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BIM teaching as support to integrated design practice

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Preliminary report

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An increase in the size of projects, ambitious design objectives, and a greater number of participants in the planning process, call for an effective integrated planning practice, and an adequate software support, such as the BIM (Building Information Modelling) tools. However, the BIM skills as demanded by practice are not represented in lecturing plans and programs at technical universities. This paper presents the interdisciplinary BIM design course conducted at the Vienna University of Technology. The feedback received from students has proven to be beneficial for creating guidelines for further BIM teaching activities.

Key words:
modern modelling in civil engineering, interdisciplinary course, integrated planning process, BIM

Prethodno priopćenje

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Izobrazba o primjeni BIM-a kao podrške integriranom projektiranju

Povećanje opsega projekta, ambicioznih projektnih ciljeva i broja sudionika u procesu planiranja zahtijeva učinkovito integrirano planiranje i prikladnu računalnu podršku, poput BIM alata (eng. *Building Information Modelling* - BIM). Vještine rada u BIM-u, a koje se traže u praksi, nisu zastupljene u nastavnim planovima i programima tehničkih sveučilišta. U ovom se radu prikazuje provedba interdisciplinarne BIM projektne izobrazbe na Tehničkom sveučilištu u Beču. Povratne informacije studenata pridonijele su stvaranju smjernica za daljnju izobrazbu o BIM-u.

Ključne riječi:
suvremeno modeliranje u građevinarstvu, interdisciplinarni kolegij, integrirani proces planiranja, BIM

Vorherige Mitteilung

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Bildung zur Anwendung von BIM als Unterstützung für den integrierten Entwurf

Ansteigende Projektumfänge, anspruchsvolle Projektziele und Teilnehmerzahlen verlangen eine wirksame integrierte Planung sowie die entsprechende EDV-Unterstützung, z.B. mittels BIM Werkzeugen (eng. Building Information Modelling - BIM). Entsprechende Anwendungskenntnisse, die in der Praxis verlangt werden, sind nicht in den Unterrichtsplänen und Programmen technischer Universitäten vertreten. In dieser Arbeit wird die an der Technischen Universität in Wien durchgeführte interdisziplinäre, projektorientierte Bildung zur BIM Anwendung dargestellt. Das Feedback von Studierenden trug der Entwicklung zukünftiger Bildungsrichtlinien bei.

Schlüsselwörter:
moderne Modellierung im Bauwesen, interdisziplinäres Fach, integrierter Entwurfsprozess, BIM

1. Introduction

The complexity of building design and construction is increasing, given the backdrop of changing requirements (e.g. energy and resources efficiency) and the advancement of technical systems. Construction projects increase in size and so does the number of planning process participants and disciplines. Hence, the multi-disciplinary collaboration is of critical importance, and an effective team decision-making is a mandatory prerequisite for meeting functional and environmental requirements. This in turn necessitates the use of new planning methods and IT-supported tools, in order to deal with complex issues and manage the joint team knowledge [1, 2]. Building Information Modelling (BIM), being a powerful planning tool, promises to enhance an integrated project delivery [3], thus reducing the fragmentation of the architecture, engineering and construction (AEC) industry.

Moreover, BIM is not only considered a powerful modelling tool for design and construction, but also as a life-cycle optimization and management tool. Facility management sector thus obtains a building-model with the highest data-richness, allowing realization of full BIM benefits in the building's operation, maintenance, and future refurbishment. The study by Gillian and Kunz [4] identifies building owners as a group that reports the greatest perceived BIM-use potential, although it is simultaneously the group of professionals that utilizes BIM the least. In the Central European region, the BIM use in the facility management and operation is still rarely encountered. Numerous problems are reported by the facility management practice in this context, such as the lack of knowledge and resources for the continuous model maintenance and management, the lack of standardization, and diverging planning and facility management standards.

BIM involves generation and management of digital representations of a structure, with the focus on physical and functional characteristics, which enables interdisciplinary data exchange within the planning and construction teams. Therefore, BIM tools empower interdisciplinary collaboration, providing it with a common building model, i.e. with the joint data and knowledge base for planning and optimization [5]. On the other hand, with the technological advancement of BIM tools, numerous possibilities for coupling various simulation and predictive tools with the digital building model have evolved, allowing optimization of building performance from the early design stages, and further on along the life cycle, which again makes BIM tools suitable for life cycle management [6].

Despite numerous potentials of BIM, the overall BIM effectives are still difficult to evaluate, and its capabilities are not well understood [7, 8, 9], especially in the context of multidisciplinary collaboration. BIM is experiencing a slower rate of adoption in most of Europe, compared to the situation in the United States or Scandinavian countries [10]. The Austrian AEC industry is especially characterized by a very strong engineering tradition and is based on fragmented, sequential planning procedures. The Austrian construction sector, as compared to other European countries, shows an above average number of patents-applications. At the same time, it is extremely regionally oriented, generally displaying a small-patterned economy with a low cooperation-experience as related to product-development [11].

This reluctance to collaborate, together with the fragmented nature of the AEC industry, has been identified as one of major obstacles hindering BIM adoption and extraction of full BIM potentials, greatly exceeding obstacles relating to technological issues. BIM implementation requires changes along the lines of technology as BIM is not a new CAD. Changes related to the process, work practices, collaboration, and communication across disciplines, are needed. Furthermore, the people involved also need to change as new roles and functions emerge, and the participants require specific training and have to acquire new skills [12]. Succar [13] advocates BIM adoption along several stages, namely pre-BIM, modelling and integration; within the fields of technology, process (i.e. interaction of numerous planning and construction stakeholders, and documentation and information), and policy (i.e. rules and principles of decision-making in integrated planning). The largest potentials are therefore in the intersections of the fields, which calls for an integrated practice. Finally, the BIM adoption strongly addresses the integration of technology along the lines of corporate strategies and management, as argued by Jung and Gibson [14]. The understanding of highly complex interdependencies and uncertainties of the real-world practice, which affects the interdisciplinary 3D-object usage, is crucial for an efficient BIM practice [15]. In order to respond to the changing requirements in the AEC practice, we have organized an interdisciplinary BIM-supported design studio, both to teach BIM-based building design, and to test the fitness of BIM for an integrated building design. A further aim was to establish an interdisciplinary BIM collaboration platform, and hence to embed this emerging technology into the curricula, advancing the planning practice through adequate education of future planners. The focus of our research, as presented in this paper, is on the evaluation of people- and process-related issues of BIM usage in building design. Based on the insights gained through the BIM adoption research, we argue that these are the crucial factors for enhancing the BIM-supported practice in the Central European region.

The remainder of this paper is structured as follows: the state-of-the-art literature on BIM in teaching is briefly reviewed in Section 2. Section 3 presents the research design of the explorative study and the interdisciplinary design studio for BIM teaching. Section 4 describes the focus group interviews and the qualitative and quantitative content analysis, which were the methods used to gather feedback on the interdisciplinary BIM course, and to evaluate this data. Section 5 presents feedback from the participants, and Section 6 concludes the paper by summarizing its findings and discussing future research based on the lessons learned from both the design studio and focus-group discussions. Furthermore, suggestions for practical adoption of BIM are given.

2. Experimental studies on BIM teaching

Given the relative novelty of BIM technology in the construction sector, obstacles such as longevity of construction projects, data protection and corporate policies, it is a well-established practice to conduct BIM studies by means of student experiments. Poerscheke et al [16] conducted a multi-disciplinary design class (architecture, landscaping, structural engineering, construction, mechanical and electrical engineering), in which students work with a given pre-design of an elementary school. This is to be optimized collaboratively with respect to evaluation criteria like the usability, sustainability etc. The intention of this study is twofold: (i) testing adequacy of BIM tools for each discipline and (ii) testing interdisciplinary collaboration. They conclude that BIM and simulation tools are useful for the enhancement of analysis and synthesis, but also that they do not enhance creativity or idea generation, for which the actual driver is interdisciplinary collaboration. Plume and Mitchel [17] organized a design studio where the interoperability via Industry Foundation Classes (IFC) was primarily tested. This study also utilizes given preliminary projects. Students of various disciplines perform cost estimation, thermal simulation, and acoustic analysis, using a common model via an IFC model server. This study was carried out in 2004/2005, at the time when technical possibilities of the main modelling tool ArchiCad and the supported IFC version were still rather limited. Since then, many of the addressed problems, such as versioning, have been solved. However, many of the problems of semantic nature persist - e.g. the definition of the "room" being different for architects and building physicists [18]. Dossick et al [19] focus on the analysis of communication and creation of new knowledge in spatially distributed student teams that collaborate in virtual environment on compiling 4D, scheduling and organizational analysis. In their study, modelling in real time supported messy talk, and therefore increased creativity. Peterson et al [20] use BIM in order to facilitate construction project management. They conducted a comparative study of two classes at different universities to address the necessity for further research in multi-disciplinary projects. Tsai et al [21] measured the time-effort needed to model a structure based on 2D drawings, and the efficiency of data transfer from a BIM model to scheduling software. For this study, students modelled real projects in order to gain an insight into resource planning while using BIM tools.

This review of the state-of-the-art in BIM teaching reveals that the early design stages remain an underexplored topic. Either prefabricated building models (prototypes) or later phases of projects - when the architectural design is already completed, were investigated in the above presented studies. In these cases, the architectural model serves as a knowledge base for the engineering or project management services (scheduling, cost management). Few studies investigate the earliest stages of a project, when the initial design evolves and the first joint model is created in a collaborative way. Thus, we lack knowledge on how the initial building design is created, analysed and optimized in an interdisciplinary and collaborative manner, using various BIM tools as support for improving both the building and the process quality.

3. Research and Course Design

In order to promote and simultaneously evaluate the use of BIM tools in the AEC practice, we organized an interdisciplinary design studio called "Interdisciplinary Design Concepts using Building Information Modelling". The studio had two focuses: integrated design in a multi-disciplinary setting, and the use of BIM tools with a special emphasis on interfaces and new functions. The study was a part of the research project "BIM_sustain" funded by the Austrian Research Promotion Agency and by the participating BIM-software vendors and developers. The study consisted of two interdisciplinary BIM courses conducted in the winter terms of 2012/13 and 2013/14. After the first year, the student feedback and the experience of the teaching staff were evaluated, and the design of the course was adjusted according to the lessons learned.

The first goal was to evaluate the multi-disciplinary collaboration when employing BIM tools in order to test if and how these BIM tools support integrated building design processes. The second goal was to test adequacy of BIM tools for modelling requirements of specific disciplines, as well as the data transfer and exchange with other disciplines. This paper will primarily focus on the evaluation of BIM as a support to the integrated building design, and on student feedback and instructors' lessons learned with regard to BIM teaching.

The design studio was organized in collaboration with the Faculty of Civil Engineering and the Faculty of Architecture and Urban Planning from the Vienna University of Technology. The studio took place in the autumn of 2012, and again in the autumn of 2013, and each time the studio work lasted one semester. The disciplines considered were architecture, structural engineering and building science and, accordingly, the participating students were from the respective curricula (architecture, civil engineering and building science). The class was monitored and finally evaluated by the Institute of Management Sciences, Faculty for Mechanical Engineering; via pre- and post-questionnaires and focus group discussions, as well as through evaluation of protocols. For this class, a total of twelve tools for architectural modelling, structural modelling, thermal simulation, daylight simulation and compilation of energy performance certificates, were used in various software constellations (namely ArchiCad, Revit, Allplan, REFM, Scia, Sofistik, Plancal, Tekla, Archiphysik, TAS, EnergyPlus, Dialux). The use of the software was facilitated through the software education and support as provided by the software developers (project-partners).

In the first year, which served as a pilot experiment, the design studio involved 11 student teams, with 39 students

Table 1. Course design in 2012 and 2013

Nastavni plan i program	First iteration winter term 2012/13		Second iteration winter term 2013/14	
ECTS	Civil Engineers	6 ECTS	Civil Engineers	6 ECTS
	Architects (elective)	2 ECTS	Architects (elective)	5 ECTS
	Building science	8 ECTS	Building science	10 ECTS
Task	Design of a low-energy office GFA = 7.500 m²		Design of a cultural center GFA = 3.000 m²	
Contact time	Weekly meeting of the course instructors with each team			
Presentations	two intermediate presentations, one final presentation			
Evaluation	25 % Joint model 25 % discipline related model 25 % integrated concept quality 25 % interdisciplinary collaboration			
Team building	predetermined by course instructors based on software skills and predefined software constellations		Team building workshop, free choice of team	
Software selection	Predetermined by instructors based on software skills		Free choice of modelling software constellation as a team	

participating. The first course iterations assignment was a sustainable office building design, for which students were provided with a functional program, site-plan with orientation and set origin, and the layer-structure and colour scheme for room-stamps. The students were assigned to the use of the software they were most familiar with, according to their self-evaluation in the pre-experiment questionnaire. The teams were then put together based on software constellations: each team used a different combination of BIM-software for the architectural modelling, structural modelling and analysis, thermal and daylight simulation, and the analysis and modelling of the ventilation system. The software-matrix was compiled by the supervising team, in order to gain insight into the software interoperability and compatibility. The task of the teams was to develop a preliminary integrated design, consisting of the architectural and functional design, load bearing structure, HVAC (ventilation) and energy design, together with the proof of the concept used (simulation and optimization). Therefore, the teams had to hand in an architecture model including the structural design, thermal and ventilation models (as representative of MEP), as well as the thermal simulation and energy certificate.

According to their curricula, the students were assigned different number of ECTS credits (architects 2.0 ECTS, engineers 6.0 ECTS, and buildings science 10.0 ECTS). The credits proved not to be adequate for the workload.

In the fall of 2013, i.e. during the main experiment, 12 teams with a total of 43 students (13 architects, 8 civil engineers and 22 building scientists) participated in the interdisciplinary BIM design studio. Based on the experience gained during the first class, the design of the course was altered: In order to simplify the task the assignment was changed to the development of a multi-functional event centre. Furthermore, a kick-off workshop was organized where the students were encouraged to form the team and to decide on the software they wanted to work with. At the next session, a one-week collaborative pre-design workshop was offered. The credits for the class were increased to 5.0 ECTS for the architecture students, thus leading to a more balanced distribution of workload and scores.

Table 1 summarizes the course tasks and differences between the awarded course credits in the winter terms of 2012/13 and 2013/14.

4. Method

The observations and results presented in this paper are based on the feedback of the participants collected during focus group discussions after the interdisciplinary BIM courses. For both iterations of the course, participants from each discipline (i.e. architects, civil engaineers and building scientists) were invited at the end of the semester to separate group discussions, during which they had the opportunity to exchange their impressions and evaluate the course and their experience with the BIM process and the BIM software among members of their own discipline, instead of among members of the interdisciplinary team in which they worked throughout the semester.

Focus group discussions are aimed at collecting qualitative data from discussions of a relatively homogeneous group on a specific topic [22]. Due to group dynamics and group discussions, the data gathered by focus groups are typically more detailed and extensive than the data resulting from mere interviews. Table 2 summarizes the participants in the six focus group discussions after the first course and the second course on the interdisciplinary building planning.

Table 2. Focus group participants by year and discipline

Role	1. iteration winter term 2012/13	2. iteration winter term 2013/14
Architects	9	13
Civil Engineers	11	7
Building Science	15	20
Teams	11	8

The discussions took about one hour and started with a general introductory question by the moderator ("How did you experience the interdisciplinary BIM course"). Topic guideline questions covering collaboration with other roles during the planning process and experience with BIM software, which were not addressed by participants during the discussion, were asked only in case the discussion stopped.

The discussions were audio recorded, transcribed and then analysed by summarizing the content analysis [23, 24]. This summarizing of the content analysis is aimed at collecting the main contents of the material, which is in our case the feedback of the students participating in the focus group discussions. Starting from the original transcripts, the content is simplified, generalized, and finally bundled to content categories that reflect the content at a more abstract level. Additionally, in order to obtain more objective quantitative data about the content of the focus group discussions, they were analysed through the quantitative content analysis [25] by two independent coders. This was done to enrich the collection of topics accomplished, and the content analysis summary, by adding more detailed information about the importance of these topics measured in the relative frequency of these content categories in the overall discussions.

5. Focus group discussions

The categorization and coding process of the transcribed discussions derived the following content categories: people related issues, the course, aspects of the software used, general discussion about BIM and the task, collaboration within the team and reflection. Through this lens, the frequency of the statements related to the content category was analysed as illustrated in Figure 1.

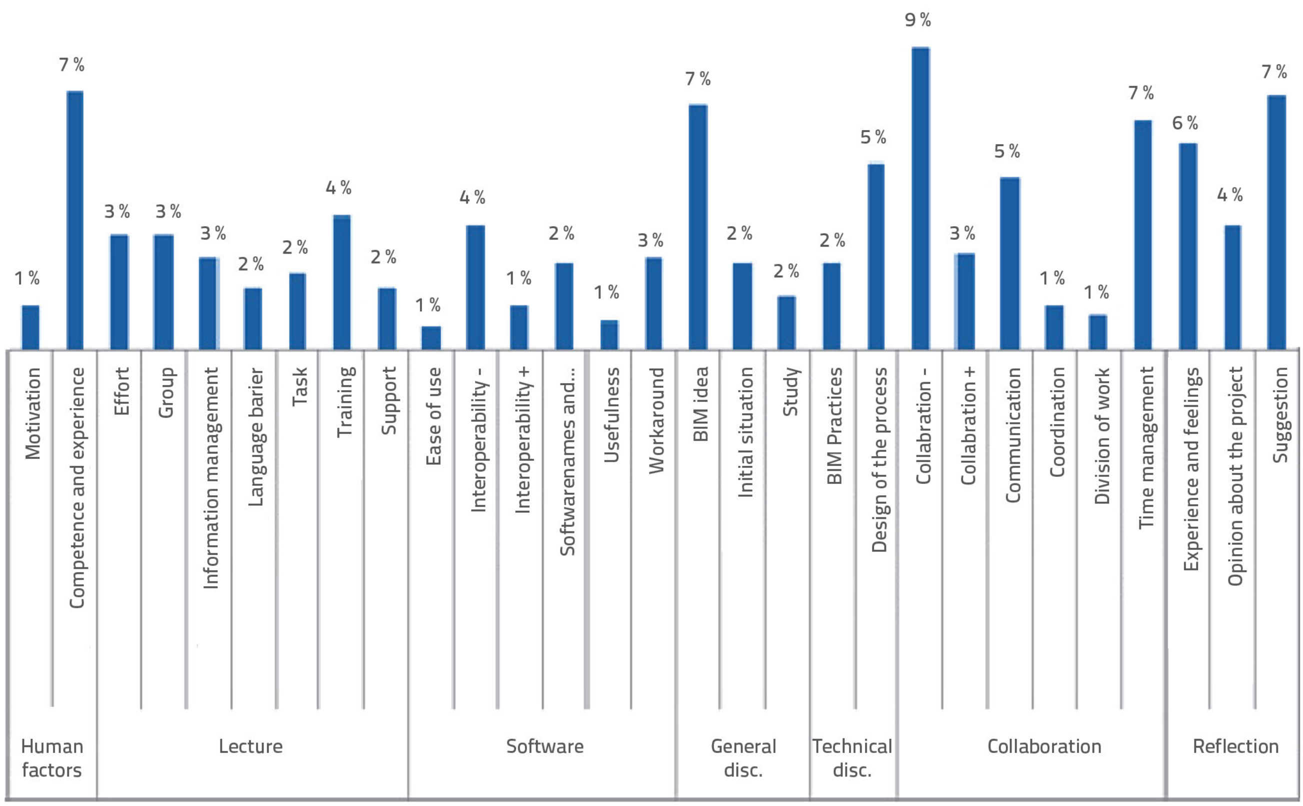

Figure 1. Detailed presentation of focus group topics addressed during main experiment

Problems in collaboration between team members were one of the most important topics throughout the discussions (9 %). This was followed by general discussions on the idea of BIM and its pros and cons (7 %). Other important topics were the competences acquired and personal experience gained during the interdisciplinary course (7 %), the problems of time management and adhering to deadlines (7 %) and suggestions for improvement of the course and integrated planning procedures in general (7 %). Besides this purely quantitative representation of the importance of the topics for discussion participants - measured in the percentage of thought units that can be assigned to these categories - as derived from quantitative content analysis, the summarizing content analysis provides a more detailed information about the actual thoughts of the participants as described in the remainder of this Section. The main discussion topics deal with

- process - i.e. the team decision-making and integrated planning practices
- people - i.e. the communication and conflict between team members from various disciplines
- software - i.e. the functionality and usefulness of modelling and simulation tools.

Besides these three central BIM-related issues, the discussions also focused on some administrative topics that are related to the context of BIM-teaching in interdisciplinary university courses, such as the general value of interdisciplinary BIM courses, the equality of courses across disciplines (which influences the motivation of the students), the design quality trade-offs due to additional work and, finally, discussions on the course schedules and overall workload. While for most of these topics the discussions were not significantly different after both iterations of the interdisciplinary BIM, we did identify major differences for some topics that can be attributed to the changes in the course design between the two iterations.

5.1. Process

Team decision making and integrated planning

The integrated planning approach was appreciated by the students, and it was felt that a collective progress was made. Bringing different disciplines together was seen as a good experience. Although conflicts did arise, they were also seen as a positive stimulus. Joint meetings and decision-making sessions increased commitment to the joint project. Civil engineers and building scientists positively experienced the integrated approach as a possibility to influence the project at an early stage and therefore avoid having to solve performance and structural problems after the design is finalised. The design-workshop, as implemented in the second run of the experiment, was also appreciated, especially by the building science and civil engineering students, because it gave them the opportunity to contribute to the design and to understand the design concept better. This also improved communication within the team. Architects, however, reported in the second experiment that the cooperation was difficult at the beginning of the course. Especially when all team-members were sitting together in the design-workshop, they felt as if the input from the building science and civil engineering limited their options and restricted their design. In some cases, the architects felt the revision requests to be an unwanted and disturbing interruption in their work, especially when they implemented changes to the model. In some groups, the adaptations were made by building science and civil engineering students, which led to fewer conflicts as this did not mean an increased workload for group work. The participation, contribution and communication were improved if some common ground was found between the students (like for example building-science students with a background in architecture). Thus it can be concluded that interdisciplinary courses can assist in establishing a better understanding of the tasks of other disciplines, which is beneficial for teamwork in interdisciplinary projects. Though BIM should support integrated planning, not all teams really followed the integrated approach but worked on the project in a sequential manner after the start of the project, and were unsatisfied with this.

5.2. People

Coordination, communication and conflict

Many problems in the teams seem to be dependent on the people and not on their role (discipline) within the project, i.e. the problems resulted from the general interdependency situation in the project, and in some groups also from the personality of the group members. Additional sources of conflicts were problems with data exchange between software. This led in many cases to an additional workload because the model had to be reworked to take into account changes that caused redundancies. Changes had to be discussed and then implemented by someone in charge. Groups that met for data exchange tasks faced fewer problems. However, groups without problems also managed their other work without meetings, and so direct communication does not seem to be a must for problem-solving. In general, sources of conflict were seen quite differently. While some groups performed well and saw problems only with the software, others stated that conflicts mainly arose not from personal conflicts but from instances when people did not fulfil their tasks in the joint project.

The students self-organized their favoured communication channels and made increased use of social media. Asynchronous communication (e.g. Facebook groups and Dropbox for the exchange of documents) was used by many teams, especially because students attended other courses, simultaneously worked on other projects, and had part-time jobs, which made physical interaction difficult. The Skype, mobile phones and e-mails were also used. Communication was also hindered by language problems as the course was taught in English and German. As not all the students spoke German, the communication and all the documentation and information

was changed to English in the second run, and thus the communication within the course was improved.
Project members agreed that there is a need for a project leader. Architects took over the coordination, deadlines, hand-ins, etc. This may be due to the fact that the process was initiated by the architectural modelling, which moved architects to the project-leading role. This was also recognized by other team members. The communication was perceived as one-way by some architects, who complained that only they send out something and do not receive any feedback. Others stated that they received only feedback on e.g. dimensions from civil engineers. To the question of why a more detailed input was not provided despite expectations, only factual information of the kind 'this is the way it should be' was communicated. On the other hand, some building scientists and civil engineers also complained that their suggestions were not taken into consideration.

5.3. Software

BIM software

Software knowledge and skills are important, as otherwise a lot of effort would go into learning the software and many problems would arise because of the lack of this specific knowledge. Even if not familiar with the import/export functionalities, a familiarity with the software is necessary because otherwise this lack of familiarity with software poses an additional burden. This was also observed during group formation in the second course when, in the entry questionnaire, the software experience was evaluated by the participants as more important for group selection than team composition. There were quite different experiences with the interoperability of the software depending on the software constellations used in the team. The two-day software trainings were appreciated but also considered insufficient for proper use of software on a complex project. Learning how to use software is a process that takes several years, and cannot be covered by one or two-day software instructions. Some, but certainly not all, software problems can therefore be attributed to the lack of software knowledge or unfamiliarity with the import export functions of the software.
However, it is generally considered that the BIM-software lacks interoperability. Data exchange led to multiple errors. In case of errors it was not clear what actually caused them. Users had to go one or more steps back and to redo the data export activity. One participant suggested to move error messages and consistency checks from import to export so that they can be solved at the source. It was also suggested that only tested software combinations should be used for teaching purposes in order to decrease the additional workload for the students. In most of the teams data exchange problems led to the models being redrawn which counteracts the BIM idea, i.e. only in few cases a group worked together on a single model throughout the entire project.
Participants argued in detail that the interoperability is not as good as one might expect and as it should be for practical use. They consider that software developers have incentives not to be too compatible as they want to sell their product. It is considered that contemporary design is not very well supported by BIM software, i.e. that BIM is better for simple projects and in later stages of the project.

Simulation software

The users appreciated general software functionalities of simulation tool kits. Lacking software knowledge, however, led to lower confidence in the validity of the results. According to the focus group discussion participants, the interdisciplinary course was a good opportunity to combine different software for different purposes in a single project and experience what they can accomplish if applied together in a bundle.

5.4. Administrative issues

The value of interdisciplinary BIM courses

Participants in all groups mentioned that they benefited from the interdisciplinary course because they gained valuable insight on how the other disciplines approach their tasks. Preconceptions about the other disciplines were detected in some instances. Practice demands and assumes knowledge on interdisciplinary planning, but this was barely discussed in any of the curricula.

Equality of courses

Awarding ECTS within interdisciplinary BIM course should be as balanced as possible when students of different curricula participate in the project. Above all, course credits influence the effort spent on courses. Also the type - mandatory or elective -influences to some extent the priority of the course for the students. Inequality can cause feelings of unfairness and envy, reduce the willingness to contribute, or cause conflicts if some have higher/lower stakes in the project than others. It was especially problematic in this case as the course was mandatory for some students and elective for others. This caused differences in the motivation of participants. Especially for elective courses, but of course also for mandatory courses, the ECTS should somehow reflect the workload. Accurate information about the total time spent on the course (when ECTS are not representative) would allow students to better plan their resources. Learning the software and coordination with other disciplines is very time-consuming, and should not be underestimated. Participants, furthermore, should be at the same level in their studies to be able to contribute equally. Therefore, graduate and undergraduate students should not be mixed in groups. This was perceived as a problem by both sides, the potential receivers and potential providers of input and feedback that did not receive or could not provide this input and feedback. It is also important that the information is symmetrically distributed, so as to avoid situations in which some roles have more or better information from their instructors, which could place their group members in a weaker position in the joint project.

Design quality trade-offs

Compared to a traditional design class, students from different disciplines were required to work together within this project. Additionally they had to cope with unknown software and with the issue of data exchange. All this had an impact on the quality of the design, e.g. some students preferred simpler design solutions in order to avoid problems with data transfer. This is supported by the often stated opinion that BIM limits creativity and is only suited for simple problems. While interoperability problems or the lack of knowledge of BIM and the export/import functionalities of software led to simpler designs in some teams, some architecture students explicitly resisted the software regime and opted against attempts to reduce complexity to make model transformation easier. Architects also reported that, due to their position at an early stage of the process, they felt pressure from other professions to deliver input fast regardless of quality. Furthermore, improvements were seen as critical, because they led to rework. This altogether might also lead to an inferior design quality.

Schedule and workload

For a good interaction in an interdisciplinary course, it is necessary to determine deadlines for the design delivery, because subsequent disciplines need the input for their tasks. Changes in the original model cause rework loops and extra efforts in consequent l disciplines, especially as import does not work and remodelling and repair is necessary as discussed subsequently.

In the first phase of the course, the work pressure was put on the architects. Detailed information and decisions have to be communicated in order for the other disciplines to perform accurate simulations and calculations. Nevertheless, the early involvement of all the professions is generally seen as positive by all parties. Overlapping competences (e.g. building scientist with architectural background) facilitate understanding within the group, and allow shifting of work between disciplines. However, involvement of other disciplines should take place from the very beginning of the project, as it was the case in the kick-off team-building workshop of the second course..

In later phases of the project the workload of the architects was lower (only some adaptations due to input of the later disciplines) and the main work shifted to the civil engineering and building science. The workload for architects at the beginning of the course is considered critical as is the resulting time pressure originating from other roles. Many of the civil engineers and also building scientists report time pressure for later tasks due to lengthy design process.

Effect of changes in the course design

We observed a polarization of the satisfaction of architects with the process and integrated planning in the second cycle of the course compared to the firstcycle, despite the introduced team-building workshop and design week. Though the feedback of later disciplines - civil engineering and building science - was very positive as they were involved in and experienced early design phases of a project, the architects' feedback was not as consistent. Some architects honoured the input of their colleagues from other disciplines, but others complained that their demands and suggestions limited their creativity. In addition, the demands to deliver a first architectural model for following discipline's evaluations and simulations imposed further pressure on them. On the other hand, the possibility to independently choose software did not greatly affect the course and the discussions. The participants reported that the existing software skills were the major reason for selecting a group - as it is difficult to learn a new modelling software in just one semester. The free choice of software did not positively influence the evaluation of the software usefulness or interoperability. As could be expected, the reduced task volume led to fewer complaints about the workload and also to fewer import-export problems. However, these problems could not fully be suppressed.

6. Conclusions

The first iteration of the course demonstrated that the use of BIM tools alone is not sufficient for improvement of an integrated building design. Some student teams, though using BIM tools, were still working in a sequential manner, starting with architectural design, continuing with structural engineering and building physics, using re-active instead of pro-active processes. Collaboration between the members of these teams only worked out in the last stage of the project, before the final presentation, for which a complete model was required. This situation improved with the second run of the experiment due to implementation of a kick-off meeting including an adequate teaming workshop that established a team spirit and revealed the common sense of the joint project. The focus group interviews pointed to major problems with incompatible software constellations, which lacked interoperability, causing numerous problems and conflicts at the interpersonal level.

Learning from the pilot, a better structured design process was developed for the second iteration of the interdisciplinary BIM design studio. Integrative phases alternated with individual planning sequences. A kick-off workshop was organized for team building, where students were able to select the software and the team. The software combinations were designed carefully with regard to compatibility and interoperability based on our findings from the first course, in order to support the process and prevent extensive conflicts with teams due to software issues. The focus group interviews revealed stronger focus on collaboration problems and benefits during discussions, while software interoperability was not the major topic any more. The students reported that they selected their team primarily based on their software preferences and skills, and not for reasons of personal or professional compatibility.

As presented in previous section the feedback of the participants in the focus group discussions generates a huge body of information on the interdisciplinary BIM teaching. The topics were

- integrated planning process
- coordination and conflicts between people
- software functionality and interoperability
- administrative issues concerning the design of the interdisciplinary course.

In general, it can be concluded that the students were mainly focusing on learning or testing the new functions (data transfer and exchange) of BIM tools. Another challenge for the participants was the interdisciplinary collaboration, which is also a learning process. With these two newly introduced tasks, the students were not able to adequately cope with the improvement of the building design. Therefore, in both iterations of the course the resulting projects proved sub-optimal in terms of design quality. This emphasizes the trade-off of interests when several new requirements are imposed in the course at the same time. Different perspectives of the participants on several topics were noted. This was observed not only among the students that performed the roles of different professions in the design process, but also among students and lecturers. For instance, lecturers see inferior quality of the resulting models, while students on the other hand point to good performance. Given the obstacles they had to face with other disciplines involved in the process and with the software, the achieved results were satisfactory for them.

Time pressure and stress are especially noticeable in the later planning stages, calling for an accurate time management and structuring of work-packages and deliverables. Interoperability is still a dominant issue. Positive experience overweighs the negative one, especially for the architects and structural engineers, who describe the data exchange as well as the collaboration with other disciplines as interesting and inspiring. Some architects confessed that they were under pressure due to interdisciplinary collaboration, as well as limited in creative expression. The professional experience of team members and knowledge of other disciplines (e.g. building science students with a bachelor degree in architecture) contributed to better understanding within the team, since such members were familiar with the work-scope and requirements of the other discipline. Very efficient teams are characterized by proper regulation of rules for modelling and coordination within the team in the early stage of the project. In many teams, architects were assigned management and coordination tasks, partially due to the fact that after producing an architectural model they had fewer duties in the project, and therefore more latitude. Varying motivations and incentives can be conflict triggers, such as the varying number of ECTS for each discipline - a problem of varying rewards can often be found in the planning practice. Due to intense collaboration on a joint model, the group dynamics plays an important role in the BIM supported design.

These observations and results, together with our considerations, constitute the basis for the following implications for future interdisciplinary BIM courses:

Impose a firm time schedule - later planning stages suffer from missed deadlines or prolonged design phases by the architects. This causes not only stress and negative team climate, but also the overall project quality suffers, as there remains no time to incorporate findings of the simulations into design updates. Architectural design takes time, and should therefore be handled in a design studio prior to the start of the actual BIM course; or alternatively the BIM courses that involve creation of an integrated architectural design can be organised as two semester-courses only. If a sufficient time is given for evolution of an integrated architectural design, then the design quality will be higher, which was observed to be insufficient in the evaluated courses.

Enforce verified software combinations - Chose software combinations that are known to be interoperable. The additional tasks of team coordination and the actual operative design and optimization tasks consume a lot of time - as it should be the case in a BIM-course. Coping with import and export problems and eventually redrawing the whole model is not only time consuming at the cost of more important tasks, but at the same time it is very frustrating for participants to learn that some software combinations just do not work properly, even if the software claims to support industry standards (ifc).

Clear rules and responsibilities - though they might vary between groups so that there is no absolute best set of rules for modelling and task allocation, the participants should be encouraged to determine group rules and responsibilities within the group. These investments before the actual joint project starts will pay off tremendously as they can prevent conflicts and inefficient excess work.

Same input same output - To ensure the motivation it is important to give the students the same incentive, namely equal ECTS for their courses, otherwise they might refuse to perform the tasks they are assigned to, and so the entire group will suffer. The true workload of the BIM course should be communicated transparently. Students are willing to invest some time in order to make themselves familiar with this relevant planning approach. However, they need clear information for their semester planning as well.

Due to the diverging university curricula, the conduct of interdisciplinary design classes may prove challenging without an explicit support from the university management and the deans from different faculties. However, innovations in BIM teaching are necessary for the advancement of both education and planning practice [26, 27]. The same principle applies to the practice - interdisciplinary cooperation demands more communication and coordination. It therefore requires support at the corporate and project-organization level in order to generate sufficient resources and acceptance. In summary, one can confirm the thesis that BIM software holds significant potentials for an integrated building design, analysis and optimization. However, in order to enable a full realisation of these BIM potentials, an adequate teaching and education focusing on required skills, and a more intensive communication and team-coordination, is mandatory.

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