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DESIGNING AND EVALUATION PROCEDURES FOR INTERDISCIPLINARY BIM USE – AN EXPLORATIVE STUDY

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ABSTRACT

Building information modeling (BIM) tools are increasingly present in the architecture, engineering and construction (AEC) industry. This software tool chain not only requires new knowledge on the level of technology, but moreover, a new knowledge of people related skills and re-configuration of the process. There is hope that BIM tools will increase the degree of process integration and support the multi-disciplinary planning practice. In order to test this assumption and gain first insights in multi-disciplinary collaborative planning process using various BIM tools, an experimental study in an university course on multi-disciplinary design was carried out. The results of our analyses indicate that BIM software is perceived as highly useful but not interoperable. The lack of interoperability and resulting problems are also the main topic of focus group discussions conducted after the course. Architects are less satisfied with the interdisciplinary planning process. Early coordination, concerning organization and software, proved positive for later collaboration.

KEYWORDS: BIM, interdisciplinary planning, process integration, experiment

INTRODUCTION

The architecture, engineering and construction industry (AEC) faces a need for integrated planning procedures that enable efficient collaboration and knowledge sharing among the disciplines involved. Building Information Modeling (BIM), i.e. the joint usage of digital building models throughout the building life cycle by the involved actors, is argued, in practice and academia, to enable collaborative planning by facilitating communication and information exchange between diverse participants in the planning process. The usage of BIM should improve efficiency and quality significantly, while simultaneously reducing planning time.

BIM is expected to bear a large potential for the enhancement of design integration, thereby enabling a shift from fragmented design tradition still largely dominating the AEC industry (Fellows and Liu 2010). Advantages of BIM can be identified on two levels – real and virtual. In real world, through software and model interoperability, project-value is increasing along the fragmented AEC value chain, enabling the communication and collaboration of different tools and stakeholders. On the virtual level, simulation and therefore optimization of construction process is possible in the early design phases, at still low cost (Grilo and Jardim-Goncalves, 2019).

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Rekkola et al (2010) argue that integrated design is still handled rather loosely in practice – often the creation of single BIM model is sufficient for the project to be referred to as integrated project, regardless of actual interdisciplinary data sharing and model use. Former BIM research has largely focused on solving of technical issues related to the data exchange and creation of functional interfaces. However, current research emphasizes that process-knowledge beyond technological issues, like workflow management and business practice accommodate the actual benefits of BIM. Rekkola et al (2010), for example, identify problems and benefits of BIM-supported integrated planning processes in the following areas: (i) people (competence or knowledge problem), (ii) process (work-flow, timing, contracts, roles) and (iii) technology (software). They argue that for enhanced integrative practice an interrelation of people, process and technology is compulsive. The lack of knowledge of BIM supported process and related people-problems in their opinion causes the slow BIM-adoption, that can currently be observed in practice. Moum (2010) goes even further in her study of five design team stories using 3D BIM in an interdisciplinary setting, in claiming that technology issues are secondary, and non-technological issues are the central problem in BIM supported design. The nature of architectural design, based on tangible “baking bread” and intangible “playing jazz” capabilities, makes the successful and efficient BIM tools implementation particularly difficult, where technology usability, user behavior and team interactions are interlaced in multiple ways and require careful balancing across these two processes.

BIM is experiencing a slower rate of implementation in Europe than in the United States, especially in Central Europe (McGraw Hill, 2011). Given the lack of best practices in the Central European planning tradition (involving architects, planners and contractors) we decided to accomplish an explorative study to explore potentials and deficits of BIM in the multi-disciplinary design process within design studio class with student participants. BIM in teaching is already a relatively well-established method, especially in the field of construction management. Peterson et al (2010) focus on teaching project management methods using BIM tools, in single-disciplinary setting, extracting project management relevant data (scheduling, masses for costs) from architectural models and transferring the data in various project-management tools. Hyatt (2010) uses BIM tools for scheduling, LEED certification scheduling and 4D simulation. Both authors, Peterson et al and Hyatt conclude that “real” tools are of significant importance – the work experience in the first case or the field trip experience in the second are crucial factors for learning or grasping of optimization potential of a project much more than technology. Poerscheke et al (2010) study multi-disciplinary design (architecture, landscaping, structural, construction, mechanical and electrical engineering) where students optimize a given pre-design of an elementary school in collaborative manner for usability, sustainability etc. The intention of this research is twofold: to test BIM tools for fitness for each discipline on the one hand and the interdisciplinary collaboration on the other. They conclude that BIM and simulation tools are useful for enhancement of analysis and synthesis but do not enhance creativity, the actual driver for idea-generation is the interdisciplinary collaboration. Plume and Mitchel (2007) test in their course the interoperability of BIM tools via the IFC interface, again using 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 course dates back to winter term 2004, where the technical possibilities of the main modeling tool *ArchiCad* respectively the supported IFC version were still limited, and many of the addressed problems, such as versioning have been solved. However many of the problems of the semantic nature still remain unsolved – e.g. the definition of the “room” being different for

architects and building physicist. (Kovacic et al 2013). Dossick et al (2012) focus on the analysis of communication and creation of new knowledge in spatially distributed student teams that collaborate in a virtual environment, compiling 4D scheduling and organizational analysis. In this domain modeling in real time actually supports the messy talk and thereby increases creativity.

None of the above discussed BIM teaching approaches focuses or actually deals with the process of initial, collaborative building design. These instead apply either prefabricated building models and designs or are in later design phases where the architectural design is completed, and architectural model serves as knowledge base for project management tasks (scheduling, cost management). There is still lack of knowledge about the creation of the initial building design, its simulation and optimization in a collaborative manner using the various BIM tools to support both, the improvement of the building quality as well as planning process quality.

RESEARCH DESIGN

In the evaluation of BIM performance in multi-disciplinary design process, we primarily aimed at examining the role of BIM in the integrated design process in the earliest stage, where the architectural model is initially created including structural predesign and energy (HVAC) concept. **Further aim was to** examine the fitness of BIM tools for requirements of each discipline concerning data-exchange. Thereby both technical issues, such as usefulness of tools and interoperability in heterogeneous software environment, as well as non-technical issues such as diverging professional languages and semantics, communication and organization, play equally important roles. As framework for the evaluation the triangle 'technology – people – process' was used, as research shows that despite the focus on development of technology in BIM research (software interoperability, advancement of singular models, versioning and model sharing), the actual success of implementation largely depends on people (skills, understanding, capacities) and process (management strategy, process design) (Arayici et al 2011, Singh et al 2011, Gu and London 2010).

For this purpose we conducted an exploratory study with graduate students in a design studio class: "Interdisciplinary Design Concepts using Building Information Modeling". A total of 39 students from architecture, structural engineering and building science collaborated in eleven multi-disciplinary teams, each group used a different BIM software constellations. The design class was organized and supervised by three departments of the Vienna University of Technology: The Department for Industrial Building, Faculty of Civil Engineering, Department for Building Physics, Faculty of Architecture, and the Department for Management Sciences, Faculty for Mechanical Engineering which was in charge of the evaluation of the experiment.

The teams were given an assignment of a sustainable office building design, for which they were provided with a functional program, site-plan with orientation and set origin, layer-structure and color scheme for latter room-stamps. The students were assigned to teams – each featuring a different combination of BIM software for architecture, civil engineering and building science as shown in Table 1 – according to their software experience based on a self-evaluation in a pre-experiment questionnaire. Each team used a different combination of BIM-software for the architectural model, the modelling and calculation of load bearing structure and the thermal and daylight simulation, as well as ventilation calculation, simulation and modeling. The task of the teams was to deliver a preliminary integrated design, comprising of architectural and functional design, load bearing structure, HVAC (ventilation) concept and energy concept together with a proof of concept (simulation and optimization) – shown exemplary for one of the

groups in Figure 1. The teams had to deliver architectural-, structural, thermal and ventilation (as representative of MEP) models, as well as thermal simulation and energy certificate in collaborative manner.

Team	Architectural Model	Structural Model	Engineering	Building Science (Thermal Simulation: TAS, Energy performance Certificate: Archiphysik, Daylight Simulation: Dialux)	
	CAD	CAD	FEM	CAD	Calculation
1	Allplan	Allplan	Scia Engineer	Allplan	Allplan
2	Revit	Revit	Sofistik	Revit	Plancal
3	ArchiCAD	Tekla	Dlubal RFEM	Plancal	Plancal
4	ArchiCAD	Allplan	Dlubal RFEM	Plancal	Plancal
5	Revit	Allplan	Scia Engineer	Plancal	Plancal
6	ArchiCAD	Allplan	Dlubal RFEM	Revit	Plancal
7	Allplan	Tekla	Sofistik	Revit	Plancal
8	Revit	Tekla	Scia Engineer	Allplan	Allplan
9	ArchiCAD	Revit	Dlubal RFEM	Plancal	Plancal
10	ArchiCAD	Allplan, Tekla	Dlubal RFEM	Revit	Plancal
11	ArchiCAD	Tekla	Sofistik	Revit	Plancal

Table 1: BIM tool constellations

TEAMS AND COLLABORATION

The class involved 13 architects, 11 civil engineers and 15 building physicists, working in 11 teams, each team comprising at least one of every discipline, several groups comprising 2 building scientists and 2 architects.

The time-schedule of the design-class was strictly organized - the course and experiment took one semester. The class was structured as succession of weekly feedback sessions, as well as two intermediate and one final presentation. The two intermediate presentations were at the point in time succeeding the interdisciplinary model exchange. The first presentation included the presentation of digital architectural model, and of structural and energy concepts, the second the architectural and structural models and energy simulation, and the final the optimized integrated model with thermal simulation results. In between the weekly feedback sessions and

the software training crash-courses took place, where supporting software vendors introduced the specific BIM software functionalities and provided data exchange support. Besides to the software training, the students were given an introductory lecture on BIM basics and principles.

After assigning the students to the teams and to the task, the teams were left to themselves in terms of organization and coordination. The only obligatory meeting was the Friday discussion session, where attendance of the complete team was required; as well as the attendance of the two intermediate and one final presentation.

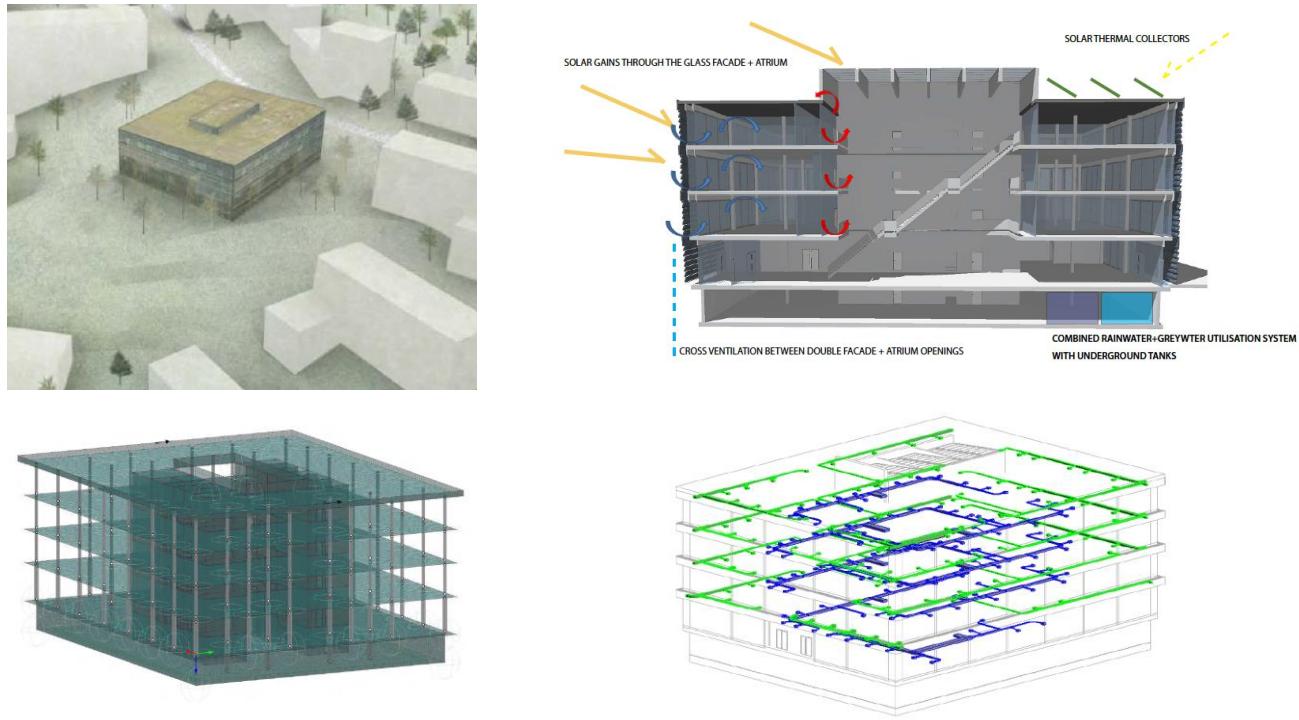


Figure 1: Exemplary resulting models of a student-project: architectural, structural, energy concept, ventilation

RESULTS AND DISCUSSION

Our analyses of the technical and the inter-personal aspects of the multi-disciplinary integrated planning processes in the eleven groups of the experiment bases on several data collected during and after the course. The experiment was evaluated on the level of people, process and technology, via protocols and time (self-)assessment, post questionnaires concerning the BIM software and the BIM planning process and outcome, as well as focus-group discussions with the representatives of the three disciplines after the experiment. Observations of the course instructors are addressed later in this section.

The students were keeping and delivering time reports, in order to determine efficiency, but also to allocate temporal resources spent on specific activities (communication, coordination, modeling, technical problems). Additionally, participants kept protocols which allowed to uncover problems related to the technology (data exchange, data transfer problems), but also people- and process-related issues (conflicts, communication difficulties, lack of work-flow definitions, etc.).

The time reports included the time categories: software training, design (generating ideas, sketches, modeling), technical planning (analysis and calculation, model adaptation, preparation of the presentation), weekly feedback session, technical problems (online support of the vendors, model exchange related problems, model adaptation for import/export, problem solving) and organization (direct and indirect communication, meetings) – see Figure 2 for a exemplary Pareto-diagram of the total work time spent by one of the groups on these activity categories. The results for time assessment vary between groups, however a consistent observation is that most of the time is however used for the technical planning, followed by technical problems.

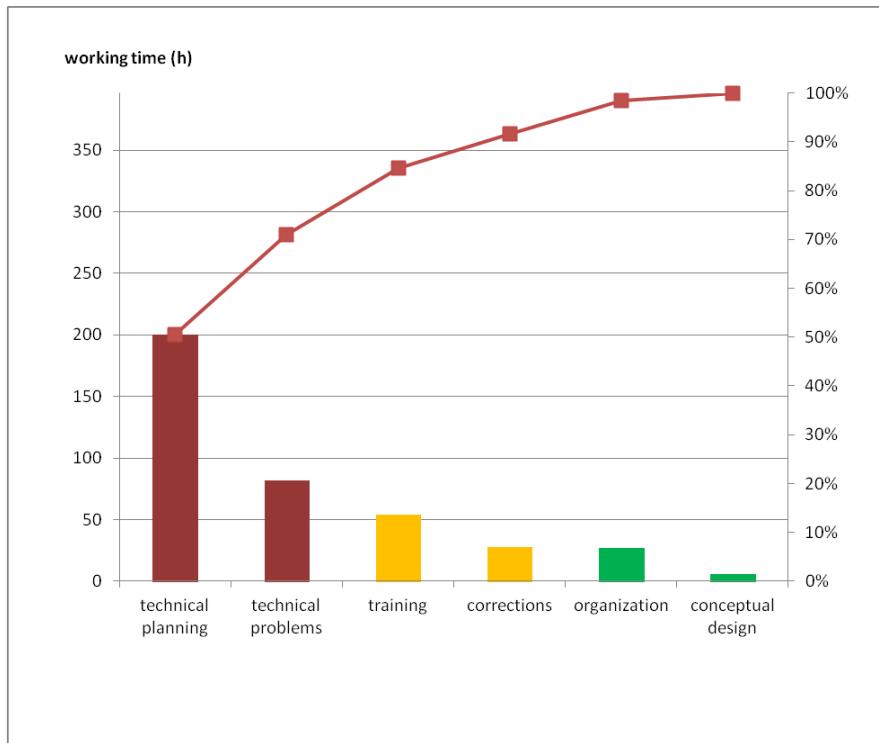


Figure 2: Exemplary Pareto-diagram of time assessment (Group 2)

After the experiment a questionnaire based survey was conducted as well as three focus group discussions, one with which each of the three disciplines architects, civil engineers and building scientists. A focus group is a qualitative research method in which groups of people are asked about their perception, opinions, beliefs and attitudes toward products, concepts, ideas, etc. (Marshall & Rossman 1999). Questions are asked in an interactive setting and participants can freely talk with each other. The method originates from marketing research, but can also be used for usability engineering of software and web sides (Nielsen 1993).

The focus group discussions were analyzed by means of content analysis (Koeszegi and Srnka, 2007) by two independent coders in a four step procedure. First the audio records were transcribed, followed by a separation of the whole content into thought units. In a third step a category scheme was developed base on theoretical considerations (deductively) and the data at hand (inductively), see Table 2. In a last step the data is coded. The quality of steps two and four are controlled by statistically measuring the inter coder unitizing and coding reliability to secure objectivity of the content analysis.

Category	Description	Example
ease of use	discussion concerning the ease of use of BIM tools	<i>"So to perform a change in SCIA is super easy"</i>
usefulness	discussion concerning the usefulness of BIM tools	<i>"I do not think it is good that it is possible to make a change in SOPHISTIC, or that this is changed automatically."</i>
interoperability	discussion concerning the interoperability of BIM tools	<i>"He gives a feedback back in REVIT. It says: 'there is a problem with a building part' you have to have a look at it!"</i>
training	discussion of BIM and software training	<i>"Training helped, but I would not be able to learn a software, without a project."</i>
software support	discussion of software support	<i>"I had a mistake, as I wanted to make an opening in the slab for the core, and the openings were not visible, and I have asked the software support"</i>
technical discussion	(detailed) discussion of technical issues	<i>"What FE net size did you set?"</i>
general discussion	general discussion concerning BIM	<i>"BIM is gains increasing importance in practice, because ..."</i>
negative collaboration	Expression of negative experiences in collaboration with other disciplines	<i>"Problems..came up(..) with static"</i>
positive collaboration	Expression of positive experiences in collaboration with other disciplines	<i>"But with the architect it worked very well, so(..)"</i>
suggestion	suggestions for general improvements or solution of specific problems	<i>"What could be useful when organizing a project like this would be that architects have already finalized their part."</i>
confirmation	Filler words and general acceptance	<i>"That is right."</i>
misc.	off topic discussions	-

Table 2: Content analysis coding categories

The results of this content analysis procedure are summarized in Figure 3. The focus group discussions showed that issues of interoperability dominated the focus groups. Early

coordination (organization and software) proved positive for later collaboration. The positive experiences outweigh the negative, especially for the structural engineers and building science. This is intuitive, as these are the professions that benefit from BIM, even though they do not create the original BIM. Time pressure and stress were noted in later planning phases, which calls for carefully designed time and process management.

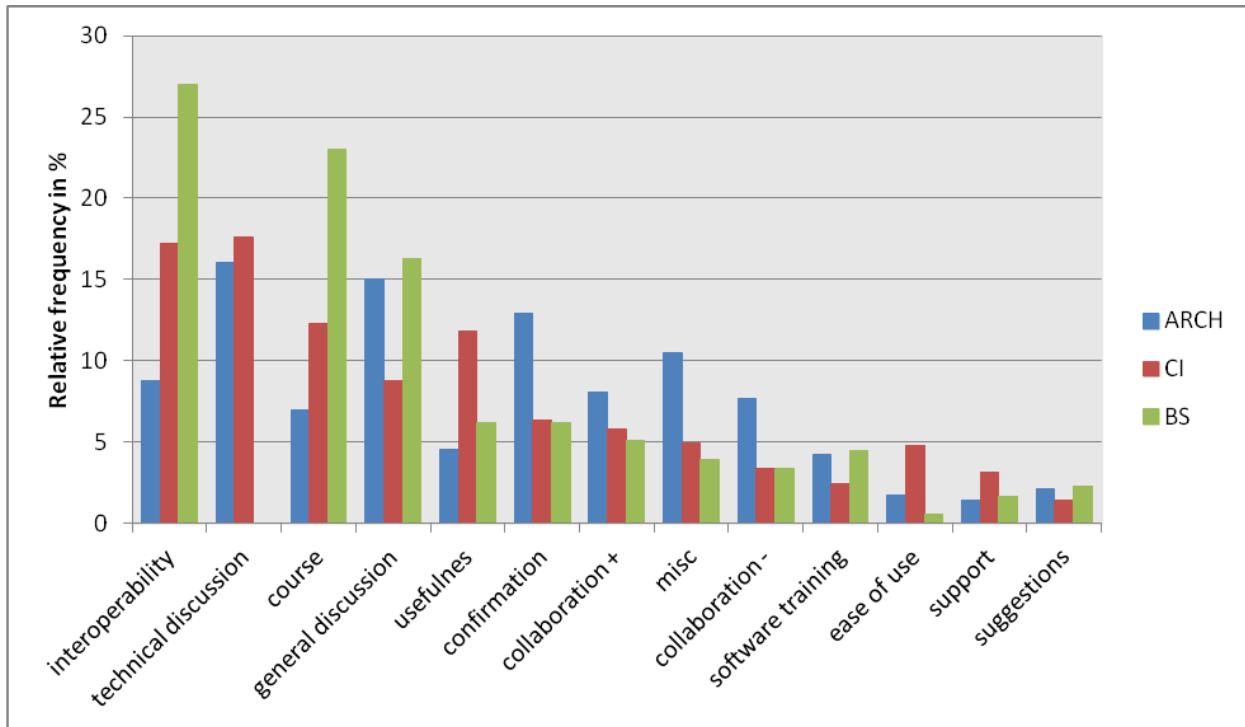


Figure 3: Content analysis of focus group discussions

The post-questionnaires assessed satisfaction with process (“I have performed my tasks efficiently”), with result (“The aims that I have set have been achieved”) and cooperation. The software related questionnaire included questions related to ease of use (“The software increases my productivity”), and usability (“In total I think the software is useful for my tasks”) according to technology acceptance model (TAM) of Davis (1989) model and additionally interoperability as a BIM specific feature of software applications. These latent constructs were measured by multiple items on a 5-point Likert scale ranging from low/disagree (1) to high/agree (5).

The satisfaction with the process and result is generally relatively high (see Figure 4) in all of the disciplines, however architects (usually the creators of the original BIM model) are less satisfied with cooperation, which holds true at a lesser extent for the other roles, too. The focus group discussions demonstrated that issues of interoperability dominated the focus groups. Early coordination (organization and software) proved positive for later collaboration. The hypothesis that exclusively through use of BIM tools the integrated planning would be enhanced was not affirmed. An integrated design process requires a careful process design involving teaming, design of communication and data-exchange beyond BIM technology in order to fully enhance the process integration.

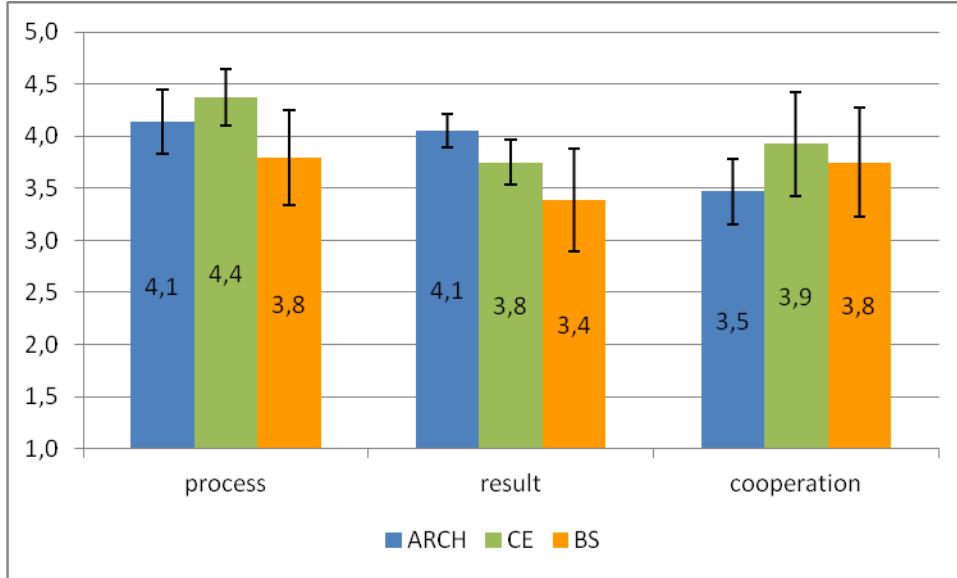


Figure 4: Results of the general questionnaire

The results of post-questionnaires concerning software acceptance (Figure 5) show that users assign BIM-software a high perceived usefulness, lower ease of use and extremely low interoperability of different software solutions. This is especially true for civil engineers and building scientists. Interoperability is of the greatest importance for the structural engineers and building science students, since they extract the data from the original, architectural model, however is judged as very problematic. Improving especially interoperability would have the strongest positive effect on the acceptance of BIM-software according to our analyses.

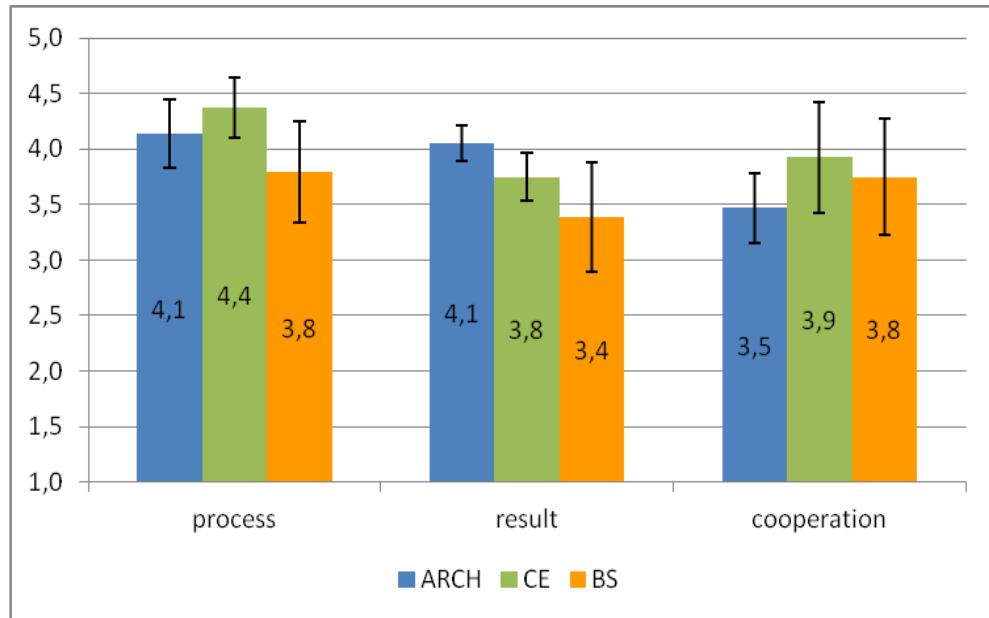


Figure 5: Results of the software questionnaire

Besides these analyses based on the data gathered from the groups the course instructors and supervisors observed several aspects concerning the quality of design, workflow-organization and class administration during the weekly feedback discussions and the three presentations, which are discussed subsequently.

The students were primarily concerned with mastering the software, modeling and interdisciplinary data exchange, which resulted in projects of average or even below average design quality. Due to the numerous difficulties in terms of interoperability and model exchange, many improvements of design were “sacrificed” in order to minimize the necessary rework. In some cases the design was not optimized as result of the consensus in the team to prevent additional calculation and simulation effort for the engineer or building scientist in the team. A further problem – though not just BIM-related, but rather related to software usage in general – concerning the outcome quality is the interpretation of results – the students are relying on the results generated by the software tools and often are not able to verify or interpret them. In some cases manifold over- or under dimensioning of the load bearing elements, or generated heating loads in summer have not been reported as faulty at presentations.

The work flow-organization turned out as sequential design, despite the instructions and requirements to present integrated projects. In most of the groups the architects started with the initial design and modeling, counting as model “owners”. The disciplines that followed were expecting necessary model-adaptations for failed data-exchange or design-improvement after the simulation or calculation to be carried out by the architect, as “model owner/creator”, which resulted with numerous conflicts. The “teams” were not feeling as teams until the final presentation, which required the presentation and delivery of the integrated digital model. At this point in time finally all of the team members felt working on a joint project, much more than only optimizing the architect’s model. We assume that the lack of team-spirit and joint aim setting can be contributed to a required but missing kick-off meeting where teams could be initially formed.

The class involved cooperation of two faculties (civil engineering and architecture) and of three different disciplines (architecture and building science are both master curricula of faculty of architecture), which posed challenges for the involved course supervisors in terms of administration and organization. Numerous constraints on the schedule had to be considered due to the different curricula. The same holds true for the organization of the class as different course-management-platforms for each discipline were used. The administration of the class in terms of ECTS credits represented the main difficulty, because of the unbalanced reward of credits for each discipline. For the architects the class was offered as elective class rewarding 2 credits, for civil engineers as project class rewarding 4 credits and for building physics students as master project course rewarded 10 credits. The differences in course credits were compensated by additional tasks (reports, further analyses etc.) but certainly influenced the effort and motivation of the participants. This disproportional reward represented a major issue for balancing of workloads within the teams and was resulting in many conflicts with both team members and faculty.

CONCLUSION

The assumption that exclusively through use of BIM tools the integrated planning would be enhanced can not be supported by the results gathered in the explorative experimental study

we presented and discussed in this paper. The participants worked in a sequential manner especially in the first part of the experiment, where the architect was expected to provide an architectural design, as well as to create the architectural BIM. This model then was used by the successive disciplines for their subsequent modeling. Many conflicts and discussions arose on the issue of model management, changes and adaptation of the original model, which are necessary for the proper transfer into the subsequent engineering and thermal simulation. In general, the architect was expected to carry out all of the adaptations, which led to numerous conflicts – who has to do what and when?

The lack of team spirit and joint vision can be attributed to the lack of an organized, moderated kick-off meeting as well as to the lack of time and space for face-to-face student meetings and workshops. The expectation that student teams will be able to organize themselves for collaborative work without support was not affirmed.

The main challenge remains the improvement of the quality of the projects following the maxim “form follows function” instead of “form follows tool”. Careful balancing of BIM tools usage and interdisciplinary design workshops involving traditional media such as model building, sketching and mapping could enhance a more creative way for finding innovative solutions, however the optimization of results largely depends on experience and practical know-how of involved disciplines. In general our results comply with the findings reported by Poerschke et al (2010), and the focus group discussions comply with practitioners focus groups (Gu and London, 2010).

After the pilot experiment in winter term 2012 we ran a second experiment in 2013. Lessons learned from the pilot experiment were incorporated in the design of this experiment: A designed process, including teaming workshop and a variety of integrated, intensive workshop phases and the phases where team members can work by themselves. Furthermore, more credits were assigned to the architectural students (5 credits), due to the reorganization of the studio and more support of the faculty administration. We plan to compare the results of the two instances, to gain more insight on (i) benefits of BIM for enhancement of integrated planning and (ii) on its impact of process-design on planning results (satisfaction, work-flow, efficiency) as soon as the collected data is edited and evaluated.

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