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OPEN BIM IN COURSE ON ADVANCED BUILDING DESIGN

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Abstract
A course in advanced building design worth 10 ECTS points is offered to master's students at the Technical University of Denmark. Students are given a task to design a 20-40 storey office building in teams of six students. In addition to submission of reports and technical analysis the students shall hand in BIM models in open BIM, specifically in IFC-format. The paper describes how the course and use of BIM is evaluated **by** the students, and the finding correcting the delivered BIM models in IFC-format. Use of model servers and BCF are briefly described. Issues regarding challenges in coordination, teamwork building and mutual dependencies were registered from students' evaluation of the course. Overall, the students reported becoming familiar with open BIM and experienced the freedom to choose their preferred BIM tool for each specific job to see if it was possible to coordinate a building design project using open BIM. Graduate students working in the building construction industry expressed satisfaction with the course.

1. Introduction

The Technical University of Denmark has offered a course in Advanced Building Design for Master's students studying Civil Engineering or Building Design since 2008. The course is offered once per year. The course is designed as a multi-disciplinary course, with students split into teams consisting of six students. Each student in the team has their own aspect of responsibility in the team to assist in the overall design of a 20–40 storey office building. These 'aspects' are called subjects and are divided into six areas: architecture, structural design, energy/building services, geotechnical design, fire safety and project management. It was pre-decided during preparation of the course that the deliverables should comply with the national Danish ICT requirements, which were introduced in 2007 and made mandatory in state projects [4] above a certain threshold.

The students were given a task to either design a building from scratch based on a building programme or to develop an existing design from an architectural competition into a

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preliminary design stage. Despite the differences in the starting point, the students had to develop an outline design during a 13-week period in the autumn, worth 5 ECTS points, and then to work out a preliminary design during a 3-week period in January, when the students worked full time on the design task. The second period was also worth 5 ECTS points.

2. Methodology

This paper is primarily based on the experiences gathered between 2008 and 2016 by the author, who is responsible for course 11080: Advanced Building Design [1] at the Technical University of Denmark (DTU). Wherever possible, students' evaluations [2] of the course have been included. In addition to the ordinary evaluation of the course results, additional evaluations are included [3]. Trends found while correcting the students' submissions also include undocumented statements from graduate students that are now working in the field.

3. Participants

The primary participants in the course were the students and the professors. In addition, individual speakers from design companies, contractors and software companies gave selected lectures or provided advice during the course. Prerequisites for solving the tasks in the course is on BIM area the preceding BIM-related courses that introduces model-based working methods and the most used tools in the sector, Revit, Sigma, Solibri, Dynamo etc. [8]. On the other specialist subjects, the students have carried out similar qualifying courses.

3.1 Students
The course has had between 48 and 108 students per year since its inception, see Table 1. The number of students varied based on whether the course was a mandatory or elective course in the study programme to become a Civil Engineer or a Building Designer. The students were encouraged to complete the course just before completing their Master's thesis, in order to prepare them as best as possible to benefit from and use experiences from their former courses in this course. This was mainly because the students were expected to work independently in selecting and designing solutions and to only use the professors as consultants.

The students were requested to have completed prior courses in CAD/BIM (Building Information Modelling) and discipline-specific courses at the Master's level before participating in the present course. There was no guarantee that each individual student would be able to work within their area of expertise as all the roles in each team have to be filled.

The majority of the students who take part in the course are Danes studying at the Technical University of Denmark, but one-third to half of the students are international students studying one semester or even carrying out their entire Master's study at the university. All the students have been trained in engineering skills but some lack training in BIM tools and BIM-based working methods, especially the foreign students

There are different reasons for the students following the course. Some students need the course to fulfil requirements in their study programme, while others may see the course as an option to use their skill in a realistic setting. Some students are interested and want to explore the possibility of using BIM-based working methods in practice, while others may see BIM tools as disconnected from engineering design.

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Table 1: Participants in course 11080: Advanced Building Design [1]

Year	Number of students	Number of teams
2008	69	10
2009	101	16
2010	85	13
2011	77	14
2012	48	9
2013	56	6
2014	74	13
2015	108	17

3.2 Professors

The course is led by a diverse group of professors and lecturers, henceforth herein just called professors, based at the department of civil engineering or in industry. Each professor is a specialist in one of the six aforementioned disciplines in the subject areas. Some disciplines are led and assisted by one professor while others are handled by two people. In some previous years, the Department of Management also participated in teaching the course, but that has not been possible for a numbers of years.

The role of project management has for a number of years been combined with the role of BIM manager. The professor for the project management aspect has a mixed background in open BIM and project management.

However, it must be stated that the majority of the professors from university or industry taking part in the course to date have not been specialist experts in BIM-based methods, and they have more generally considered BIM tools as drafting tools that are useful for producing design documentation. Consequently, they may not have always been familiar with the working methods that are influenced by integrating BIM tools in the design process, by sharing models or by using information technology as a vital component to maintain a consistent information model of a design that can also be actively used in decision-making.

4. Tasks

In the course, each team must develop an outline design and carry out a preliminary design of a 20–40 storey office building. Each team has to deliver a client report, a subject report per subject and subject-specific building information models, except for the project management subject. The deliverables are due in the beginning of December as an outcome of the Outline design stage, and then in late January an updated version of the material reflecting the preliminary design stage must be submitted.

After a few weeks of work, each team must deliver a team contract, while after 4–5 weeks, each subject requires delivery of a schedule and a specification detailing what information each subject needs from the other subjects. After 6–7 weeks, each team is required to give a presentation on the current state of their work. In addition to developing and delivering an outline proposal, each team is also required to perform a review of another team's outline proposal. Finally, each team must present a poster of their preliminary design.

Specific requirements have been developed for the reports and calculations that have to be includes for each subject [1]

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The role of BIM manager has, in most cases, been combined with the role of the project management. The BIM manager coordinates the development of BIM models and facilitates the generation of an ICT specification that specifies which tools the team should use and how the models should be coordinated, shared, and communicated. There are no specific requirements about which tools the teams should use, but when submitting BIM models it is mandatory that they should contain information about the architecture, the structural system, the ventilation system for one floor, the basement and the foundations, and finally the stairs and lifts that are a part of the fire safety system. If a sprinkler system is used, the system on one storey should be modelled. All the models have to be submitted in IFC [5] and native format. The Level of Development or Level of Detail is specified according to the Danish version of the level of development/detail. The first submission must be at level 2 [6], while the final submission must be at level 3 and one storey should be at level 4.

In 2015, it was made mandatory to upload the BIM models to a model server during the course, and it was made voluntary if the teams wanted to document the communication between the subjects in a team by using BCF [7].

5 Lectures and team sessions

During the autumn semester, a few joint lectures are given, but for the most part the different subjects involve subject-specific lectures or question and answer sessions run in parallel for all subjects. The number of students per session is 1/6th of the total number of students, which in the event of a low number of students could make the courses resource demanding. During the semester in the autumn, the students are expected to put in nine hours of work per week, with four hours reserved for lectures and team sessions on Tuesday mornings.

5.1 Lectures

All the students are given a joint introduction to the course, while over the years, different options have been tested, such as a focus on performance in teams, Belbin roles in teams, systems engineering and BIM-based working methods.

All the students were invited to participate in a joint lecture on Revit. Based on the replies from the projects managers, the notion of having more joint sessions performed in training in Revit was rejected.

Students are generally offered lectures or guides each week organised by the professors in each subject. Due to the background of the professors, there are differences in the role BIM is given, and thereby which tools that the students are required to use in order to solve the design task. All the engineering disciplines inform the students about what types of analyses they are supposed to perform. All the demonstrated engineering IT tools are selected based on engineering criteria without consideration of the interfaces to other programmes. The students are introduced to a programme to calculate the energy loss through the building envelope, which is mandatory to use in order to get a building permit in Denmark.

For the subject of project management, BIM managers are given lectures in relation to BIM in ICT-agreements, the required content in the delivered BIM model, the use of the Solibri Model Checker, how to handle coordinates in Revit in relation to export to IFC, export to IFC from Revit and coordination of models in IFC format. Depending on the need, students have been offered additional sessions in Revit.

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In 2015, the students were also given lectures or a demonstration of the open source model server from the Netherlands. Lectures in the generation, use and coordination of issues through the use of BCF files were also given.

Special sessions were arranged for students designing the building services/energy systems. In the past, training sessions have been given in MagiCAD and Revit – building services. Students have been given information on national contact persons in order to get access to training in ArchiCAD and Tekla.

5.2 Team sessions

The teams are expected to meet for a minimum of one to two hours each week. Some students have arranged additional sessions where they meet, despite it possibly being difficult to find a suitable time slot that fits all the team members due to their obligations in other courses. The team sessions are mainly supposed to be used for coordination between the different subjects. The project manager is expected to facilitate the team sessions and use the sessions to get updates from each member of the team. This in order to help the team to identify areas that should be coordinated and to identify tasks for each member of the team that can ensure that the team will meet its obligations in relation to the mandatory deliveries given in the course.

6 Working methods

The teams are only given specific requirements for deliveries and milestones, and the working methods to develop the design of the office building can be decided upon by the team. Each professor within each subject provides guides for the order tasks that have to be performed. The following primary working methods have been identified:

- 2D based, non-integrated;
- 3D based, non-integrated;
- BIM based, light and partly integrated.

6.1 2D based, non-integrated

This method is based on a traditional 2D drawing production. It typically involves the student taking the role of an architect to start drafting, often using AutoCAD. These drawings are used for coordination and form the starting point for many of the engineering analyses. Analyses of different areas are performed from polygons in the drawings. The coordination between plans, sections and elevations are done manually.

As it hasn't always been mandatory to hand in BIM models by the end of the 13 weeks' period, some teams have therefore prepared all the deliveries from non-BIM-based documentation. One member of the team, usually the BIM manager, produces a geometrical BIM model. This model is delivered by the end of the 3-week period. The BIM model and drawing are often not coordinated. The process is considered as a non-value added process, as the required documentation is produced by traditional means. The BIM model is not used for calculation of the area or as input in the engineering tools.

6.2 3D based, non-integrated

The teams using a 3D non-integrated workflow produced 3D BIM models. They often started with the architectural aspect and when the design was stable one or several students then

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produced 3D models of the ventilation system, the basement/foundation and the sprinkler system if one was to be installed. In some cases, a pure structural model was created in which the students included the structural components in the architectural model.

The models were used for drawing production and exported to IFC, but in most cases there was a lack of integration with engineering tools. The main purpose of the models was to avoid geometric clashes in the design and to maintain a coherent set of drawings where sections, details and elevations were coordinated. The models could also be used for the calculations of areas and quantities.

The models were generally not integrated with engineering tools, and it was therefore up to the students to maintain consistency in the design.

6.3 BIM based, light and partly integrated

Few teams were motivated or had the skills to integrate BIM models with engineering and cost estimating tools. The content of the models was usually limited to objects with a geometric representation, the identification of object types or spatial relationships, whereas technical and environmental specifications were not usually included.

The integration with engineering and cost estimating tools could be done through plug-ins, and in some situations through IFC to e.g. cost estimating and energy simulation tools. A very limited number of teams used the BCF format to coordinate consistency between the models and to solve problems or propose solutions during the design.

There have been no demonstrations of the active use of the model servers in relation to sharing or reusing information, albeit the model servers have in some situations been used for giving access to a federal model.

7 Experiences

The experiences from the course are divided into three different sections and cover different areas: Students, Organiser and BIM.

7.1 Students

There were very mixed experiences reported from the students on the course [3]. Many students complained about the relevancy of the tasks, the lack of structure, inconsistent feedback from the professors, the high focus on BIM and the dependencies on other team members. A comment from a student was "Too much work with the 3d model, is this course a drawing course or what?" [2]. The development in the students' evaluation about if they have learned a lot has improved and can be seen in figure 1.

Some students felt they were forced to participate in the course despite their study line having a non-building focus. This problem has since been solved.

Students that were used to being given tasks with one solution were easily frustrated when given a problem and put in a situation where there were many solutions and they had to find the most appropriate solution in collaboration with interest from other domains. The students were given more guidance as more milestones were included in the course, in order to assist the students in making decisions when needed, but the design aspect was kept in place as it is a key part of the course and an essential part of the course for becoming an engineer.

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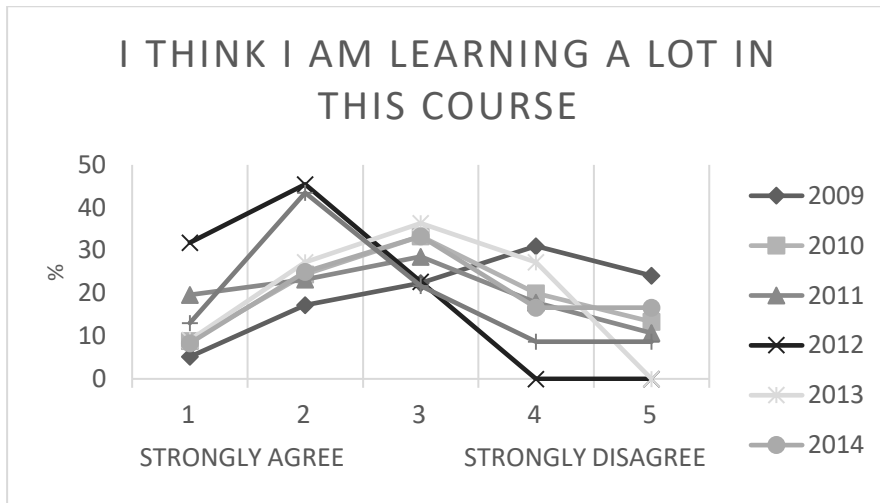
Figure 1: Development in the students' evaluation on the gained learning

The inconsistency of the feedback from the professors is caused by two reasons. One reason is the lack of coordination, which is unfortunate and should be eliminated. The differences in the importance of a BIM-based working method are one of the key problems, since some professors primarily focus on their own domain and lack skills in how BIM can be used within the design. Another reason for the inconsistency in the feedback is due to the fact that different domains can provide different guidance on the same subject. This is, on the other hand, a realistic scenario as e.g. a fire engineer might want to locate the stairs along the façade in order to ease evacuation, whereas an architect and the client might want to use the space along the façade for offices. This is considered as an invertible situation that cannot and should not be avoided addressing in the course.

A number of students consider BIM as drafting tools that are taken care of by other professions and consider this is therefore not relevant for civil engineers who should instead concentrate their effort on their calculations. This students' attitude is considered to be based on input from professors during their study and from working in industry. Unfortunately, those that consider the BIM-based working method to be more efficient, less error prone and capable of enabling the investigation of more design options do not speak up sufficiently in support.

The dependencies on other students and team members work in the course is ambiguous as it is intended that one subject or domain in the course will have to implement the needs of other subjects or domains. But it is also a real problem that the progress and quality of the design of the entire building depends on the contribution from each member of the team. Based on interviews with students that have completed the course, it was clear that a well-functioning team supports gave a positive evaluation of the course in general, and that dysfunctional teamwork had a negative impact on the evaluation of the course. However, teams are allowed to expel students from a team if a student is violating the team contract that all members sign at the beginning of the course.

7.2 Organiser

The students were in general very active during the course, and spent many hours in developing interesting and technical feasible solutions. It is disappointing for a person who

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believes in the benefits of BIM to see numerous students solving the design task without trying to benefit from state-of-the-art tools and interoperability. Most students, like most people, only wanted to use tools and methods that they were familiar with. However, although students studying at DTU were given courses in BIM, the BIM-based working methods weren't implemented in most courses, while the students working part time in industry are more likely to have witnessed a change towards a stronger position for a BIM-based working methods, but also a situation in which these methods will have suffered from legal and contractual issues, lack of BIM competences, lack of interoperable solutions and software with numerous technical problems.

A majority of the professors were not used to or did not have experience with BIM-based working methods, which had an impact on the students as the professors could not demonstrate in practice how a BIM-based working method should be developed and set up.

Some students invested significant resources in order to model the design in BIM tools. This indicates that adopting a BIM working method requires a significant effort and that the technology needs to be developed even further.

Graduate students working in the building construction industry expressed satisfaction with the course, since they say it prepared them to participate in design teams and gave them experience of working with problem solving and finding solutions Some students decided to do a thesis in the area of BIM, based on their experiences in the course.

7.3 BIM

Regarding the outcome from the course with respect to BIM and open BIM, the following findings were registered. Some students did not deliver models in both IFC and native formats. In a few cases, it was not possible to export the models from Revit to IFC, but in most cases it would have been possible to solve the problems by using a newer version of Revit and an IFC plug-in. In some cases, it was necessary to add more RAM to the PC in order to be able to export the models. Another issue is that the process of exporting to IFC can take hours for large models, and sometimes the students abandoned the translation because they thought it had stopped.

In the past, there have been problems with the wrong swing on doors while exporting from Revit but that problem has been fixed in later versions of Revit. In some cases, the students had not checked the position of the different domain models.

Despite guidance from the professor who stated that walls should be modelled floor by floor in the preliminary design stage, the walls were often modelled from the ground floor to the roof as one element.

8 Submissions in open BIM format

Between 2008 and 2016, more than 600 students in approximately 100 teams submitted BIM models in the IFC format. Three different projects were used in the course, and therefore it was not possible to make a direct comparison of the models. Figure 2 shows the structural model from 2008/2009, and figure 3 shows a poster from 2014/2015.

All the teams submitted architectural models containing walls, windows, doors, curtain walls, ceilings, slabs, furniture, sanitation, light fixtures and some finishes like flooring. Models submitted since 2012 also contain spaces, as this has been made a specific requirement since then.
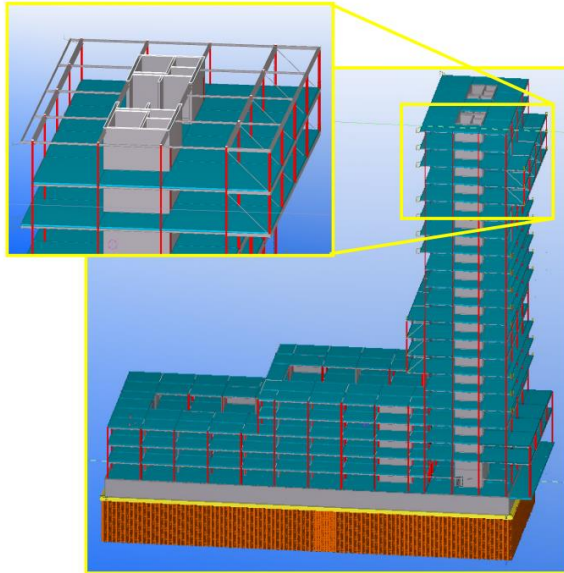
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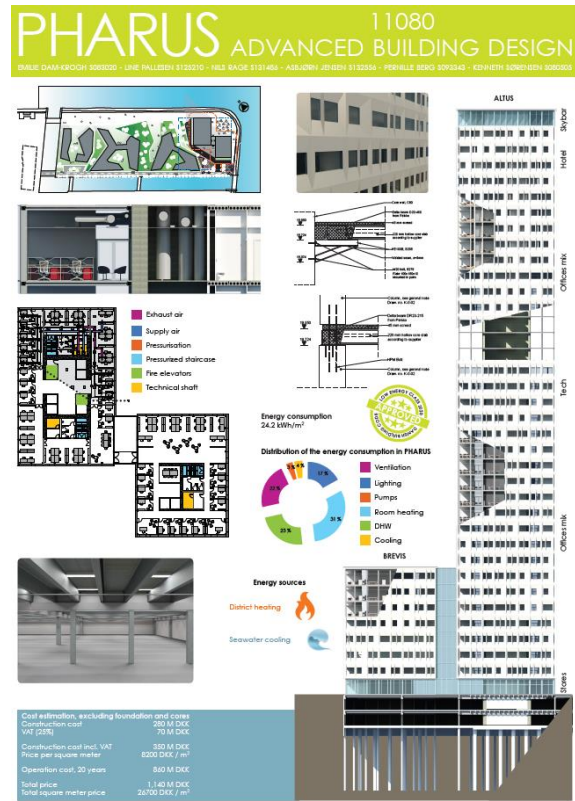22-24 August 2016, Technical University of Denmark, Lyngby, Denmark

Figure 2: *Structural model* from 20*08*/20*09 from team 2.*

Figure 3*:* Poster from *team 14 from* 2014/2015 parts of the BIM model and use of data from the models.

In some cases, the structural model was included in the architectural model, but a number of teams made specific structural models. However, when a structural model was developed, most of the structural elements were also included in the architectural model.

The building service models always contain the ventilation system for one storey. In some models, the heating system and, in a few cases, the supply of drinking water was also included. Cable traces were also included in some models.

The geotechnical models contain the basement, foundation and piles, if piles are used. The fire safety models contain potential sprinkler systems, while a few models also included spaces representing vertical escape routes.

The models are partly coordinated, but are not clash free. There are often clashes between building services elements and walls and slabs. In general, there were no vital problems regarding coordination, but there have been examples of building services elements penetrating the roof and doors/windows, which then cannot be opened because there are obstacles in front of them. From a geometry point of view, the BIM models supports the coordination between the structural system in the building with the structural system in the basement and foundation, while the routing of building services components is coordinated with the spaces, shafts and walls and slabs.

The IFC models were submitted in IFC 2x3 format, and consisted almost only of entities or objects and relations. There were typically very few properties attached to the entities or

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objects. The models were often supplemented with visualisations that were generated from BIM models.

In 2015, samples of BCF files were submitted, with BCF mainly used to solve issues regarding geometric coordination.

9 Conclusion

Six hundred students completed the design task in groups of six students over 8 years. Issues regarding challenges in coordination, teamwork building and mutual dependencies were registered from students' evaluation of the course. Overall, the students reported becoming familiar with open BIM and experienced the freedom to choose their preferred BIM tool for each specific job to see if it was possible to coordinate a building design project using open BIM. Graduate students working in the building construction industry expressed satisfaction with the course, since they say it prepared them to participate in design teams and gave them experience of working with problem solving and finding solutions.

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