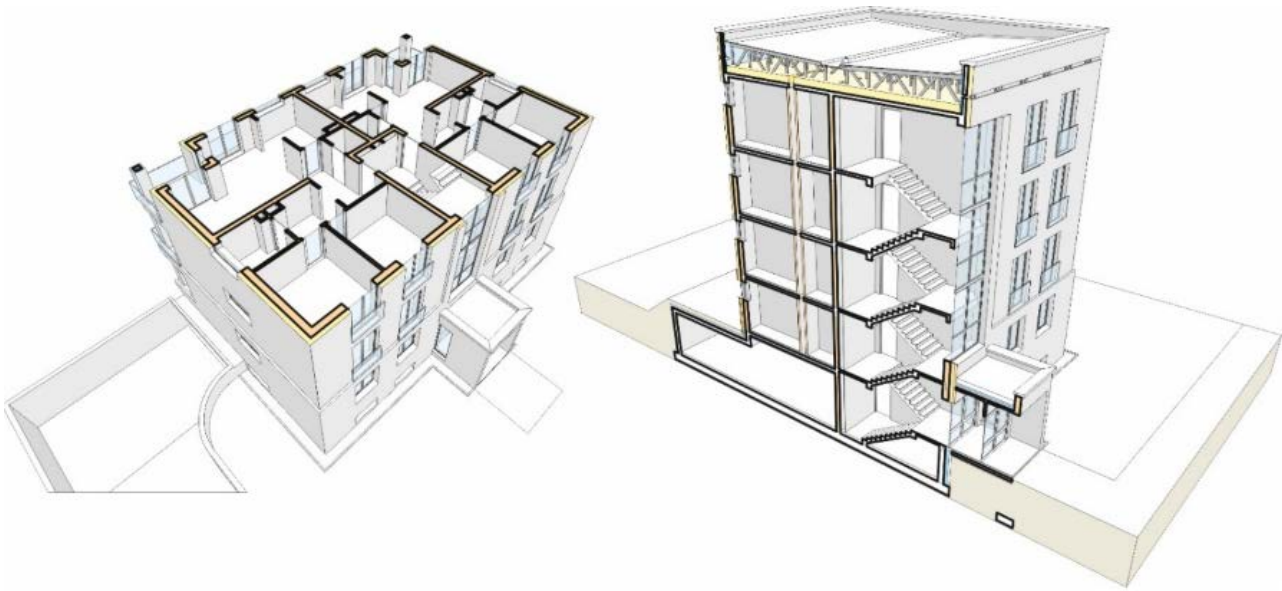


Figure 3: A virtual model of a multi-family residential building (3D floor plan and cross-section) prepared as part of the building construction teaching module.

BIM IN BUILDING SURVEYING

A group of students working with ArchiCAD software during the building construction module in the fourth semester had the opportunity to address the problem of surveying an existing building and comparing two standards - a traditional building survey prepared in 2D CAD software on the basis of two-dimensional measurements of a building and a BIM-standard building survey, based on a 3D laser scan of the entire building followed by developing a virtual model in ArchiCAD using a so-called point cloud.

The building of a high school in Kraków was surveyed 10 years ago, using the traditional method. The building survey focused only on one side wing across the entire height of the building and was used to prepare a design of an external elevator for disabled persons. The building survey was prepared in the form of two-dimensional floor plans, cross-sections and elevations in 2D AutoCAD format. The students participating in the educational project were provided access to the AutoCAD files, which they could import to ArchiCAD as so-called independent 2D areas. This made it possible to compare a traditional building survey with a modern BIM building survey by superimposing 2D drawings on the floor plans and cross-sections generated from the spatial model of a virtual building.

The goal was to develop a design for the adaptation of unused attics for utilitarian purposes, e.g. classrooms, laboratories and open rooms for individual learning. The design was to be prepared to the BIM standard, which is why the building survey was also being prepared in the form of a virtual building model. The building survey was performed using laser scanning, preceded by a tachymetric measurement.

- A tachymetric measurement was the first stage of work. Tachymetry is a surveying method of quick measurements including on-site height and position, which is meant to determine the co-ordinates and height of given points (in this case the distinct points of a building) in an adopted reference system [2]. It is based on the simultaneous measurement of directions, vertical and horizontal angles, as well as distance to selected terrain features. Tachymetric measurements were performed using a theodolite.
- The second stage was laser scanning using a FARO laser. The new, highly mobile Focus S70 laser scanner by FARO makes it possible to perform quick, simple and precise measurements of complex objects and buildings [3]. The scanner records façades, complex structures, roof trusses, installations, and so on, delivering realistic and detailed scanning results with a scanning range of 70 m. The incorporated eight-megapixel high dynamic range (HDR) imaging camera records detailed images, offering a natural and colourful layer for the scanning data even in difficult lighting conditions. The laser scan produces 3D image files in the form of a point cloud [4]. The point cloud is a set of several million points constituting a geometric representation of the scanned structure. Each of the points has XYZ co-ordinates, as well as a reflection intensity parameter. The point cloud obtained through scanning has a scale, which makes it possible to perform measurements without the need for fitting (e.g. see Figure 4). Afterwards, based on a three-dimensional point cloud, orthophoto maps are generated, which are projections performed using two-dimensional, orthogonal co-ordinates.
- The third stage of work was the generating of a virtual building model on the basis of the point cloud and orthophoto plans. This was the most labour-intensive and costly - from the developer's point of view - stage of work (e.g. see Figure 5).

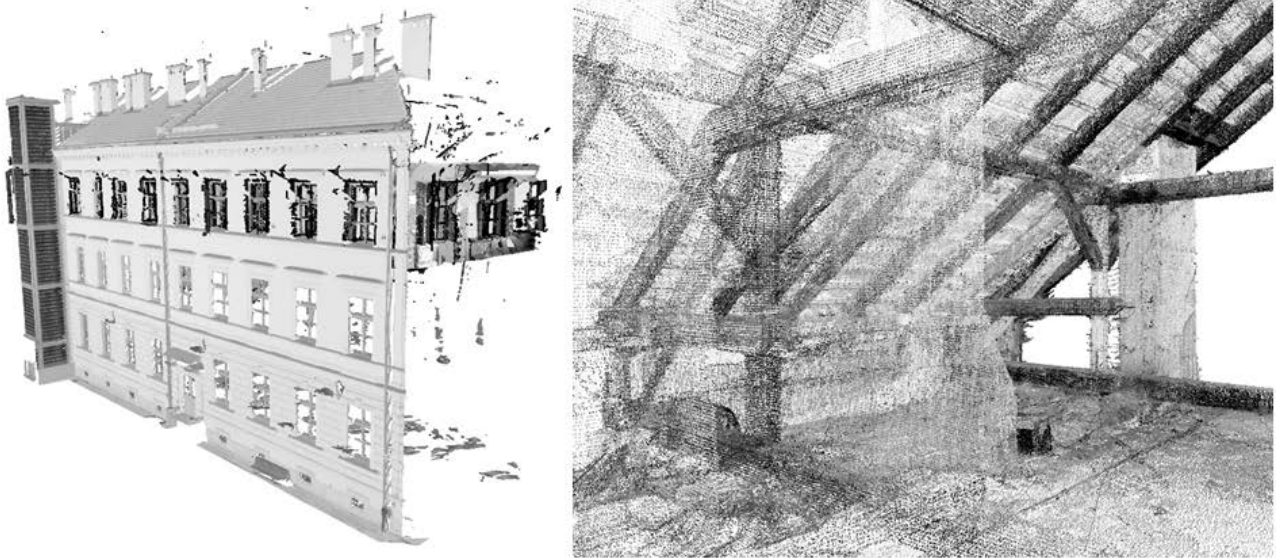


Figure 4: Point clouds generated by laser scanning.

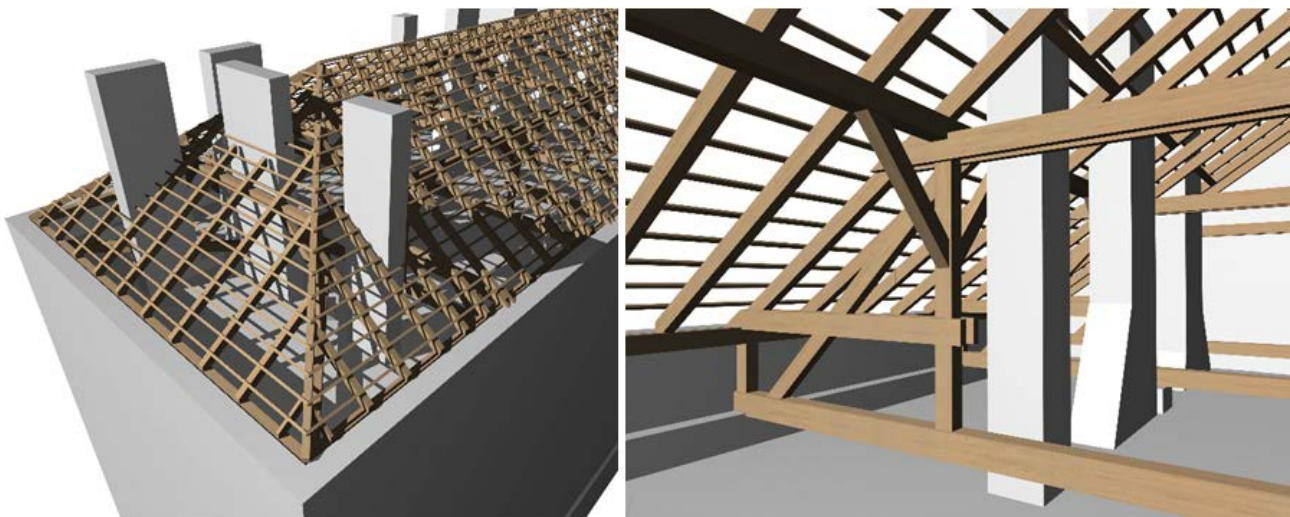


Figure 5: Virtual model - roof truss.

The comparison between the traditional building survey and the BIM one, based on a point cloud, highlighted the inaccuracy of the former by up to 10 - 30 cm in only one wing of the building! Despite an accurate measurement of the rooms, the inaccuracies amassed primarily due to mistakes in assessing the widths of the partitions. The most serious errors were the result of an inaccurate orientation of the building relative to the geodesic grid and adopting erroneous angles between the main wings of the building. The superimposition of the 2D CAD drawing and the orthophoto map of a storey made it possible to quickly verify and determine the scale of the errors.

The survey of the historical building showed the benefits of BIM, while also making students aware of the necessary and relatively large workload required to fully and faithfully model a building.

CONCLUSIONS

To sum-up, the benefits of introducing BIM technology into the professional toolset of architecture students are significant and varied. The most distinct benefit of BIM is to enable the production of cohesive, parameterised and interactive design documentation, in which corrections introduced in one place are automatically updated throughout the rest of the documentation. This makes it possible to eliminate most errors and collisions typical of 2D CAD documentation. Furthermore, BIM allows excellent design presentation. The model represents reality and constitutes a comprehensive communication tool meant to convey information about the scope, stages and result of a design.

That a design is fully three-dimensional means a shorter time to prepare a visualisation and the ability to set up virtual walks. Building information modelling also makes it possible to use various simulation tools, which allow architects to analyse even the most mutable and unpredictable factors, such as insulation, and calculating the energy efficiency of a building [5]. Of note is yet another aspect of BIM technology. Today, designs that are given to students to prepare, in 90 percent of cases, are individual efforts. In reality, work in the architectural profession is based on teamwork,

common dependencies and awareness of roles within a team and shared responsibility for the success or failure of a project. Thus, comes an additional challenge faced by the education system - how to teach students to work as a part of a team.

Building information modelling is becoming the standard for modern design and should be incorporated into the education of future engineers and architects. Highly developed countries face a significant problem caused by a lack of specialists who can proficiently operate this technology [6]. The response to this challenge must first and foremost be the introduction of BIM into university curricula and to train academic teachers, that is, train the trainers.

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