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Nikolaus Frimmel | Benjamin Gauss

Vienna, January 29th, 2014

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II Abstract

Building Information Modeling (BIM) describes an object-oriented, digital representation of a building, which enables interoperability and data exchange using a universal file format. Building Information Modeling supports a building's complete life cycle from initial design to eventual deconstruction, involving various professions such as architects, civil engineers, building scientists, facility management and emergency services for example. With BIM becoming more and more important in the building industry it is vital that problems with the process and related software be identified and resolved. Eliminating or at least alleviating issues would enable a more widespread use of BIM, helping the building industry as a whole. This thesis examines data from an experiment in which groups of students of architecture, civil engineering and building science develop a building together using different combinations of BIM software and the BIM approach. This experiment is held at Vienna University of Technology within the frame of an interdisciplinary research project involving various university departments, as well as business partners from the BIM software industry. Data is collected using focus group interviews and pre- as well as post-questionnaires on technology acceptance and team performance. Gathered data is analyzed using a content analysis of the interviews and quantitative analysis of the questionnaires. Results show that problems arise both with interdisciplinary collaboration caused by deficiencies with communication and with the used BIM software regarding interoperability between different solutions for different professions. Following the analysis, suggestions for improvement of both process and software are formulated. Stakeholders in a BIM project should communicate frequently and openly, while software developers need to improve the interfaces of their software to allow for smooth importing and exporting of models. Additionally, increased appreciation and respect of the other disciplines' work by involved parties would improve the collaboration and thus efficiency and effectiveness in a BIM project. Following the developed suggestions should help save time and costs in future projects employing the method of BIM.

III Abstract (German)

Building Information Modeling (BIM) ist eine objektorientierte, digitale Darstellung eines Gebäudes, die Interoperabilität und Datenaustausch in einem universellen Format ermöglicht. Building Information Modeling unterstützt und begleitet den kompletten Lebenszyklus eines Gebäudes, vom ersten Design bis zum schlussendlichen Abriss. Das betrifft verschiedenste Berufsgruppen, etwa Architektur, Bauingenieurwesen, Bauphysik, Gebäudeverwaltung und Einsatzkräfte. Mit zunehmender Bedeutung von BIM für die Bauindustrie wird es immer wichtiger, dass Probleme mit dem Prozess und der verwandten Software identifiziert und anschließend gelöst werden. Eine Verbesserung von BIM würde zu einer weiteren Verbreitung beitragen und damit der gesamten Bauindustrie helfen. Diese Arbeit untersucht Daten eines Experiments, während dessen Studierende der Architektur, des Bauingenieurwesens und der Bauphysik in Gruppen ein Gebäude mittels Verwendung verschiedenster BIM Software und des BIM Ansatzes planen. Das Experiment wird im Rahmen eines interdisziplinären Forschungsprojekts an der Technischen Universität Wien durchgeführt. Beteiligt sind, neben Abteilungen der TU Wien, auch Wirtschaftspartner aus der BIM Softwareindustrie. Daten werden mittels Fokusgruppeninterviews und Fragebögen zur Technology Acceptance und zur Teamperformance erhoben. Die Auswertung der gesammelten Daten erfolgt durch eine Inhaltsanalyse der Interviews und durch quantitative Analysen der Fragebögen. Die Ergebnisse zeigen, dass Probleme sowohl mit der interdisziplinären Zusammenarbeit durch Defizite in der Kommunikation im Team als auch mit der verwendeten Software bezüglich Interoperabilität zwischen den verschiedenen Lösungen auftreten. Nach der Analyse wurden Verbesserungsvorschläge gleichermaßen für den Prozess und für die Software formuliert. Beteiligte an einem BIM-Projekt sollten offen und regelmäßig kommunizieren, während die SoftwareentwicklerInnen die Schnittstellen zwischen ihren Programmen verbessern müssen, um die Interoperabilität zu erhöhen und einen einwandfreien Import und Export von Modellen zu gewährleisten. Außerdem würde eine erhöhte Wertschätzung der beteiligten Berufsgruppen für die Arbeit und Bedürfnisse der jeweils anderen zu einer besseren Zusammenarbeit und dadurch zu höherer Effizienz und Effektivität beitragen. Die Berücksichtigung der erarbeiteten Vorschläge sollte dabei helfen Zeit und Kosten in zukünftigen Projekten, die die BIM Methode verwenden, zu sparen.

1 Introduction

The term Building Information Modeling (BIM) describes an object-oriented, digital representation of a building, which enables interoperability and data exchange in a universal format (Kiviniemi, 2008). BIM is first and foremost a process focusing on modeling and information sharing (Succar, Sher, & Aranda-Mena, 2007). Despite growing interest in the increasingly powerful technical possibilities of BIM software, the development of know-how regarding the actual design process is still in its early stages. Growing project size as well as higher complexity of building geometry and stricter requirements respecting environmental efficiency leads to an increase in complexity of design and building processes. As a result, the amount of involved disciplines and thus the number of specific software solutions rises, generating the need for better interfaces, communication and cooperation. Using existing BIM software and processes, several problems arise. These problems include, but are not limited to the difficult collaboration of different software solutions due to individual data formats, and incoherence of data after automated synchronization. There are also semantic problems, such as individually needed information by each participant, but also the different methodology and languages used by each discipline to describe buildings. A high amount of work, preparation, communication and technical know-how is needed to manage, filter and synchronize the heterogeneous information in the building industry context. As of yet, no sample solution or guidelines exist, which leads to considerable overhead during the process and makes it prone to errors. (Process Optimization for BIM-supported Sustainable Design, 2012)

As will be further explained in the *State of the Art* section of this work, Building Information Modeling is a quite new but very promising development in the building industry with a lot of potential. There is potential in BIM not only for cost and time reduction, but also for better collaboration and communication between the different participants in the planning process of building design. To us, and therefore in this work, especially the interdisciplinary collaboration and communication between architects, civil engineers and building scientists is important. As Business Informatics students we are interested in how new solutions can advance the way participants in a project work together, thus improving its results.

This thesis and its results and conclusions are part of a 2-year FFG (Österreichische Forschungsförderungsgesellschaft[1]) research project at Vienna University of Technology called *BIM Sustain*. During this research project an interdisciplinary lecture comprising

[1] https://www.ffg.at/

[2] www.iso.org

[3] sd = standard deviation|IQR = inter quartile range|25% = 1st quartile|75% = 3rd quartile|n = number of

students of architecture, civil engineering and building science will be held twice. In the lecture, the students are assigned the task to design a building with certain specifications, using different combinations of BIM software provided by business partners who are also part of the project. Before the lecture, students fill out pre-questionnaires about their demographics and previous experience with the software in use and are then put into groups of two to five students. After the participants finish their projects, they fill out post-questionnaires and partake in structured focus group interviews for their respective discipline (either of architecture, civil engineering and building science) where they share their experiences. The resulting questionnaires and focus group interviews of the pilot experiment in the winter term of 2012 make up the data aggregated and analyzed in this work. The questionnaires were analyzed using statistical methods and for the focus group interviews we conducted a content analysis. The results and conclusions of this work will also be used to improve the lecture in the winter term of 2013. Improvements will include, but are not limited to, the structure of the lecture and the specifications of the project as well as the composition of the groups of students and the methods and means of data collection. (Process Optimization for BIM-supported Sustainable Design, 2012)

The overall topic of the thesis, to formulate suggestions for improvement of the software and the process regarding Building Information Modeling as well as creating a guideline for improved collaboration between the participating stakeholders, had to be broken down into smaller research questions to be able to answer them satisfactorily. First and foremost it is important to identify problems with the process as a whole. These problems could be with communication, work environment, skill sets, and collaboration or even with the project definition itself. It was important for us to find out where problems came from and how they manifested themselves during the course of a complete project. After identifying problems with the process, the second important point to examine is which problems arise with the software used for designing the models and conducting calculations during a BIM project. Only when the software as an aid to the whole process works well, can efficiency and effectiveness be assured or enhanced. The focus here was on the interfaces between different software solutions which serve as means to import and export models of a building between each of the different programs used by architects, civil engineers and building scientists respectively. Only when these interfaces work flawlessly can the time-saving aspect of BIM be maximized and used to its full potential. If problems dominate the software, time is actually lost rather than gained due to necessary reworking and redrawing.

BIM is not only a multifaceted process with many stakeholders, but also the software used for designing a building and perform necessary calculations has many features and is very complex to work with because of the sheer amount of functionality. To be able to use BIM software to its full potential, a lot of training and experience is necessary, which most students do not yet have. It was thus very interesting to us to find out how exactly training and experience prior to the BIM Sustain experiment influence the participants' work and the eventual outcome which is why this is also a question this thesis will try to answer. Learning more about these influences can help improve the effectiveness of training and introduce new ways to learn how to use the software effectively.

As already mentioned before, the main stakeholders in a BIM process we are looking at in this thesis are architects, civil engineers and the building scientists which were the three roles to be fulfilled in the project description of the lecture. The section Methodology (chapter 3) will deliver more detail about the project and its setup. These stakeholders have different prerequisites, views, opinions and requirements concerning the BIM process. This means that the outcome of the focus group interviews and of the questionnaires differs between the different professions. To be able to answer questions about these differences and how they affect the process we will look at the different perceptions of positives and negatives for each role. If a role is less satisfied with a specific aspect of the process than others, then this imbalance needs to be addressed to ensure an equal benefit for all involved parties in a BIM process. Last but not least we will look at the specific software suites used in this experiment to find out which programs have issues and which interfaces work well. This is important to the software developers taking part in this experiment as they need the feedback to be able to improve their software further.

Our motivation for writing this thesis was not only the high relevance of software evaluation for Business Informatics, but also that we could be part of an interesting research experiment contributing to the evolvement of BIM and its software solutions. During our studies we obtained knowledge about software engineering and software evaluation as well as usability engineering and usability evaluation, which was directly used in the course of analyzing the data of the pilot experiment. The practical part of actually scientifically analyzing questionnaires and focus group interviews, including the content analysis of the interviews, was something we did not previously experience in our courses at university and was thus very exciting and educational. This thesis and its part in the FFG research project were a great chance for us to put our theoretical knowledge to practical use and we were eager and motivated to contribute. Our contribution is not limited to using the data for this thesis, but we also helped with data analysis during the experiment and with the creation of reports relevant to the research team. Our suggestions for improvement of the experiment and data collection are used in the second iteration of the experiment at Vienna University of Technology.

Especially this immediate effect our work had was very motivating for us. Many students put a lot of work into their theses but their results are only ever seen by their advisors and have no actual impact on the field. Being able to see results being used by an interdisciplinary research team at a renowned university was very gratifying for us and certainly a strong factor when we were choosing a problem to work on for our thesis. Additionally, the feedback from our results and the results of the project as a whole have a strong impact on software development in the field of Building Information Modeling, as the software developers are also stakeholders in the experiment. This means that our contribution helps to improve not only the software, but the industry as a whole and it is very rewarding to know that one's work actually helps with the progress of an important field and could potentially change many lives for the better.

The research questions this thesis will try to answer are the following: Which problems can be identified in the BIM process? Which problems occur with BIM software? How does training and experience influence the students' work? How do perceptions about the negatives and positives of the process differ by profession? Which software causes problems, which interfaces work well? How can the lecture and the experiment be improved to get better data in the winter term 2013? The last question applies to selection of participants, composition of groups, details of the tasks students have to complete, means and methods by which data will be collected as well as means and methods by which data will be aggregated and analyzed.

1.1 Structure of the Thesis

The remainder of this thesis is structured as follows.

In the *Introduction* the term Building Information Modeling is introduced and the contents, goals and motivation of and for this work are described. Furthermore, an overview of the research project this thesis is embedded in is given. (Author: Benjamin Gauss)

The *State of the Art* section describes what BIM is, what its advantages and disadvantages are, how it was developed in the past, what the outlook for the future is, how industry users perceive its features and how it is being used today. (Author: Nikolaus Frimmel)

The section *Methodology* is divided into two main parts, which are questionnaires on the one hand and focus group interviews on the other. Questions which are answered in these sections are: Which data was collected and why? How was the relevant data collected? Which methods were used for aggregation, structuring and analysis? (Author Methodology Questionnaires: Nikolaus Frimmel, Author Methodology Focus Groups: Benjamin Gauss)

The methodology section is followed by the *Results* section. This section includes visualizations of aggregated and filtered data as well as different representations of data from the focus group interviews and the questionnaires. Data from the content analysis is presented for the first complete iteration of the analysis and for the final iteration to highlight improvements in between the iterations. The results of the questionnaires are statistically explored. (Author Results Questionnaires: Nikolaus Frimmel, Author Results Focus Groups: Benjamin Gauss)

The last section in this work discusses the *Conclusions*, which can be drawn from the analyzed data and the results. This section aims to answer the research questions formulated above with the support of results from the content analysis and the analysis of the questionnaires. (Authors: Nikolaus Frimmel and Benjamin Gauss)

1.2 *BIM Sustain* Research Project

As mentioned previously, *BIM Sustain* is the interdisciplinary 2-year FFG (Österreichische Forschungsförderungsgesellschaft) research project this thesis is embedded in. Details about the project will be provided in the following sections.

1.2.1 Goal

The goal of the project is the development of strategies for time- and cost-efficient BIM-supported planning processes. In contrast to previous research projects, additionally to the technical side regarding interoperability and software evaluation also human factors as well as communication and the interdisciplinary process itself are examined. Through the involvement of software developers immediate feedback can be given and a close cooperation can be reached.

In the experiment, the students have to design and optimize an architectural model, a structural framework model as well as a building physics model. These models will be created in three different ways: in the traditional 2D planning, with a central BIM model focusing on architecture and with an integrated BIM planning process. Through thorough qualitative and quantitative analysis these simulations provide insight into issues of productivity, efficiency, communication as well as division of labor within the project. The experiment aims to identify critical points for a successful and efficient implementation of BIM as well as to test the software tools. Eventually a BIM-assessment tool for stakeholders in a BIM process should be developed. Additional goals are assessing interoperability and usability of the BIM software tools in an integrated project delivery (IPD) model. Finally a guideline for an IPD process model should be created. (Process Optimization for BIM-supported Sustainable Design, 2012)

1.2.2 Stakeholders

The main stakeholders in this project are the participants in the research team at Vienna University of Technology, the software development companies involved as business partners and the students. (Process Optimization for BIM-supported Sustainable Design, 2012)

Research team

The research team consists of three departments at Vienna University of Technology. The first department is the *Institute of Interdisciplinary Construction Process Management, Research Area Industrial Building and Interdisciplinary Planning, VUT (IBAU)*. DI Dr. Arch. Iva Kovacic who coordinates the research project is from this department, as well as DI Lars Oberwinter and DI Christoph Müller. The second department is the *Department of Building Physics and Building Ecology, VUT (BPH)*. Researchers from this department involved in the project are Univ. Prof. Dr. A. Mahdavi, Dipl.-Ing. Dr. Kristina Orehounig, Dipl.-Ing. Ulrich Ponts and DI Kristina Kiesel. The third department is the *Institute of Management Science, VUT (IMW)* where Univ. Prof. Mag. Dr. Sabine Köszegi and Mag. Michael Filzmoser PhD from the *Department of Labor Science and Organization* participate in the project. The tasks of the research team are organization and design of the experiment, planning and execution of the lecture as well as analysis and compilation of the collected data and the development of a guideline and tools. (Process Optimization for BIM-supported Sustainable Design, 2012)

Business Partners

All business partners are market leaders in the area of BIM-supported planning and software. During the experiment, the business partners help out by providing support and workshops regarding their software solutions for the students who use them. The seven business partners are *A-Null Bausoftware, Artaker, Dlubal, Die b.i.m.m GmbH, Nemetschek Österreich, Plancal and Construsoft Gruppe.* (Process Optimization for BIM-supported Sustainable Design, 2012)

Students

Also involved in the project are students from Vienna University of Technology who can choose to take part in the lecture as an elective course. The sample of students includes students enrolled in the bachelor/master program *Architecture*, students enrolled in the bachelor/master program *Civil Engineering* and students enrolled in the master program *Building Science and Technology.* (Process Optimization for BIM-supported Sustainable Design, 2012)

1.2.3 Structure

The research project is divided into four phases, with each phase taking about six months. The phases and their contents can be seen in Figure 1 below.

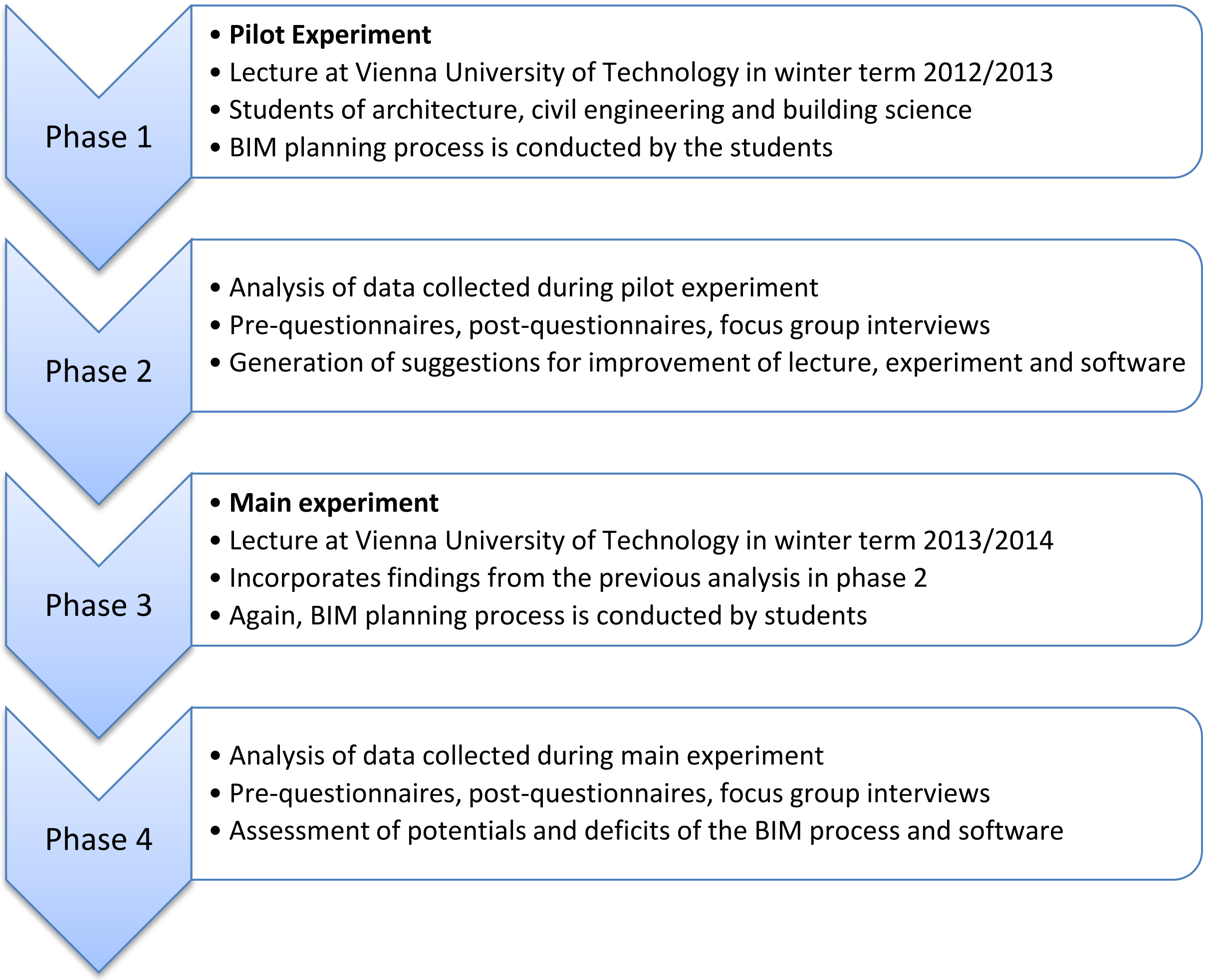

Figure 1 – Phases of the Research Project *BIM Sustain*

1.2.4 Methodology

The main part of the experiment consists of a lecture called *BIM Sustain* held at Vienna University of Technology in the winter terms of 2013 and 2014. In this lecture, students of architecture, civil engineering and building science form groups to perform a building planning process with specific requirements. The groups should consist of at least three students assuming the roles of architect, civil engineer and building scientist. The requirements of the building to be designed are the same for all groups. However, the software to be used by the individual group members in their roles is different for every group. Before the experiment, the students fill out pre-questionnaires regarding demographical data as well as industry and software experience. During the lecture, the students are supported by the business partners who provide software support and workshops to help the students with their tasks. The institutes tasked with organizing the lecture provide support as well, since the students' experience and prerequisites possibly vary quite a bit. After the experiment, students fill out post-questionnaires regarding their experiences during the lecture and partake in focus group interviews. The focus group interviews are conducted by members of the research team; there is one for the architects, one for the civil engineers and one for the building scientists. Different groups not only use different combinations of BIM software, but also three different planning approaches, which can be seen in Figure 2 below. (Process Optimization for BIM-supported Sustainable Design, 2012)

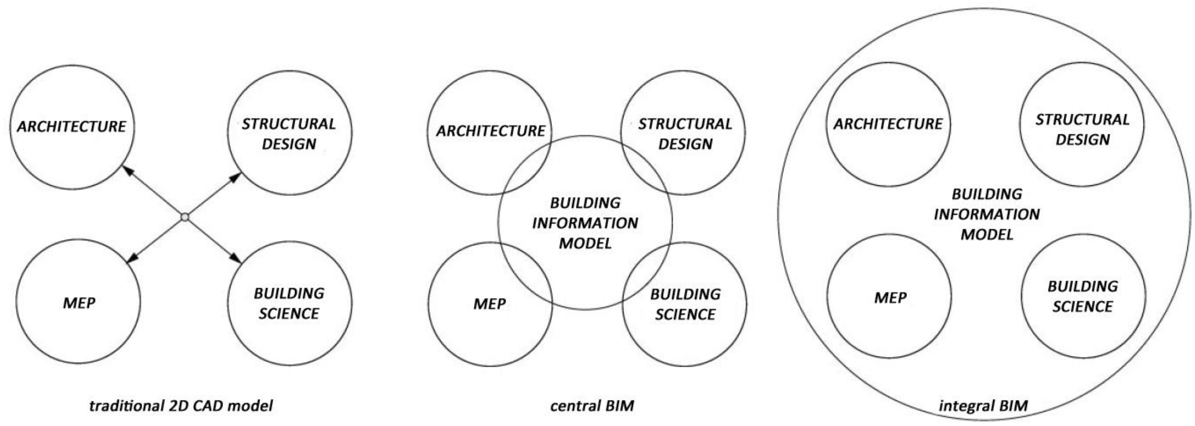

Figure 2 – BIM Approaches

The *2D CAD traditional* model approach means that the initial model is drawn by the architect, then sent to civil engineers and building scientists who in turn draw their models to do necessary calculations, give feedback to the architect who then has to adjust their model and so on. In the *central BIM* approach all disciplines work on the same model, which is usually an architectural model, which is then adjusted and enhanced with data from the other professions. This is the current commonly used method in the transition phase from traditional 2D planning to BIM planning. The third approach is the ideal BIM approach called *integral BIM.* In this approach, each profession uses its own specific tools, which are interoperable, so that models can be imported and exported with persisting information from all disciplines. In the pilot experiment, which is the basis for this thesis, 2D planning and the central BIM approach are used. (Process Optimization for BIM-supported Sustainable Design, 2012)

1.2.5 Lecture in the winter term 2013

The lecture in the winter term 2013 comprised 11 groups and 38 students in total. The groups and the software they used can be seen in Table 1 below.

Group	Members	Software Architecture	Software Civil Engineering	Software Building Science
1	3	Allplan	Allplan, Scia	Allplan
2	4	Revit Architecture	Revit Structure, Sofistik	Revit MEP
3	4	Archicad	Tekla, RFEM	Plancal
4	5	Archicad	Allplan, RFEM	Plancal
5	3	Revit Architecture	Allplan, Scia	Plancal
6	4	Archicad	Allplan, RFEM	Revit MEP
7	2	N/A	Tekla, Sofistik	Revit MEP
8	3	Revit Architecture	Tekla, Scia	Allplan
9	3	Archicad	Revit Structure, RFEM	Plancal
10	3	Archicad	Allplan/Tekla, RFEM	Revit MEP
11	5	Archicad	Tekla, Sofistik	Revit MEP

Table 1 – BIM Sustain Lecture Groups and Assigned Software

2 State of the Art

The building industry is an industry branch that is generally considered as being very tough and having quite a lot of competition. Players in this business are constantly challenged by tight budgets and schedules, limited or wrong information, and sometimes even pressure from the public (if the project is a public job or of special interest to the community, e.g. in the case of landmarks) (Davis D. , 2007). Any easing of this pressure or facilitation of the process is thus greatly appreciated, and one of the innovations that can have such an effect is Building Information Modeling (BIM). Another aspect that distinguishes the construction industry from other fields of business is the large amount of necessary visualization – in hardly any other industrial sector is the creation of models from the early stage on as important as here (Davis D. , 2007). The advantage of BIM compared to previously used solutions is that it enables architects, engineers and other players to visualize their ideas in 3D, offering the client a very lively look at the building to be developed.

But visualizations are not only useful for visualizing things – letting the client view the design one thought out is a nice gimmick of 3D planning, but the real idea behind BIM is to “build the building virtually before building it physically in order to work out problems, and simulate and analyze potential impacts” (Smith, 2007). This way, problems can be found and solved very early in the planning phase and alternatives can be assessed more easily, including the simulation of different scenarios and various ideas for the construct. These features provided by BIM also allow stakeholders to decide on a certain design according to aspects like energy usage, sustainability and lifecycle costs as well as environmental agreeability.

The relevance of BIM does not end with the handing over of the key at the end of the construction phase, as one might think – the building model developed can and shall be used to facilitate building management and maintenance, as it serves as a kind of index of spare parts needed and time schedules when and which servicing is needed, so the whole life-cycle of the facility is supposed to be supported (Smith, 2007). This can not only lead to a more satisfactory end of the construction phase for all parties involved, but catalyzed by this also to a better customer loyalty and the tightening of collaboration for future projects. Also, since we live in the 21st century, the handing over of folders filled with lists or CD-ROMs seems outdated compared to the storing of a model at a ubiquitous server (East & Brodt, 2007). Such availability of data is not only important for the everyday life of building support staff, but also in case of an emergency, for example, allowing emergency services and first responders to easily access building plans or information about the materials the structure is made of. At least, there will be the time when the life cycle of a building is at an end –

deconstruction can also profit from the information stored in the building information model (buildingsmart.org, 2013).

Of course, an approach using BIM here also supports integrity of the data to a great amount, so the implementing of the BIM standards is not only important for software supporting construction design, but also for such suites supporting facility management, for example Computerized Maintenance Management Systems (East & Brodt, 2007). Deke Smith (Smith, 2007) sees Building Information Modeling not only as a new way of planning construction projects, but as the re-design of the whole construction industry. Deciding to develop data as BIM models is seen as a strategic investment and can support a lot of steps in the planning process.

Building Information Modeling is an approach for accomplishing building design and planning of the construction process involving various disciplines (Sacks, Kaner, Eastman, & Jeong, 2010). The three-dimensional models that result from that process and its various steps including the different disciplines involved in the creation of a building are to be exchanged between not only various persons and companies that conceptualize a building, but foremost between their dissimilar software solutions. "It's the 'I' in BIM. When I talk to people really implementing BIM the same idea exists everywhere—that the reason to use BIM is to create a database of information that represents the design and [enables] digital organization" (Jay Bhatt, senior vice president of AEC Solutions for Autodesk, a world leader in design and engineering software, during an interview quoted by (McGraw-Hill Construction, 2010)). To achieve this, Building Information Modeling is supposed to enable the exchange of a model not only between the architect, whose work focuses on design and the civil engineer, who is in charge of the structural analysis, as well as simulating various scenarios such as earthquakes (Vienna UT, Curriculum Civil Engineering, 2013). Other professions, such as building science, should take part in this exchange of information, too. Building science occupies itself with the calculation of the energy consumption and environmental factors of a building as well as other facility-management related topics such as lighting, heating or air flow within the structure (Vienna UT, Curriculum Building Science, 2013). We mentioned before that the whole life cycle of the structure should be supported, so other professions like contractors, facility managers and authorities need the information from the model as well. What has to be considered when trying to compare results gained by the different disciplines is that each profession has its unique workflows, and the software solutions for these workflows sometimes are in very different stages of development.

As buildings and thus the projects during which they evolve tend to become more and more complex (Vienna UT, Curriculum Building Science, 2013), BIM is becoming more and more important to facilitate and sometimes even allow the development of such construction projects in the first place. The larger the project, the more the planning process is believed to benefit from involving BIM (McGraw-Hill Construction, 2010). As it has happened in most industries, the building industry too emerges towards a smarter, more data-rich way of doing business, using the possibilities not only of computer-aided design (CAD) programs, but also intensifying the communication between the working steps, allowing a tighter, more accurate, more productive design process and thus one of higher overall quality as well as worker safety (Sacks, Kaner, Eastman, & Jeong, 2010), (McGraw-Hill Construction, 2010).

A BIM model has several elements, which we will list here exemplarily. The first objects that come to mind are of course the physical elements of a building such as walls, doors, windows, columns or slabs (a sort of concrete plate). As already mentioned views are a part of a BIM model, so 2D and 3D renderings and plan are included or can be generated from the information. Since a building information model contains much more information than a blueprint drawn on paper, it also contains details like the properties of the above-mentioned elements. By properties, one understands information that describes an object in a more detailed way. A property can be anything for example of thermal, optical or structural nature, to just mention a few, like the material one wall is made of. Relationships between objects are modeled as well and are a central feature of building information models since they enable the high degree of (automated) model analysis that is another key advantage of BIM (See, 2007). Examples for relations between objects include connections, voids, bounds, supports or containment.

BIM does not only facilitate the exchange of models and data over the whole length of the task, but also offers more powerful visualization and simulation capabilities than traditional CAD programs (Sacks, Kaner, Eastman, & Jeong, 2010), (McGraw-Hill Construction, 2010). According to the Smart Market Report 2010 (McGraw-Hill Construction, 2010), BIM "represents the start of a transition to an integrated digital information infrastructure that will ultimately revolutionize almost all aspects of the construction industry". In this report, McGraw-Hill Constructions not only researched the overall use of BIM in Europe (which they limited to Germany, France and the United Kingdom for the sake of conductibility), but also looked at the relating results from a previous, analog study conducted in North America (McGraw-Hill Construction, 2010). A similar, but much smaller study evaluating BIM's perceived impact on key performance indicators (KPI) in the construction business was already conducted in 2007 by Patrick Suermann and Raja Issa and published in the Journal for Building Information Modeling (Suermann & Issa, 2007).

2.1 Diffusion of BIM

The Rosewood experiment has a similar setup to our experiment, but concentrated on the design and detailing of precast facades of a 16 story building in Dallas, Texas (Sacks, Kaner, Eastman, & Jeong, 2010). The goals for the study were, like ours, to identify collaboration workflows, although their focus was on conventional CAD systems and the identification of the capabilities of object exchange when using BIM as well as the identification of new IFC objects that might yet be missing in the standard. An important task for the authors was to compare the productivity between the two types of design processes – using 2D CAD versus 3D BIM.

The results of this experiment are quite outstanding – by comparing journals and time-keeping by the participants, a productivity gain of 57% when using BIM instead of 2D CAD tools was calculated, and the modeling was overall more accurate (Sacks, Kaner, Eastman, & Jeong, 2010). The study also showed that there can be no such thing as one to one relationship between different models – the levels of detail needed by architects and precast fabricators vary way too much, an aspect that can be said of most of the professions involved in the planning process. While architects do not focus too much on the differences between the second and the tenth floor in their models, it makes a lot of difference for any profession that has to consider statics, transportation and fabrication effort for the individual parts of the building (Sacks, Kaner, Eastman, & Jeong, 2010) – internal reinforcements do not change the design from the outside. The company "Design + Construction Strategy" calls a BIM-based model in an advertisement in the Journal of Building Information a "visual portal to a database of building information" (Journal of Building Information Modeling, 2007). Taking this realization into account, a sort of "intelligent interoperability" (Sacks, Kaner, Eastman, & Jeong, 2010) between the vast arrays of different models is needed. As the authors point out, such differences can be included in every model from the beginning on if very close collaboration is practiced, but this of course implies a huge work load that is not really necessary. A smarter solution is that each profession can work on its own representation of the same building, making the building information model kind of an aggregation of all the different aspects of domain-specific views. The call for interoperability not only being technically correct arises, but also for it to do some kind of interpretation and correspondence between these views (Sacks, Kaner, Eastman, & Jeong, 2010).

In the Rosewood experiment, the validity of the import and export between programs was evaluated as well. As expected, a lot of problems were reported in this regard – grid lines were missing, objects were mapped the wrong way, some entities were missing completely because the IFC format did not support them, curved panels and reinforcement embeds were missing, making a lot of rework such as remodeling, redrawing and other cumbersome tasks necessary. In the first attempt with a certain software version, the re-import of the model coming from the software used by the precast fabricators into the architects' programs proved to be impossible (Sacks, Kaner, Eastman, & Jeong, 2010), so the model had to be split into small portions, which only changed when an upgrade to a newer release was possible. Rafael Sacks and his colleagues also point out that not only the IFC standard is to blame, but also some lack of software functionalities could be observed – for example, the architectural program does not represent certain kinds of reinforcements (Sacks, Kaner, Eastman, & Jeong, 2010). That way of course, they cannot be imported correctly, even if they are in the IFC file. Another issue is the lack of user skill to use the BIM functions correctly (Sacks, Kaner, Eastman, & Jeong, 2010), hinting towards a lack of training or experience. Concluding after the Rosewood experiment, the call for a BIM standard that stipulates what information is needed in the model when wishing to exchange it between different software packages is formulated.

2.2 Building Information Modeling Use in the Industry

2.2.1 Perception of BIM

Throughout their study, the authors at McGraw-Hill construction differentiate between three professions: architects, engineers and contractors. In Europe, architects are the pioneers when it comes to BIM, showing an adoption rate of 47%, followed by engineers (38%) and then, far behind, by contractors (24%) (McGraw-Hill Construction, 2010). Overall, the adoption of BIM in North America is way higher than in Europe (49% versus 36% of the respondents, (McGraw-Hill Construction, 2010)), but simply looking at these numbers gives the wrong impression of the European construction industry. Although fewer professionals use BIM in their projects, a slightly larger percentage (45% compared to 42%) consider themselves experts or at least advanced users when it comes to Building Information Modeling, and the fraction of users who have been using BIM for five years or more is almost twice the number from North America (34% versus 18%).

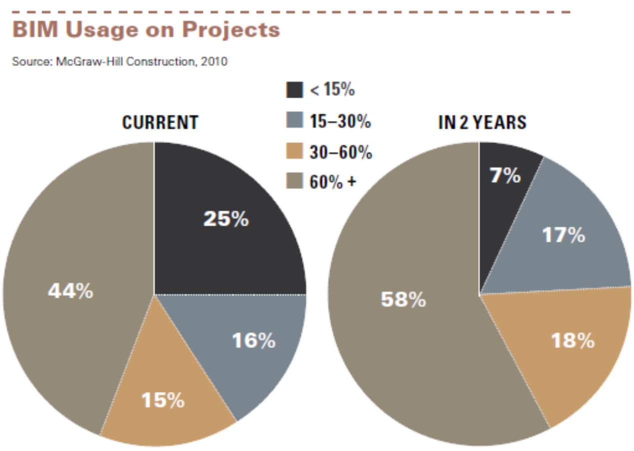

Figure 3 – Expected BIM Usage in 2 Years' Time (McGraw-Hill Construction, 2010)

An interesting fact to notice here is that respondents who do not use BIM are generally optimistic towards using it in the future; only 27% of Western European potential users do not plan on using BIM at all in their future endeavors (McGraw-Hill Construction, 2010). 37% of non-users asked by McGraw-Hill are open to exploring BIM and its possibilities, while almost a quarter thinks it will be a valuable addition to their way of working. BIM adoption in Europe in the past has been steady but flat, while the growth not only in the field of new users, but in the percentage of projects BIM is used in general, is expected to grow continuously (McGraw-Hill Construction, 2010) – this can be seen in the responses by users in both the beginning and the expert level.

When looking at users at the expert level, the portion of heavy users (defined as such that use BIM in at least 60% of their projects) is almost the same in North America and Europe, while the usage at the beginner level shows a significantly larger difference: only 20% of American users from this group make use of BIM in more than 15% of their projects, compared to 46% in Europe (McGraw-Hill Construction, 2010). Subjects of the European study also show great optimism and have high expectations for the further advance of BIM in their field of work – according to the responses given, the number of frequent users (including BIM in 30% of cases or more) is expected to increase from 60% to 75%. Contractors expect the largest increase in BIM usage – frequent users are expected to grow from 11% to 54%. This is not unexpected since at the time of the questioning, contractors reported the smallest percentage of BIM adoption (McGraw-Hill Construction, 2010).

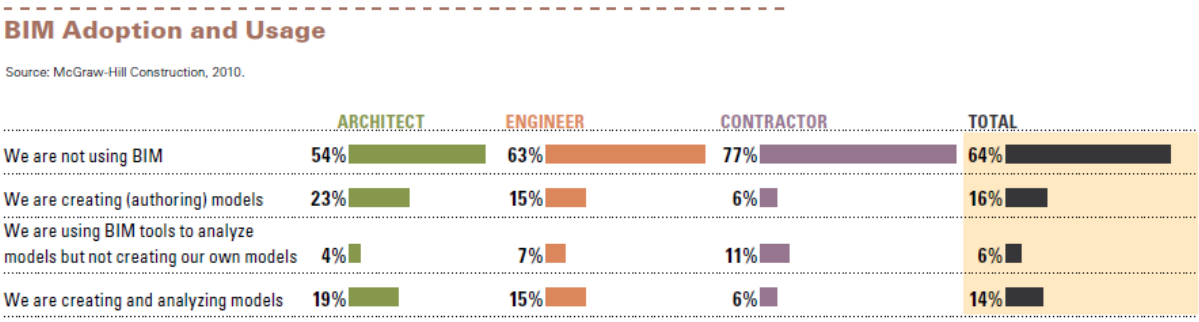

Figure 4 – BIM Adoption in Europe (McGraw-Hill Construction, 2010)

Of course, not only the percentage of people in the construction industry using BIM is of interest, but also the value gained from its application, which was also investigated by McGraw-Hill Constructions. According to their report, a large share of users (74% in Europe, 63% in North America, (McGraw-Hill Construction, 2010)) perceives a positive return on investment (ROI) from BIM. Participants from both regions who measure the ROI formally also come to a positive conclusion (in 82% of the projects, positive returns are reported, (McGraw-Hill Construction, 2010)). The interesting thing to see here is that the users' experience level is directly linked to the height of perception of BIM's return on investment – in other words, the more users knows about and use BIM, the higher they rate its value for the firm (McGraw-Hill Construction, 2010). Overall, the group with the highest percentage of a perceived positive ROI are the architects, followed by engineers and contractors in Western Europe.

2.2.2 Financial aspects

When talking about investment and its return, the question arises where the money invested in BIM is put to use exactly. The highest priority for European BIM adopters to direct money to is the development of procedures for the usage of BIM within their teams and company (McGraw-Hill Construction, 2010). The purchase of software that supports Building Information Modeling follows close behind, differing in only a few percentage points. Of course, when someone wants to start using more advanced software, they often face the problem of lack of hardware capacity to run it. When thinking about this aspect, one must not only picture a bunch of workstations that have to provide a certain amount of computing power, but also the interoperability has to be supported by servers, network devices and similar equipment, making the investment into hardware the third ranked focus of financial resources directed towards BIM in the broad sense (McGraw-Hill Construction, 2010).

However, not only computers have to be able to deal with the demands a new software package puts them up against, but also people to operate the program have to be trained in its usage. This is not only necessary to enable them to use it at all (depending on the complexity), but especially if the software is to be used effectively and efficiently, including all its features. Training is a very important aspect when talking about BIM (Sacks, Kaner, Eastman, & Jeong, 2010), (McGraw-Hill Construction, 2010), which can be seen in the results section of this thesis as well as in the Smart Market Report, where 90% of experts, but only 13% of beginners believe that they are using a lot of the features provided by Building Information Modeling. Only 6% of respondents think they exhaust BIM to the fullest, while the majority of users in all levels think that there is more to be gained. Also, 57% of BIM users say that not only their own training is important, but the number of people on a project who know their way around BIM is an important factor for success (McGraw-Hill Construction, 2010). Not only training, which we see as the dealing with a new technology when first starting to use it, has great influence on the success users have with BIM both under the perceived and measured aspect, but experience is very important as well. The opinions on benefits (see listing later in this section) gained by the usage of BIM is reported by about twice the percentage of expert users than by beginners (McGraw-Hill Construction, 2010).

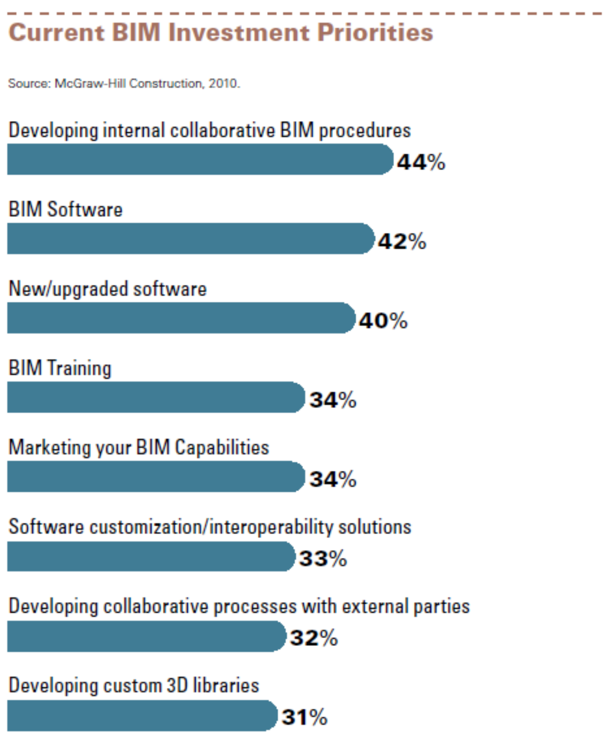

Figure 5 – Current BIM Investment Priorities (McGraw-Hill Construction, 2010)

The main, underlying idea of any investment in any industry is to gain value from it. We talked about the return on investment already, but especially in the construction business, relations between a company and its clients are very important, which is why especially users on the advanced and expert level invest a lot of money into marketing – after all, investing into a new technology can also be made profitable by using it to gain new clients and business relations. Also, more and more clients require the usage of BIM on their jobs (McGraw-Hill Construction, 2010), so when thinking in that direction, the usage of the technology becomes less and less optional. Generally spoken, users expect to be able to conduct their work more efficiently on all levels of experience, while reduced costs at the bottom line are mainly thought to be realized by experienced users (McGraw-Hill Construction, 2010).

Thinking about the future of the business one operates in is a very important aspect when trying to decide if an investment should be made or not. To rank the many potential benefits of BIM, the researchers of the Smart Market Report (McGraw-Hill Construction, 2010) asked a lot of industry experts which of the aspects they see as the most important one in five years. The top five answers differ in only a few percentage points, the top one being better-designed projects in general. Greater satisfaction with the outcome and the overall results of the planning process is expected as well, which is especially interesting because it supports intangible and hard to measure aspects like employee happiness and thus workplace motivation, for example (Herzberg, 1987). Buildings designed with the use of BIM are expected to perform better in general, hopefully leading to reduced costs in maintenance and an increase in sustainability. Speaking of reduced costs, especially contractors believe that Building Information Modeling supports the use of prefabrication, which is the answer ranked at number four, followed by an anticipated lower risk in the building process and better predictability of outcomes (McGraw-Hill Construction, 2010).

Since adopting BIM is a risk especially for small enterprises (the costs are relatively high), there are a lot of companies in the construction business that are quite hesitant to adopt Building Information Modeling fully but rather use a series of advanced three-dimensional software solutions and generate the rest of the needed data by hand, which is of course a cumbersome and time consuming task (Sacks, Kaner, Eastman, & Jeong, 2010). This leads, according to the data collected during the Rosewood experiment (Sacks, Kaner, Eastman, & Jeong, 2010), to fabricators almost never receiving architecture models, but rather generating the 3D models they need for their purposes manually, built on the two-dimensional drawings they get from the planning side. Of course, the more such redundant work has to be done, the more error-prone a process becomes – after all, humans tend to make mistakes, so misreading, misinterpretations and resulting inconsistencies between the different blueprints are quite common (Sacks, Kaner, Eastman, & Jeong, 2010). As one can probably image easily, such flaws can entail a huge amount of changes, which are costly at the least, and even more costly and tedious to eliminate the later they are discovered. But being human of course has its advantages too – when each phase of planning is conducted not by a computer but by a worker, the chance to not only cause mistakes and inconsistencies increases, but also find them on the semantic level arises, something that computers usually are not capable of.

2.2.3 Other gains provided by using BIM

Simply looking at the financial aspects of the introduction of a new technology is usually not enough to paint the whole picture. There are several benefits reported by BIM users that in fact influence business ratios such as the return in investment, but deserve to be looked at individually because they also facilitate the process, for example. Thus, they have a positive influence not only on funds, but also on time spent and staff satisfaction, in turn leading to a number of positive consequences. Such consequences were identified by the Smart Market Report (McGraw-Hill Construction, 2010) and the KPI based study (Suermann & Issa, 2007) as the following:

Reduction of errors in construction documents – BIM is believed to allow errors to come to light earlier in the building process, mostly by ensuring that all participating parties have complete and accurate information. As we know, the earlier an error gets detected in a large project, the cheaper it can be fixed.

Reduction of time spent in specific workflow cycles – using Building Information Modeling, communication and management of delivery times and deadlines is achieved more easily. The overall level of expertise is thought to be increased as well. The communication within the team is enhanced as well by the sharing of information.

Reduction of necessary rework – as mentioned in the first point, detecting errors early can be a great advantage. Ultimately, every flaw that is detected in the planning stage saves time, material and thus money at the construction site. Also, intangible issues like frustration of personnel and giving an unprofessional impression to the customer are of course reduced if everything works according to plan. The reduction of rework is the top benefit seen in the adoption of BIM throughout all participating groups.

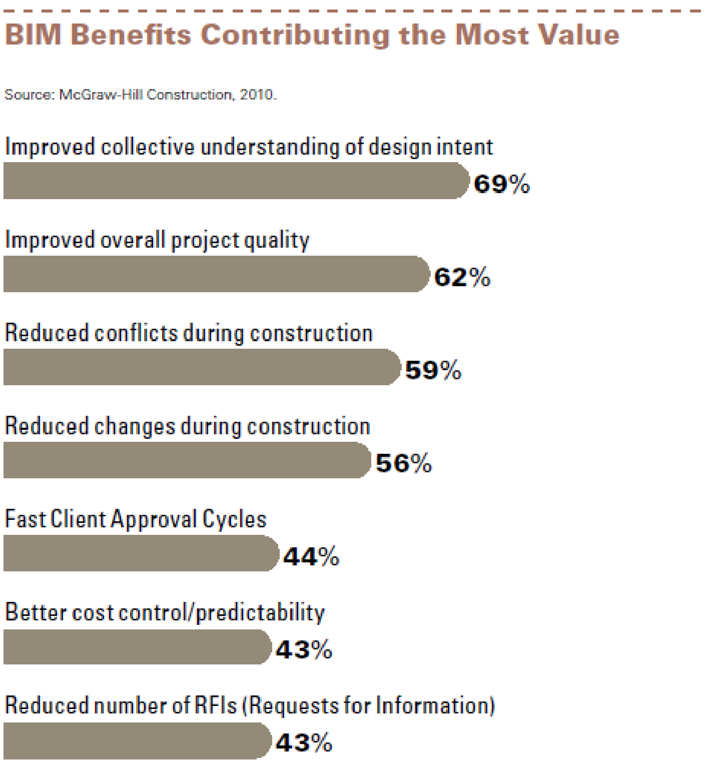

Figure 6 – BIM Benefits Contributing the Most Value (McGraw-Hill Construction, 2010)

Marketing new business to new clients – more and more clients ask that BIM is being used on their construction jobs, so being able to provide a planning and building process involving Building Information Modeling immediately creates value for both the user and the client. This is, according to the Smart Market Report, especially important for contractors, where three quarters rank this as a highly important feature (McGraw-Hill Construction, 2010).

Maintaining repeat business with past clients, the improvement of collective understanding of design as well as of the overall project quality and the reduction of conflicts during construction are other examples of added value industry experts see in BIM.

As already mentioned earlier, BIM is on the rise in both Europe and Northern America. This advance is due to several factors, according to the Smart Market Report, which are (McGraw-Hill Construction, 2010):

Productivity is the main factor that drives the implementation of BIM when believing the respondents of the survey. Productivity is not only enhanced by the time saved when using the BIM operation of a design program, but also by the improved communication between the team and the different players and professions in the whole planning process. Architects in particular appreciate the possibility to concentrate more on designing and less on fabricating drafts. Users also point out that they do not only benefit in their individual tasks, but the collective result of a project is perceived as overall better when BIM is involved

(McGraw-Hill Construction, 2010). By sharing models and ideas, new approaches are often found, and collaboration potential is detected where there was none before, leading to new roles or the new distribution of such among the team. Overall, this is regarded also as speeding up the planning process.

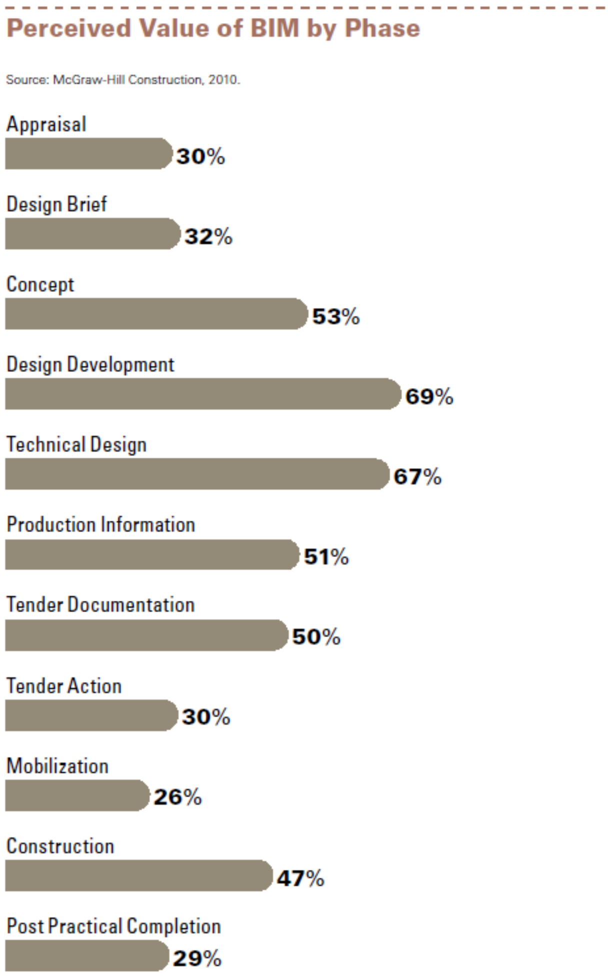

Figure 7 – Perceived Value of BIM by Phase (McGraw-Hill Construction, 2010)

The increase in accuracy in construction documents is the second highest ranked gain seen by users when they engage in a planning process involving Building Information Modeling, which can be seen throughout all participating professions. Also, reducing the time spent in the planning phase of a construction project is seen as a major advantage of BIM, for example by saving the effort of having to reenter data since it can simply be imported. As in any industry, saving time and money is an important aspect to be able to stay competitive and to keep an enterprise on the market in the construction industry. BIM is seen to be able to not only decrease the overall costs of a construction process, but also to plan it more accurately (McGraw-Hill Construction, 2010).

Among non-users, it is also believed that BIM can not only increase the safety at the construction site, but also support the use of lean construction methods, which is a term that summarizes the efforts to minimize waste and construct in an overall more economic and sustainable way (intergraph.com, 2013). In a lean construction process, everything is eliminated that does not directly contribute to the creation of value (Davis, 2007). Simulation enabled by BIM supports the lean product design, which builds upon the availability of the right information at the right time and especially its reuse at all levels. The attribute lean is often used with or synonymously to the word green. The improvement of building operations, maintenance and facility management is mentioned by potential new-adopters as a thinkable reason for adopting BIM, as well as legal reasons such as the reduction of insurance claims or litigations in general (McGraw-Hill Construction, 2010).

As we already pointed out, some aspects of a project do not benefit from BIM at all or in an amount that cannot justify the investment. Depending on the phases of the project, the value perceived by adding BIM to a project differs widely. The highest value here is scored by the design development phase, closely followed by the technical design phase, as Figure 7 above points out (McGraw-Hill Construction, 2010). When thinking about who has which tasks in these two phases, the high percentage is quite plausible – in the design phase, the architect begins with a rough sketch of the complex, and sometime later draws it up in a 3D modeling program. After finishing this task, the resulting model is handed to the engineering department for calculating whether this can be implemented that way, whether the static supports the design, etc. This is facilitated by BIM to a great extent, since it allows the model to be exchanged via the software interfaces rather than having to draw it from scratch in every software. By minimizing redrawing and re-entering of data, 16-17% of time can be saved, according to Dianne Davis (Davis, 2007). After the design is finished, the detailed technical calculations start, continuing the previous work by the engineer, investigating the material needed, the thickness of walls and floors, etc.

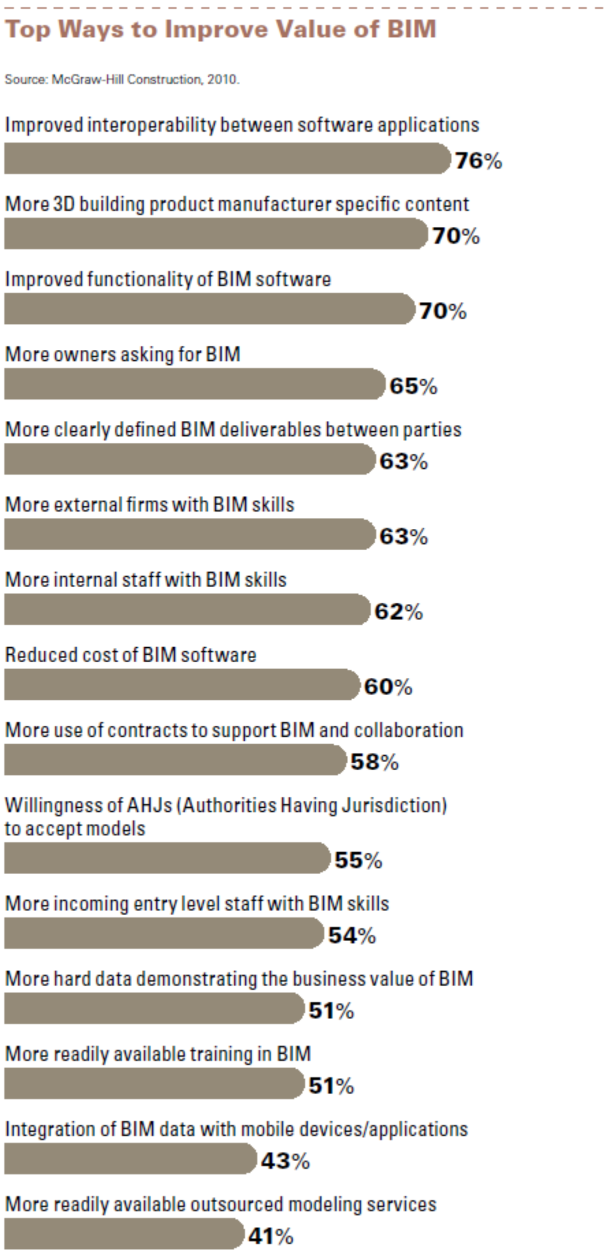

Figure 8 – Top Ways to Improve the Value of BIM (McGraw-Hill Construction, 2010)

2.2.4 Differences between professions

While all players tend to benefit from adopting BIM in a planning project, the players to profit the most are thought to be architects (71%), which was investigated within the scope of the Smart Market Report as well (McGraw-Hill Construction, 2010). The biggest benefit for this group was the 3D modeling abilities provided by BIM software, which also helps them to give other participants an understanding of their ideas, not so much the collaboration potential or other aspects. In this study, architects also showed the most experience with the usage of BIM, so the possibility that the high score for perceived value comes partly from the already discussed fact that BIM is seen as more valuable by more experienced players should be mentioned as well. While this group sees a lot of potential for the return on investment, engineers think that BIM will mostly increase the productivity and efficiency of a construction project, while also mentioning the securing of the market position as an important argument for them that argues for the use of BIM in 69% of responses. Architects are, on the other hand, also the most hesitant when thinking about implementing BIM into their workflow, and mention the high costs as the number one reason for the decision against it. Both engineers and contractors see the greatest potential in collaboration between all the stakeholders, with contractors also putting weight on the number of BIM professionals on the project. Since the last mentioned group is the one with usually the tightest budget and the most inflexible time schedule (McGraw-Hill Construction, 2010), BIM's potential of helping them keep these key figures, for example by avoiding conflicts and re-planning, is also quite important to them.

The differences in perceptions between the groups are little surprising when one thinks about the daily work of these players – the view on BIM is sort of biased by the tasks one uses it for. A contractor will hardly think about the potential for optical design provided by BIM. McGraw-Hill Constructions not only estimated the self-perception of the players, but also asked which other profession they believed to benefit the most from the usage of Building Information Modeling. Architects again won this ranking, but it is interesting to note that engineers were the only group to select their own profession in a majority of responses. The explanation the authors of the study give is that at this level of software development, the tools for structural engineering provided by BIM are more numerous than those supporting other disciplines. Contractors bring up the rear of the ranking, with neither themselves nor other players thinking of them as gaining a lot of value from BIM usage.

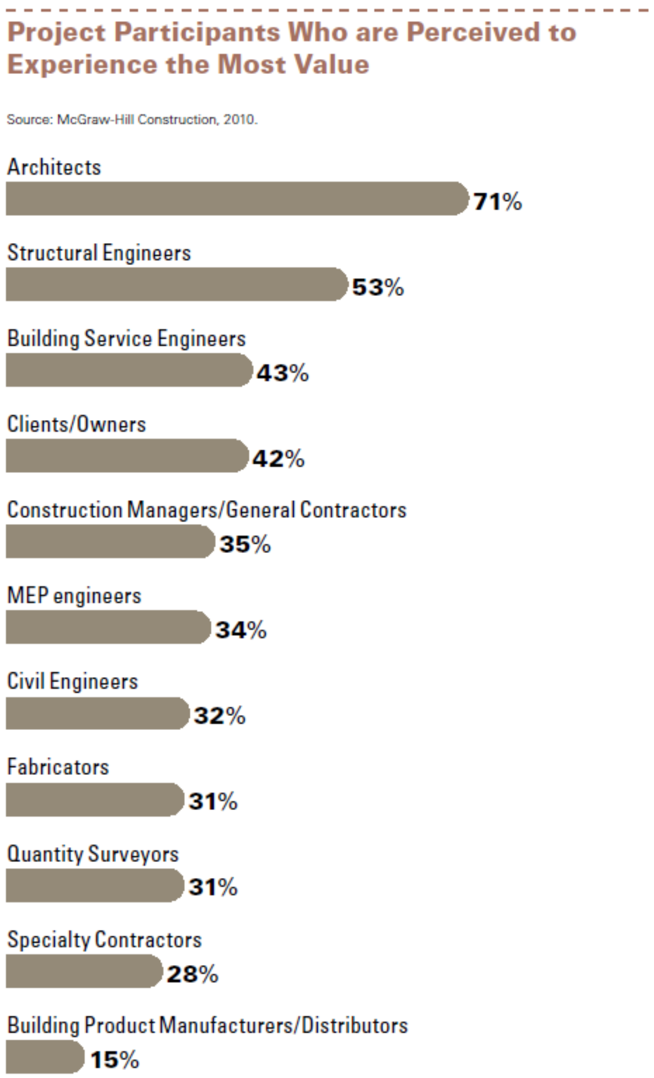

Figure 9 – Perceived Value of BIM by Profession (McGraw-Hill Construction, 2010)

2.3 Issues of BIM

As no intellectual human being would suspect, BIM of course is not the perfect, flawless answer to everything, but has some issues itself, which will be the main focus of this thesis. First of all, interoperability is seen as the major problem BIM faces according to the industry experts that responded to the McGraw-Hill study (McGraw-Hill Construction, 2010). By interoperability in this context, we mean the ability of the software interfaces between the various software solutions not only used by the different professions participating in the building planning process, but even between the programs used by the same profession, such as for calculating the ventilation of a building in one software and using another suite to evaluate the construct's energy efficiency. To really be able to use BIM as it is intended, and to have the potential to profit from its implementation as much as possible, the information exchange between the programs in use has to work flawlessly. Not only does it cost a lot of time and thus money to have to be forced to do a lot of adjustments to a model one just imported, but it is also very frustrating when a large fraction of one's time is occupied by such trivial, but cumbersome work instead of occupying with the calculations one is trained to do. Unfortunately, the standards which these interfaces have to comply to have developed much slower than the rest of the BIM world (Process Optimization for BIM-supported Sustainable Design, 2012), so issues remain here although there are efforts to formulate a state of the art standard such as we know from image processing – a JPEG file looks the same whether it is viewed in MS Paint, Adobe Photoshop or Gimp, no noses are missing or anything the like.

A very particular problem that arises with interoperability in the context of BIM is that not only the data one software gets from another has to be faultless to minimize rework and frustration by the user, but also BIM software as such is capable of interpreting the models composed in the programs to a certain extent (Björk & Laakso, 2010). The resulting models concatenate the different views of the various professions into one mutual model (Sacks, Kaner, Eastman, & Jeong, 2010). Since a computer is hardly as flexible as a human being, who can simply imagine the wall being complete on the plan and thus has a much higher tolerance of interoperability errors, missing or faulty items in a BIM model often lead to the non-conductibility of certain tasks, in turn limiting the power of the software and hence of Building Information Modeling as a whole (Björk & Laakso, 2010).

Especially architects voiced the request for being able to include more manufacturer-specific product-data in their 3D models, allowing them to plan more accurately and to visualize their ideas better in order to present them to clients and other players in the planning process alike. Not only interoperability is an issue that needs attention, but also additional functionality is thought to increase the value of BIM.

2.4 Standards

As already mentioned, for a software interface to work properly, standards are necessary. In both industries this thesis is concerned with, namely IT and construction, standards are important and part of the everyday life. When planning a building, architects and engineers as well as contractors rely on certain technical standards to be followed by all participants. In IT, the best example is probably the World Wide Web – without the standards released by the World Wide Web consortium, no website would look the same on different browsers or even machines, file transfers would not work as smoothly as they do, and so on. So the question is, why are the BIM standards not as well implemented and designed as we would wish them to be? Bo-Christer Björk and Mikael Laakso try to answer this in their paper about CAD standardization in the construction industry (Björk & Laakso, 2010). Here, they point out that the whole definition of the basic CAD standard took about one man-year, because it is a fairly simple standard. The problem with Building Information Modeling is that the models are so highly complex and include so much information for so many different purposes that the formulation of a standard for it takes a lot more effort and time. For example the IFC standard, which is also used by the test subjects in our thesis, has been in development for over fifteen years, with efforts still going on (Björk & Laakso, 2010). The authors of the paper also state that the picture is not that easily interpreted simply by looking at the numbers. The quest to define a standard and testing software for it has influenced the development of the according software and processes, so there is interplay between these two aspects of BIM development, forcing the standard to be adopted to ever-changing circumstances continuously.

CAD standards have been around for a little more than 30 years now (Björk & Laakso, 2010), but as systems became more and more advanced, models contained more and more information and were widened out to the third dimension. The need for a more powerful format emerged, one of which is Industry Foundation Classes (IFC), an open standard, a first version of which was released in 1997 and evolved from the cooperation of several large players in the construction software business.

IFC is an open and standardized model for Building Information Modeling and is developed and maintained by buildingSMART international (ifcwiki.org, 2013), (buildingsmart.org, 2013). It is the main data standard for BIM supporting software and models and registered by the International Organization for Standardization (ISO)[2] . The important thing to note here is that IFC, in its openness, does not belong to a specific software vendor or is even just maintained by one – it is neutral and independent (buildingsmart.org, 2013). In the IFC standard, exchange requirements are written down, specifying the information that needs to be included in an IFC file when wishing to use it for exchanging a model between software solutions and professions. The creators of IFC do acknowledge that the usefulness and necessity of certain pieces of data differs between project phases, so these requirements are acclimatized to the phase the project is in, picked by the user (buildingsmart.org, 2013). The buildingSMART organization also offers a certification that software development firms can undergo in order to affirm that their program indeed supports the IFC standard to a certain extent (detailed in the certificate) that allows a comfortable use of BIM (buildingsmart.org, 2013). It is important to note that IFC is a data standard; the builingSMART organization also

[2] www.iso.org

formulates standards for terms (International Framework for Dictionaries, IFD) and for the BIM process (Information Delivery Manual, IDM).

GBXML (Green Building Extended Markup Language) is the second standard used by the students in our experiment. It too is an open standard and its goal is to facilitate the transfer of data from architectural to engineering analysis tools (gbxml.org, 2013). XML has been an important part of IT solutions for a long time, enabling the exchange of information between applications with no human interaction necessary. As the naming would suggest, the main purpose for gbXML is the reduction of barriers when designing resource-efficient buildings. The standard has first been formulated in 1999 and has had a place in the industry ever since. In the words of its creators, gbXML helps to “realize the promise of Building Information Modeling, gbXML allows intelligent solutions for the design, certification, operation, maintenance, and recycling of buildings. The possibilities are limited only by the collective imagination of the building design community” (gbxml.org, 2013). To facilitate the use of the guideline, an online schema validator has been released in 2013, available on the official website of the endeavor (gbxml.org, 2013).

Despite this development of research and practice to unfold the full potential of BIM, it is necessary to design appropriate planning processes and check the interoperability of software, which is the aim of this thesis. As it is risky, difficult and costly to intervene into planning processes in practice, data is gathered from experiments with students rather than from the industry. We analyze this data to improve BIM planning process and derive suggestions for software developers.

3 Methodological Approach

Social scientists mostly use quantitative data and statistical methods to test hypotheses and draw conclusions. By using quantitative data, for example gained from focus group interviews, theories can be enriched and more depth can be added to hypotheses. To combine these two methodologies, mixed-method studies have been suggested, which combine the strengths of both approaches and might reveal what neither qualitative nor quantitative research alone would have shown. Even though there are many acknowledged advantages to combined studies, they are not yet widely used. (Koeszegi & Srnka, 2007)

In our experiment we collected quantitative as well as qualitative data to be able to look at the experiment and its results from as many points of view as possible. The use of pre-questionnaires and post-questionnaires as well as the structured focus group interviews also enables a correlation analysis for different aspects of the project. For example the correlation between previous experience with one type of software and the satisfaction with its use during the project can be measured to gauge ease of use of the program and possibly necessary training.

Figure 10 below shows the final renderings of the projects of six different groups. It is evident that their approaches were very different, yet the results are equally impressive.

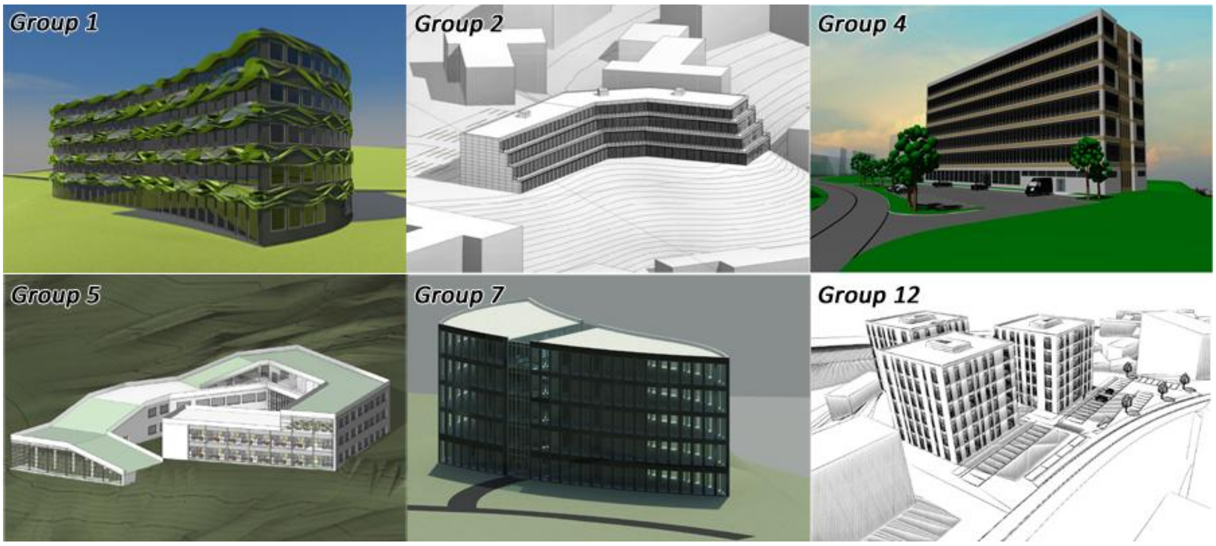

Figure 10 – Project Examples (BIM Sustain, 2012)

3.1 Questionnaires

To evaluate the software interfaces and the collaboration process during the *BIM Sustain* project, participating students filled out three different questionnaires. The first questionnaire was surveyed before the start of the project; it contained several general questions about demographical information. General data like gender, age and field of study were asked to be entered by the participants, but also several BIM-specific information was included that enables us to draw conclusions after the experiment. The time spent in the current field of study, the previous experience with Building Information Modeling in general and with the employed software solutions in specific were asked by us. This data will be used to find correlations between the satisfaction and the quality of the outcome as well as the subjects' level of expertise. As we mentioned in the state of the art part of this thesis, training and experience with BIM is usually an important factor when it comes to user satisfaction, so we expect to be able to see the same thing in our data.

The second and third questionnaires were filled out directly after the focus group interviews at the end of the course. They were created before the students started working on the project, so they are not biased by the experiences expressed by the participants during the experiment. Both the general and the software questionnaire contained three latent constructs each, consisting of 12 and 18 questions in total, respectively. There were five answers to choose from for each question, the scale was built up as follows: 1 (wrong), 2 (partly wrong), 3 (partly), 4 (rather true), 5 (true). Most questions were formulated in a way that a high score means a more positive attitude towards the subject under investigation, but some questions had inverse scales, like "I often need to consult the manual or support when using the software".

Data in total could be collected from 39 students, but not everyone handed in all three forms or filled them out completely, despite our best efforts. Complete data, meaning a pre-questionnaire, a general and a software questionnaire exists from 31 students in total.

The complete questionnaires in English and German language can be found in the Appendix.

3.1.1 Construct Validation

To be statistically able to evaluate the aspects that are suspected to make the BIM process successful, three latent constructs were included in the questionnaires. Cronbach's Alpha, a reliability measure to evaluate the internal consistency of a set of items within a survey, was used to evaluate the dependability of all our constructs. It takes into account the questions' correlation with each other and thus if they can be formed into some kind of scale (bmj.com, 2013). A reliability measure in general can be explained as the information if the subject that answered the measure would answer it again in the same way if given the questions again. Internal consistency can be viewed as the variables of the set all moving in the same direction. The technique has its origins in medicine, when patients are asked to fill out a survey according to which it is to be said whether they have a specific illness. Constructs are necessary when wishing to get an answer for a question without wanting to ask it directly – for example "do you think that interoperability works with the software you used?" just does not tell the whole story (bmj.com, 2013), so the perception of good or bad interoperability was split into six questions, which will be discussed below. For our purposes, we regard any alpha value above 0.7 as satisfactory, the best possible value being 1.

Construct	Cronbach's Alpha
Process Satisfaction	0.7024
Outcome Satisfaction	0.7789
Cooperation Satisfaction	0.8548
Ease of Use	0.8829
Usefulness	0.9177
Interoperability	0.6550

Table 2 – Constructs' Cronbach's Alpha Scores

3.1.2 General questionnaire

As already mentioned, the general questionnaire consisted of twelve questions to evaluate the students' perception of the process and the teams' collaboration during the project. As mentioned before, not only the software is challenging when applying Building Information Modeling to a design process, but also the process itself can be the cause of trouble. Especially in our case, the students received hardly any formal training, and almost none at all that told them how to collaborate within the team. Some teams did very well despite that, using common sense to create a process that let them design the building almost flawlessly, as we will discuss in the results from the focus groups interviews. Others had huge troubles, a lot of fights and some even broke off the work on the building.

Constructs

Satisfaction with the Process: Evaluating the satisfaction with the planning process on the great scale was a very important task for us in the BIM sustain project. After consulting other research mentioned before in this thesis, we expected students to face quite some difficulties in the process. Training and experience are known to play a big part in the success (McGraw-Hill Construction, 2010), and with this measure, we wanted to evaluate the perception of the process in general – what did the participants think about the way their building design evolved? The construct at hand did not ask about the collaboration within the team – we will come to that later – but focuses on the personal tasks conducted by the individual. After all, if the performance of the single stakeholder is poor, the whole team will suffer from it. We did not only want to measure potential gaps in the students' skills compared to the rest of the group, but also get the subjects to reflect and think about their own performance during the creation of the building.

This set of questions can be related to the need for training and experience since it includes questions such as „I am satisfied with my performance in the planning process“ and „My approach to accomplish my tasks was practicable“. Of course, not every negative score in this set of items can be blamed on missing training or experience – there are always some individuals who are simply not good at what they do – but we believe that an overall low score, observed over most of the sample, points in the direction that students are in need of more training and support when being thrown in at the deep end. The second question not only targets training, but also the way the individual worked in terms of efficiency.

As we mentioned earlier, efficiency and productivity are important factors in the very competitive construction business, so another item to be answered was "I fulfilled my tasks efficiently". Efficiency is a goal not only investors and bosses want their subordinates to achieve – we believe that it is also something our students will have strived to fulfill, since they have a lot of other courses to attend to and to prepare for, implying that they do not want to spend any more time on the *BIM Sustain* project than necessary, so efficiency is something we can ask for even from subjects that are not paid to do the work or have a supervisor looking over their shoulder. After all, an individual who thinks they performed a task efficiently is usually more satisfied with the own performance, pushing motivation – nobody likes to waste their own time.

A high score in this construct suggests not only a high satisfaction with the process itself, but also that the individual student thinks they conducted their work in the best possible way, not only technically spoken, but also regarding efficiency. A respondent who reports a high satisfaction with the process is not only pleased with the way they conducted their own tasks, but also thinks that they carried out their role and position during the task appropriately, for which a separate question was included in the construct. Being able to know one's place and integrate oneself into a team is a key factor for working efficiently – if the architect thinks they constantly have to interfere with the way the engineer is calculating, not only the rest of the team will become frustrated with them. Such behavior can quickly lead to a decrease in motivation and thus productivity in the group, trust and willingness to work together might suffer, and the member being criticized all the time will get frustrated as well. From the financial side, unnecessary man-hours will be invested in a task (since two people work on the same thing), which could be put to a better use elsewhere.

The Alpha reached with this item set was close to being below our threshold of 0.7 at 0.7024, suggesting that the questions of the construct were not tuned to each other in the best possible way. On the other hand, we have to take into account that the sample size of 31 students was quite small. We will look at the standard deviation and other measures to evaluate the construct more closely in the results section of this thesis.

Satisfaction with the Outcome: Ultimately, work conducted in any field is supposed to result in some kind of outcome. As we already pointed out and discussed in chapter 2, a worker's satisfaction is a very important, but also a rather hard to measure aspect when trying to evaluate a technology. The outcome in our case, of course, is a finished building design. The question how satisfied a single student is with the outcome is a bit tricky to answer, since all the experiences they made during the planning phase will be projected into the perception of the outcome by them. So even if the final building design is exactly the way the respondent pictured it at the beginning of the BIM sustain project, they might not find it that appealing if the way to get there held a lot of negative experiences for them. As we see, simply asking for the satisfaction with the outcome of the process will not suffice to receive an answer that is as unbiased as possible.

Why we are interested in the user's satisfaction with the final building design – after all, the results are rated by a professional jury – should not go unmentioned. We do not only want to know whether the students were able to use Building Information Modeling in a way that has a good design as an outcome, but also if they liked using the technology. No user will use a certain method again (unless they have to) if the experience with it so far was unsatisfactory, as everyone can imagine. This dissatisfaction can easily lead to a diminishing success of new technologies such as BIM, or make users overall unhappy when being forced to use them. As everyone knows, an unhappy individual will not work as motivated and thus as efficiently and productively as someone who likes the work they do (Herzberg, 1987).

When looking at the design process for our building, it can be easily imagined how frustrating it is for an architect if they have to modify their original, creative and very elaborate design into something ordinary because the rest of their team could not make it work. Unfortunately for some students, the BIM process is a work that has to be conducted as a team – there is simply no imaginable way that lone fighters can be successful when using Building Information Modeling. The downside of any teamwork is, as it is known, that the poor performance or unwillingness to work together of a single member can lead to bad experiences and ultimately failure for the whole group.

Therefore, questions in this construct focus on the individual's perception of the final design of our office building, including statements such as “I am satisfied with the results reached as a group” and “The goals I defined for myself are fulfilled by the results”. By asking this, we can find out whether the cumulated work of all team members was satisfactory for everyone, opposed to the satisfaction with the own work examined in the previous construct. As it was already discussed, the setting and also meeting of goals is an important aspect of workplace psychology (Herzberg, 1987), so it is interesting for us whether the employment of Building Information Modeling into the planning process can improve this, or make things even worse. As much as we would have liked to compare the results to those of groups who did not use BIM when planning their building, we have to add here that we do not have the possibility to do this, because our study is too small to be able to create a sufficient amount of observations for both practices.

Personal expectations towards Building Information Modeling and towards the collaboration process are a subject of this construct, too, taken into account by “The results are in accordance with my initial expectations”. When trying something new, like a method to plan a building that one has not used before, no one starts with a clean sheet in their mind, but everyone has certain expectations that are more or less detailed. The most common expectations towards BIM are that the overall effort will be diminished, that work will be made easier and less cumbersome, and that the collaboration between the professions in focus will be enhanced, which is the topic of the third set of questions in the general questionnaire. Of course, not everyone has a positive attitude towards new ways of doing things, so some students might have expected to fail or to have even more workload, because they have to use Building Information Modeling in the planning process.

Satisfaction with the Cooperation: As we discussed earlier in this thesis, cooperation is a very big part of the Building Information Modeling initiative, if not to say the biggest and most important one. We mentioned that a BIM model is not only there for planning a building in 3D, but can facilitate a lot of things during the planning process, such as communication and reasoning among the team members and the overall exchange of information. In order to work properly, however, it is of course important that all stakeholders use the features of BIM and their software packages as meant by the inventor.

The enhancements offered by Building Information Modeling can only be used to the full extent if the file created for the interface between the programs is valid, meaning it is engineered as well as possible. If this is neglected, the next user in the workflow will not be able to import the model properly, leading to frustration and all the other problems already discussed. In order to have the process running as smoothly as can be, people not only have to use their software precisely, but also certain characteristics of the whole planning process have to be respected. For example, it seems to be very helpful for the success of a project if the major users involved in the workflow meet up before actually starting the planning and talk about their various programs in use. That way, everyone knows a little about the requirements to the model that they should fulfill to allow everything to work according to plan, like how walls have to be drawn and labeled, for example. This is, of course, only necessary the first time this particular combination of software packages is in use, so the time and resources spent here can be seen as a one-time investment that will lead to a long-term increase in productivity.

The central thought of BIM is the designing of a structure together – cooperation between the various disciplines is a key aspect to its success. The BIM sustain project had two major research aspects – the interoperability between the software solutions on the one hand, and the process during which a building design evolves using BIM on the other hand. It was already hinted that the human factors are not to be neglected when evaluating the use of Building Information Modeling. The collaboration between the various disciplines is kind of the counterpart to the interoperability on the technical side, so we wanted to put this aspect under the microscope as well.

Cooperation between the group members was evaluated using the third construct, which included statements like “The team members communicated effectively and efficiently”, letting us see whether the team communication was perceived as satisfactory, but also whether communication was good or bad for productivity. As mentioned before, efficiency is a very important key performance indicator in the construction industry, and cannot only be limited to the work of the individual – in the first construct, we wanted to find out if participants think that they conducted their own tasks in an efficient way. In this construct here, we want to know whether the collaboration had any negative influence on overall productivity and efficiency.

“The team members cooperated well and supported each other”, was another survey item, allowing conclusions about the way the project was realized - was the building designed as a team or by a bunch of lone wolves? The question also lets us see if the students worked with each other, or rather against one another. Building Information Modeling is not a technology for selfish people, but professions need to help each other out when faced with problems, for they emerged from the putting-together of so many different aspects into one model in the first place most of the time.

As labor theory investigated thoroughly, shirking and free riding is always a problem that should be kept at the back of one's mind when several people get a mutual task (Nathan Bennett, 2004), especially if they do not know each other and thus do not feel a certain degree of responsibility towards each other. Shirking can be the death of a BIM project, since each player has a distinct part of the overall job to do, and others rely on their work to be done assiduously. A disregard of this responsibility towards the team usually leads to unpleasant aftermath. We tried to assess this by questioning "All participants in the team worked satisfactory and made their contribution".

3.1.3 Software questionnaire

Our software questionnaire consisted of 18 questions to evaluate the students' experience with the software in use during the BIM sustain project. As already mentioned above, the software is a huge part of the users' experience with BIM and thus the part of the process that has the biggest influence on its perception. If the software functionality is poor, the user will perceive the whole BIM process as not functional, since the applications in use are the central aspect of any Building Information Modeling project - after all, BIM is not about the exchange of blueprints drawn on paper. An important aspect in this context is interoperability, as we already discussed. No construction professional wants to use BIM or has the time to do so if they have to redraw every other line after importing the model. Frustration quickly occurs when one has to spend a lot of time with cumbersome, unchallenging work that does not really contribute to anything – no one graduates with a master's degree in civil engineering to redraw a load of walls that the architects before them already created. This questionnaire too consisted of three constructs with six questions each, which were again evaluated using Cronbach's Alpha. Two of the constructs are part of the *Technology Acceptance Model* (Davis F. D., 1980), evaluating ease of use and usefulness of the software in the focus.

Constructs

Ease of use: The ease of use is the first part of the *Technology Acceptance Model* (TAM). The construct is used to evaluate several different aspects in the field of usability. When a software solution is supposed to be used appropriately and without any large barriers, how easy it is to be used, especially by users who are new to it, is very important. The field of usability concerns itself, amongst other topics, with the question how software has to be designed in order to allow people to work with it as flawlessly and easily as possible. Aspects like the time needed to familiarize oneself with the software, the training investment necessary and the frequency of errors are taken into account for the ease of use. In short, it is investigated what happens when you simply hand the new program to the user – whether they need formal training, have to look at the manual very often, maneuver themselves to places they do not want to go, or make a lot of mistakes in general (Tellioglu, 2010). For example, the number of times the “go back” button has to be used is a simple indicator for poor ease of use. A high score in the ease of use area means that an operator can start working almost right away, and since time spent in training is time not spent doing something productive, this is even financially interesting. On the other hand, software with poor usability or poor ease of use tends to frustrate people, so the satisfaction with the program and even with the own work gets lower, all of which leads to a decrease in efficiency and productivity (Davis F. D., 1980), (Herzberg, 1987). For Building Information Modeling to be successful, users have to be willing to use it – which will not be the case if the work with the software solutions is tedious for them. Ease of use is not only about the initial encounters with the programs, but also about the fact whether workflows and commands can be remembered easily by the user.

To evaluate the ease of use of the software applications used by the students, they were asked about their opinions on statements like “I often need to consult the manual or support when using the software” and “It is easy to remember or discover how to perform tasks using the software”. But also the “collaboration” between user and software plays a role here – as we all know, the user usually expects the application to perform a certain task when clicking a button or entering a command. If the computer does not react as planned, confusion and mistrust quickly turn up. Since this is a part of the ease of use as well, it was included in the construct by asking the users “I find it easy to make the software do what I want it to do”.

Another aspect of usability that we already cut shortly is the mental effort one has to put into using software. Information technology is supposed to facilitate the tasks and work of daily life, not make them more cumbersome. The more thinking the individual has to invest in how to accomplish the task they have to finish, the less brain capacity remains for the actual task, like the designing of a building – we’re talking about efficiency again. Apart from that, the software can be great at the task itself, like calculating energy levels, its perceived performance will still be very poor if users constantly have to struggle with the complex and unintuitive interface. To investigate this, we had the question “Interacting with the software requires a lot of mental effort” included in our software questionnaire. The Technology

Acceptance Model has been around for some decades now (Davis F. D., 1980), so it can be regarded as field-tested sufficiently, so the high Alpha-score of 0.8829 is little surprising.

Usefulness: The second aspect of the Technology Acceptance Model is usefulness (nngroup.com, 2013), describing how effective a software application supports the tasks by the user. Usefulness is another very important aspect of usability next to the aforementioned ease of use, since software can be as easy to use as any, if it does not deliver the desired result in a reliable manner, it is of very little use in the professional field.

In the construction industry, it is quite important to have software in use that delivers calculations one can rely on - after all, a lot of lives can be lost if the static calculations are wrong in the worst case. The other main feature an application here should offer is that it does not cost a lot of time to interact with. We already talked about how IT’s primary task is to facilitate tasks for people, improving the performance when accomplishing a certain task. Software is regarded as useful when it not only facilitates these tasks but sometimes even enables them in the first place (think of complex calculations here). The score benefits if the user is left under the impression that the task is difficult to execute or even unachievable without using the software.

High marks in usefulness tell us that the students found the software very helpful; a low score suggests that they would decide for another software solution if the choice was theirs to make (which it wasn’t, they were assigned the applications and had to use them in order for us to have more samples). Such impressions might, as can easily be imagined, lead to diminishing sales for that application, which was one of the reasons for our study: construction software developers asked us to evaluate their software for their goodness and usefulness during the BIM process in order to have unbiased data to build their improvements on, since after all, today’s students are tomorrow’s industry users.

We assessed this construct again with six questions like “My tasks would be difficult to perform without this software” and “Using this software improves my performance in conducting my tasks”. As already pointed out in this section, software that is useful facilitates the performing of tasks, which we investigated by “With the software it is easier to do my tasks”. Productivity is an important key performance indicator in the construction business in general and in the Building Information Modeling process in particular, as we saw in chapter 2: a large number of users, especially engineers, see the gain in productivity as one of the biggest advantages when employing BIM in their designing process (McGraw-Hill Construction, 2010). Software usefulness should not be the bottleneck here, so it is not acceptable for an application to slow down the work of a stakeholder, which we wanted to assess with the survey item “The software increases my productivity”.

Even with the use of several questions that point to different aspects of usefulness, it is still quite difficult to really asses such an intangible feature simply based on a questionnaire (as opposed to usability experiments involving field observations and other state of the art examination methods (Holzinger, 2005)). Complicating the evaluation even more is the fact that the students have probably never heard of usability and thus can hardly be able to asses it for themselves, so we have to rely on their intuitive answers to our questions. To capture their overall, sort of subliminal impression of the software, the question “Overall, I find the software useful for my tasks” was included. Since usefulness is the second aspect of the Technology Acceptance Model, it has been used for a long time as well, leading to it being well tested in the field and thus resulting in the best Alpha score for all of our constructs, a very good 0.9177.

Interoperability: Building Information Modeling is all about the collaboration between all the different players and stakeholders that play a part in a building’s design process. A BIM model is not only the visual representation of an architect’s design – it contains a huge load of information from optical design to structural calculations, details about the materials and wall structures to be used, which way the building façade should face to have the least energy consumption, how the circulation works, where the lighting comes from and how the building’s temperature regulation system works, just to mention a few. When fully exploiting all the possibilities of BIM, even an index of used parts at a very detailed level can be included, offering information about each window and each door in the building (Smith, 2007). The information is supposed to be available as long as the building stands, supporting facility management and emergency plans, and at the end of the building’s life cycle, deconstruction.

When thinking about all the different professions and people that gain information out of a building information model and have their jobs made easier through the use of it, it becomes obvious how important interoperability is. Every professional uses a different software application that is tailored to their very specific needs in order to accomplish the tasks as effectively and efficiently as possible. No reasonable application could satisfy all the needs of all the players – such a program would have to offer design features, be able to make a huge load of calculation from earthquake simulations to ventilation, offer an easy system to re-order and maintain parts of the structure and offer evacuation plans in a format that emergency services and authorities can use. Such a utopic application would be insanely huge, expensive, slow, and, most of all, unnecessary. The smart way to realize a building information model and make its data available to all disciplines is the usage of software interfaces, allowing the various software applications to work on the same model. A building information model is supposed to be the “visual door to a database of building information” (Design+Construction, 2007). Using this interoperability, each software package can concentrate on its special strength without having the challenge to be the Swiss army knife that serves all purposes.

As mentioned earlier in this thesis, unfortunately, the interfaces currently used in BIM processes are not developed as well as they seemingly need to be, and the different programs often seem to have trouble working correctly with the gateways between each other. Two standards for BIM interoperability were used in our experiment, IFC and gbXML (see chapter 2 for more information), whose utilizability we tried to evaluate using the construct of interoperability. The first task the individual stakeholder usually has when using Building Information Modeling is the import of the model someone further up the workflow already generated into their own application, which can be of some trouble, as we will see. To capture the problems arising here, students answered the question “Data from other sources can be imported easily into the software”. After some time of working with the model, one wants to hand it to somebody else so they can fulfill their own tasks, so the next question to ask is obviously “Exporting data for the use in other systems causes problems in this software”.

After importing the model, if the interface specifications are not met properly, the first thing the user has to do is often some smaller or larger amount of rework before being able to utilize the model. For example, details have to be added that were either lost during the transition between applications or not included in the first place because they were simply not relevant for the preceding disciplines. For example, the internal structure of a wall is usually of very little interest for an architect. To asses this aspect, the item “Using data from other systems in this software necessitates a lot of rework” was included in the questionnaire. In some way, interoperability can be seen as the pendant to collaboration on the technical level. Since, as we know, collaboration is the key to successfully using Building Information Modeling and interoperability is supposed to support this collaboration, the question “The software helps to coordinate collaborative user processes” had to be part of our construct as well. The last question posed to the participating students was “Overall, I find the software is highly interoperable with other systems”, by which we tried to capture an overall impression of interoperability for the software used in the project. Since the construct of Interoperability did not reach a satisfactory score for Cronbach’s Alpha, we had to break it down into the individual questions to analyze it. The analysis can be found in the Appendix.

3.2 Content Analysis of Focus Group Interviews

Focus groups are “a technique involving the use of in-depth group interviews in which participants are selected because they are a purposive, although not necessarily representative, sampling of a specific population, this group being ‘focused’ on a given topic” (Rabiee, 2004). Focus group interviews are a means of qualitative data collection and enable participants to speak freely about a certain topic with colleagues from their profession rather than within their group. One advantage is that interviewees can express their thoughts while discussing the matter among each other without being influenced by singular questions, thus addressing issues in an order and intensity they want, allowing a ranking according to importance to be made. In structured focus group interviews, only guiding questions are posed when there are speak breaks or certain topics are not discussed. Participants are chosen according to several criteria such as age, being comfortable to talk to the interviewer and among each other and familiarity with the topic at hand. Furthermore, the role of the interviewer or moderator must not be underestimated. They are responsible for creating an environment in which the interviewees talk about the right topics and feel comfortable to share their opinion. The number of focus group interviews necessary to answer a specific research question depends on the field of study and on the question itself. For rather simple research questions like the ones we are posing here, three or four interviews can suffice. The number of participants is also important to consider. In contrast to quantitative research like questionnaires, here about six to ten interviewees are manageable and sufficient to generate enough data and gain a variety of views on a topic. Structured interviews are started with a very general initial question, after which the moderator tries to let the interviewees speak as freely as possible among each other, only interjecting when questions which should be answered are not covered otherwise. Interviews usually last for about one to two hours and are audio-recorded. (Rabiee, 2004)

After going through all the audio data for the first time and extracting information for a first overlook report we decided to do a content analysis to get the most out of the qualitative data. A content analysis is a process with five stages which transforms qualitative data into meaningful quantitative results. The stages and an overview of the process can be seen in Figure 11 below.

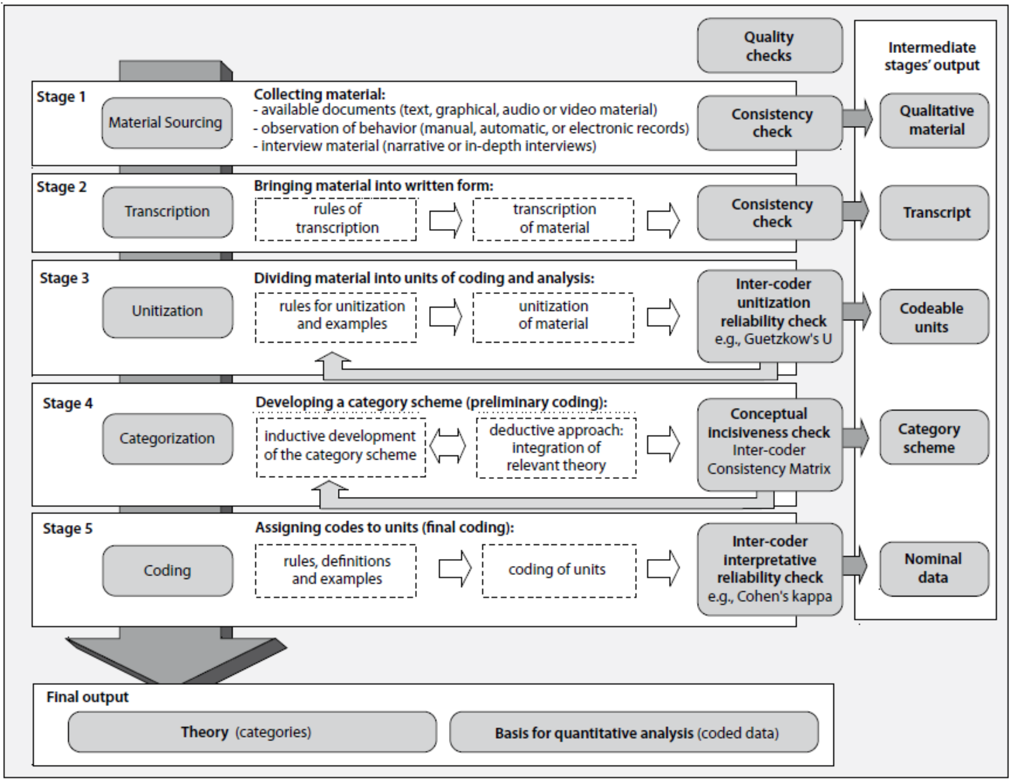

Figure 11 – Stages of a Content Analysis

3.2.1 Stages 1 & 2 – Material Sourcing and Transcription

Data needs to be collected first. There are many possibilities of collecting qualitative data, such as observations of behavior, interviews (structured or unstructured, with groups or with individuals, audio/video recordings or immediate transcripts) or already available documents or records. It's important to always document the circumstances, premises and assumptions under which data collection took place. E.g. was the interview structured or unstructured? How many people took part in the group interview? Which questions were asked and why? Which behavior was supposed to be recorded and how? Which methods were used to gather data?

In today's globalized world a very important aspect in material sourcing is the language of the material. In the best case scenario the researcher and respondent share a common first language and data gathering and analysis are conducted in said language. If this is not possible, however, a careful translation and back-translation of the material is necessary, potentially obscuring or eliminating cultural phenomena and particularities. Although sharing some problems with translation, using a "lingua franca", which is usually English, is a viable alternative. (Koeszegi & Srnka, 2007)

3.2.2 Stage 3 – Unitization

Following the sourcing of material and possible transcription the then available textual representation has to be broken up into single units to which finally categories can be assigned. The choice of how the individual units are defined is crucial. If the text consists of single spoken statements for example, it seems natural to take each statement as a unit. If also contextual factors are taken into account, for example gestures, facial expressions or tone, then a more detailed approach to unitization might be desirable. If the material is available in the form of longer text it has to be broken up into chunks to enable further analysis. So called *speaking turns* of individuals (i.e. “a communicator’s complete statement sandwiched between one or several other communicators’ statements” (Koeszegi & Srnka, 2007)) are often used as units but are not always the most useful. Better suited for analysis are so called *thought units* which represent one idea an individual is trying to express. This does not always have to be a sentence, but can also be a single word, an emoticon or just a punctuation mark. (Koeszegi & Srnka, 2007)

3.2.3 Stage 4 – Categorization

The next step is categorization, which means the development of a category scheme relevant to the problem at hand. Several difficulties arise when trying to develop such a scheme. Will new categories be developed or existing ones used? What level of detail should the scheme possess? Should the scheme have a single-level hierarchy or will there be multiple levels?

To improve reliability it is advisable to use existing “standard categories” where possible. To ensure validity however, an inductive approach of defining new categories with input from the data at hand is more suitable. A combination of both approaches, the *deductive-inductive procedure* seems to be the most advantageous and is thus the suggestion by (Koeszegi & Srnka, 2007).

A greater level of detail for the categories increases validity as the categories then more accurately describe the meaning of the coded units. The trade-off however is that the coding process is harder and achieving desirable inter-coder reliability is more difficult.

Choosing between a single-level hierarchy and a multi-level hierarchy depends on the research subject. Multiple levels are usually more concise and thus easier to handle. Especially if there are not too many categories, it might not be necessary to develop a hierarchy and a flat scheme might save time and provide more immediate insight. (Koeszegi & Srnka, 2007)

3.2.4 Stage 5 – Coding

The final phase in the 5-stage process of a content analysis is the coding phase. Coding means the assignment of categories to units. The coding and the unitization process are very subjective as the researcher acts on their own thoughts and considerations when working on qualitative material. To ensure some amount of objectivity it is necessary to let two researchers work on these tasks individually with unification afterwards. To measure the inter-researcher reliability, several quality criteria were developed in literature. The criteria used in this work will be explained later. (Koeszegi & Srnka, 2007)

3.2.5 The 5 stages in our work

Material sourcing

To conduct the focus group interviews in a productive manner and to get the best results possible, a guideline is established beforehand (see Appendix E – Focus Group Guidelines). This guideline includes an initial question to be asked and several follow-up questions to direct the discussion. The follow-up questions are only to be used in case the discussion about a certain topic became too long, stopped, or if the topic in the respective question has not been discussed yet.

Initial question: "How did you experience the building planning process of the BIM project?"

Follow-up questions:

- How did you experience the cooperation of the different project members of your team in the building planning process?
    - What went wrong or was difficult to handle, what went especially well?
    - How was the teamwork? Where there conflicts?
    - How was the coordination and communication (media)?
    - Was the work load divided equally, how did you manage division of labor?
    - Could you fulfill the tasks and keep the deadline?
    - Were there a lot of loops, how did you manage model changes?
    - What was the most impressive thing you learned during the project?
    - What was the most challenging thing in the planning process?
- What were your experiences with the software used in the building planning process?
    - How was the import/export in your team?
    - Were there bugs or errors? What was solved especially well in the software?

  - Was the software support and demonstration helpful or how can it be improved?
  - How was the joint work on one model with different software tools?
  - If you had one wish for the software developers for improvements or changes what would it be?
  - Do you think BIM is ready for use? Would you employ it in practice?
- How did you like the participation in the BIM project?
- Other questions, suggestions or complaints?

The interviews with the students were conducted by Dr. Michael Filzmoser in the media lab of the *Institute of Management Science* at *Vienna University of Technology*. Three interviews are available, one for each role in the lecture (architecture, civil engineering, building science). The length of each of the interviews can be seen in table 1 below.

Role	Length of interview	Pages of transcript
Architecture	01:14:05	25
Civil Engineering	01:28:52	40
Building Science	00:56:07	16
Total	**03:39:04**	**81**

Table 3 – Focus Group Interviews Detail

Two microphones were used as recording devices to improve audio quality and enable listeners to switch streams in case of overlapping speech or difficult acoustic circumstances. This resulted in six different audio files with a combined length of 07:18:08. The main language of the interview of the architects and the civil engineers was German, although some English discussion occurred. The interview with the building scientists was held exclusively in English as courses of the program at university are also held in English. Having only audio files available necessitated transcription of these.

Transcription

After some discussion we set several rules for the transcription process. Some of these rules were adapted from (Halbmayer & Salat, 2011), and some were set by us.

- Transcription generally word by word, repeated words only if there is a meaning behind them
- New paragraph for each statement
- Line numbering
- Single dots in parentheses per second of pauses, e.g. (..), (…..)

- Parentheses if a word or part of a statement was unintelligible with either the suspected word/statement within the parentheses or single dots per second of incomprehensibility and a question mark at the end, e.g. (..?), (ventilation?)
- Angle brackets with a description within for sounds other than speech
- Change very strong dialect to a better readable textual representation
- No record of who produced a statement, thus ensuring complete anonymity for the participants

The transcription process resulted in 81 pages or approximately 34500 words in total. The interview of the architects resulted in 25 pages, the interview of the civil engineers in 40 pages and the interview of the building scientists in 16 pages of transcript. Difficulties arose in the process due to sometimes several people speaking at once. This was especially common in the interview of the civil engineers where often a lively discussion between multiple groups of people would take place. Another issue was people sitting further away from the microphones speaking, while others who were situated closer to the microphones whispered among each other and thus obscured the relevant statements of their colleagues.

Unitization

The text from the transcripts was then segmented into units, each of which represents one coherent thought by an interviewee, the so called *thought units*. This unitization was done by two operators, to improve objectivity. To make sure the resulting two segmentations were sufficiently consistent a performance indicator called *Guetzkow's Disagreement U* was used. First, only 10% of each focus group interview was unitized and Guetzkow's U was calculated using the formula below.

$$\frac{|(Units\ Operator\ 1 - Units\ Operator\ 2)|}{(Units\ Operator\ 1 + Units\ Operator\ 2)}$$

Guetzkow's U describes the percentage of disagreement between the operators. We set a threshold of at least 80% of agreement (calculated by subtracting Guetzkow's U from 100%) for the unitization process, which was easily surpassed as can be seen in table 2 below.

	Architecture	Civil Engineering	Building Science
Operator 1	32	619	27
Operator 2	30	604	26
Disagreement U	0,0322	0,0322	0,0189
Agreement	96,78%	96,97%	98,11%

Table 4 – Results Unitizing 10%

After having unitized 10% of each focus group interview with satisfactory values of Guetzkow's U, the remaining 90% of each interview was unitized by each operator. Again, Guetzkow's U was calculated and the threshold of 80% agreement was once again met with ease as can be seen in table 3 below.

	Architecture	Civil Engineering	Building Science
Operator 1	319	619	229
Operator 2	314	604	228
Disagreement U	0,008	0,0123	0,0022
Agreement	99,2%	98,77%	99,78%
Final number of units	319	613	227

Table 5 – Results Unitizing 100%

The two sets of units were then unified by discussing each deviation individually and agreeing upon using one version or the other.

Categorization and Coding

The fourth stage, categorization, was once again done by both operators together. We decided to use a deductive-inductive approach which starts by researching relevant standard categories in literature. After agreeing on several standard categories, the inductive phase follows. In the inductive phase, we used knowledge from listening to the audio files and from transcribing the interviews to create suitable categories for the content. This was done by discussing among each other and by sampling units and their content from the interviews. Subsequently the first categorization scheme consisted of three main categories and sixteen sub-categories which were as follows.

- Main category: **Software**
  - Sub-categories: Ease of Use, Usefulness, Interoperability, Training, Support
- Main category: **Process**
  - Sub-categories: Communication, Collaboration, Lecture, Moderation, Confirmation, Suggestion, Forming, Storming, Norming, Performing
- Main category: **Miscellaneous (Misc)**
  - Sub-category: *Misc*

The deductive categories in the main category **Software** were *Ease of Use* and *Usefulness* (taken from the *Technology Acceptance Model* (Davis F. D., 1980)) as well as the custom construct *Interoperability*, which was created by the research team for the BIM Sustain experiment. *Training* and *Support* were devised inductively from experiences with the focus group interviews.

The four categories *Forming, Storming, Norming, Performing* (Tuckman, 1965) made up the deductive part of the main category **Process.** All others were created using an inductive approach.

After this joint establishment of categories, the first 10% of each focus group interview were coded individually by each operator. Similar to the Unitizing process, a performance indicator called *Cohen's Kappa* was calculated to measure the inter-coder agreement. The formula for *Cohen's Kappa* is

$$\kappa = \frac{p_0 - p_c}{1 - p_c}$$

Where p_0 is the relative observed agreement among the operators and p_c is the hypothetical probability of chance agreement which means the probability of each operator randomly saying each category. *Cohen's Kappa* can have values between 0 and 1, where 1 is a perfect agreement between the operators. For an amount of a categories, a matrix with a rows and a columns is constructed where the diagonal represents the agreeing codings of the two operators (i.e. units to which both operators assigned the same category) (Cohen, 1960). The matrix for the coding of the focus group interview of the architects can be seen below in Figure 12 as an example.

Operator 1	Operator 2																
Category	Ease	Usefu	Inter	Train	Supp	Comr	Colla	Lectu	Mode	Confi	Sugge	Misc	Form	Storn	Norm	Perfo	Total
Ease of use	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
Usefulness	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Interoperability	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	2
Training	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Support	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Communication	0	0	0	0	0	0	0	0	0	0	0	1	2	0	0	2	5
Collaboration	0	0	1	0	0	0	0	0	0	0	0	1	2	0	1	1	6
Lecture	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1
Moderation	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	4
Confirmation	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	2
Suggestion	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Misc	1	0	0	0	0	0	0	0	0	2	0	4	2	0	0	0	9
Forming	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Storming	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Norming	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1
Performing	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	2	1	3	0	0	0	0	1	4	4	0	6	6	1	1	3	32

Figure 12 – Inter-coder Reliability Matrix at 10% Coding, Architecture

The calculation of *Cohen's Kappa* for this matrix is as follows:

$$p_0 = \frac{Sum\ of\ the\ diagonal}{Total\ number\ of\ units} = \frac{14}{32} = 0.4375$$

$$p_c = \frac{1}{N^2} * Sum\ of\ marginal\ totals = 0.00097656 * 90 = 0.08789063$$

$$\kappa = \frac{p_0 - p_c}{1 - p_c} = \sim 0.38$$

Before the coding process, we agreed on a Kappa value of 0.75 which we wanted to achieve, as this is generally thought satisfactory. The value of 0.38 for 10% of the architecture interview is a lot less than that and can mainly be attributed to different understandings of the content of the categories by the two operators. The values of the 10% coding iteration of the interviews of the civil engineers and the building physicists were 0.58 and 0.66 respectively which is also too low.

What was also apparent during this first iteration of coding 10% of each interview was that some categories were redundant, while others needed splitting for further detail and clarification. After some discussion the revised category scheme looked as follows:

- Main category: **Software**
  - Sub-categories: Ease of Use, Usefulness, Interoperability, Training, Support
- Main category: **Process**
  - Sub-categories: Communication, Collaboration+, Collaboration-, Lecture, Confirmation, Suggestion, Misc, Forming
- Main category: **Miscellaneous (Misc)**
  - Sub-category: Misc, Moderation

This revised scheme also meant a reduction in the number of categories from 16 to 14. To further improve the inter-coder reliability, several coding rules were established. The rules can be seen below, where an arrow means this unit should be assigned the category after the arrow.

- Problems in collaboration → *Collaboration-*
- Errors or lack of SW functionality → *Usefulness*
- Starting Problems in the team → *Forming*
- Units are to be seen in context, so if a statement is interrupted by someone else, all of its units shall be seen in the same category (unless, of course, they concern

something else). This is to avoid filling up the *Misc* category with scrambled statements.

- Use category *Communication* only if actual communication takes place, so this category is about the content of the communication. If there is a lack of communication (or someone mentions that the communication is especially good), it shall be seen as *Collaboration*.
- Lack of skill or problems with other team members → *Collaboration-*
- Software crashes → *Ease of Use*

After the application of these rules and the use of the revised category scheme for the 10% coding of each interview, the values for Cohen's Kappa were a lot better as can be seen in Table 6 below.

Interview	Cohen's Kappa 10%
Architecture	0.78
Civil Engineering	0.83
Building Science	1

Table 6 – Cohen's Kappa of 10% after the Introduction of Rules

Subsequently, 100% of each interview was coded by each operator using the new scheme and coding rules which yielded the better results for Cohen's Kappa at 10%. Again, Cohen's Kappa was calculated to test the agreement of the two operators for 100% coding of the interviews. The results of these calculations can be seen in Table 7 below and satisfied our goal of 0.75.

Interview	Cohen's Kappa 10%
Architecture	0.77
Civil Engineering	0.77
Building Science	0.90

Table 7 – Cohen's Kappa of 100% of each Focus Group Interview

The last stage in the coding process was the unification of our results. Since the Kappa values were less than 1 in all cases, it was necessary for us to discuss the deviations in our results and agree on a category to assign to units which did not match. This was done in meetings of the two operators where we discussed all cases individually. The results of the 100% coding process were countable units with assigned categories and thus a transformation of qualitative data into quantitative data.

The next step for us was to further improve these results. The figure below shows the visualization of the data after the first complete iteration of the content analysis.

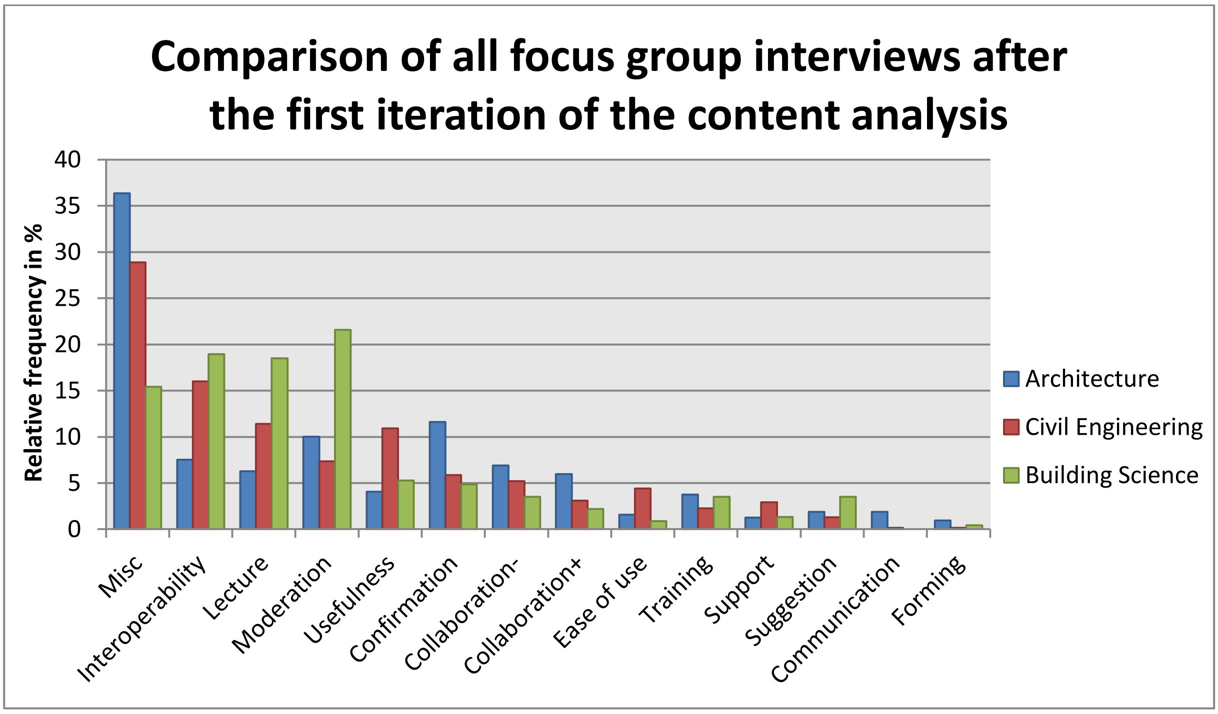

Figure 13 – Relative Frequencies after the First Iteration of the Analysis

The first observation here is that obviously the *Misc* category was defined too broadly and had too many units in it as it does not really have a meaning to analyze and was only supposed to hold leftover units which were not assignable to any other categories. Contrary to this definition, 28.3% of the combined units of the three interviews were assigned the category *Misc.*

To solve this issue we introduced, after some discussion, two new inductive categories called *Technical Discussion* and *General Discussion*. These categories were introduced to help us define units which were previously assigned to the *Misc* category in more detail. There was a lot of discussion about topics which were either technical or in the general context of the profession and we decided that introducing categories for statements in these discussions would improve our results and resolve the ambiguity that is the *Misc* category. The rules for the assignment of the two new categories were defined as follows:

- *Technical Discussion* → e.g. “How did you do that in your software?” “How thick is the wall?”
- *General Discussion* → e.g. “Your project is this one, right?” “What does it look like again?”, “Which software did you use?” etc.
- *Misc* → everything else (original definition of the category)

To further improve the result set, we decided to filter categories which comprised less than 1% of the total amount of units. This decision was made to further clean up the category scheme and to ensure that the used categories were well-defined and thus used for at least more than 1% of all units. The two categories which did not meet this criterion were *Communication* and *Forming*. After removing the categories, the affected units needed to be assigned other categories for which the following rules were created:

- Communication → Collaboration+ or Collaboration- or one of the misc categories (Technical Discussion, General Discussion, Misc)
- Forming → Collaboration+ or Collaboration- or one of the misc categories (Technical Discussion, General Discussion, Misc)

These changes necessitated a re-coding of some units. This re-coding was again done individually by each operator with a meeting for unification of the individual results afterwards. After this process was finished, we were satisfied with our results and the category scheme.

3.2.6 Final category scheme

The final category scheme which was developed incrementally and with a deductive-inductive approach can be seen below.

- Main category: **Software**
  - Sub-categories: Ease of Use, Usefulness, Interoperability, Training, Support
- Main category: **Process**
  - Sub-categories: Collaboration+, Collaboration-, Lecture, Confirmation, Suggestion
- Main category: **Miscellaneous (Misc)**
  - Sub-categories: General Discussion, Technical Discussion, Moderation, Misc

Below is a more detailed description of the individual categories. Following the name of each category is a description of the contents as well as an example from the actual data. Examples are translated to English from German where applicable. Original quotes can be found in the Appendix G – Translations.

Category	Description and Example
Ease of Use	How easy to use the software was. Includes statements about the user interface, crashes and how intuitive the use of the software is. Example: "*Making changes in SCIA is super easy."* [i]
Usefulness	Does the software do what it should do and does it deliver correct and useful results. Also includes statements about errors and problems. Example: *"I don't like, that you can make changes in Sofistik, or that Sofistik makes automatic changes."* [ii]
Interoperability	All statements about import, export and the interfaces between different software were put in this category. Example: "*No, but it returns feedback to Revit. There it states: ‚there was a problem, with this piece, you have to take a look at that'."* [iii]
Training	Everything about the introduction lectures about the different software and how useful they were. Example: "*But I could not learn to use a piece of software without working on a project. I don't learn a new language by reading the dictionary from A to Z either."* [iv]
Support	All statements regarding software support by the developers. Example: "*I had errors when I created ceiling openings in my core. The openings were not visible and I asked, and I don't know."* [v]
Technical Discussion	Discussion about technical details of the project. Especially about specific details of each respective profession – often students would ask each other questions. Example: *"Which FE net size are you using right now?"* [vi]
General Discussion	General discussion between students about their projects, studies or professions without mentioning any technical details. Example: *"Your architect used Archicad, right?"* [vii]
Collaboration-	Everything negative about collaboration and communication with other group members. Occurring problems and bad experiences. Example: "*Problems..came up (..) with the static"*
Collaboration+	Any positive remarks about collaboration and communication with other group members. Best practices and positive experiences. Example: *"but with the architect it worked very well, so (..)"*
Lecture	Remarks to structure and course of the lecture. This category is the main category for statements about the process by the students, since the course of the lecture was in fact their process. Example: *"I think in a real project there would be Meilensteine, so steps which work has to be done until when, and then a part of work has to be finished and then a part of work has to be finished and then it is given to static or to us."*

Suggestion	Constructive suggestions regarding software, process or lecture. Example: "It would be good if the project was set up in a way that the architects had a deadline and the project would then be graded and finished."[viii]
Confirmation	Confirmation of a statement of someone else to be able to tell whether participants agreed with the opinions of others, or not. Example: *"That's correct."* [ix]
Misc	Miscellaneous statements without useful content or other remarks which could not be assigned to any other categories. Example: *"Snowball effect."* [x]
Moderation	All statements by Dr. Filzmoser were marked as moderation and later filtered.

Table 8 – Final Category Scheme including Descriptions and Examples

These categories will subsequently be compared to each other and between the three professions to draw conclusions and to visualize differences.

4 Results

Using a holistic approach that includes both qualitative and quantitative data, we first want to discuss each method's results separately. In this chapter we will look at the correlation between certain variables from the questionnaires as well as discuss results from the content analysis from the focus group interviews, from which we also harvest the sequence of topics that came up in the interviews. The latter allows an insight into participants' priorities and thus enables us to weight certain problems that turned up during the planning process. In the conclusion (chapter 5) we will combine both results to evaluate the planning process from several different points of view.

4.1 Results of the Questionnaires

4.1.1 About the students

Let us start by talking about the demographics of our test subjects. Generally, one can say that the students participating in den BIM Sustain project were rather old and experienced, as Table 9 points out. The mean age was a little above 26 with the youngest student being 20 years of age, the oldest 34. The majority of students can be found in an age between about 24 and 28 years.

The experience is a little tricky to review – students were asked to enter their industry experience in months here, so participants who have been working for a long time, or who have worked the whole time during their studies, deform the average pretty much. The mean of a little above 20 months is thus of little expressiveness, also because the standard deviation is naturally quite high (see Table 9 for details). To evaluate students' experience, we should thus look at the quartiles and the box plot below (Figure 14), showing that most of our test subjects worked in the industry between 7 and 24 months so far.

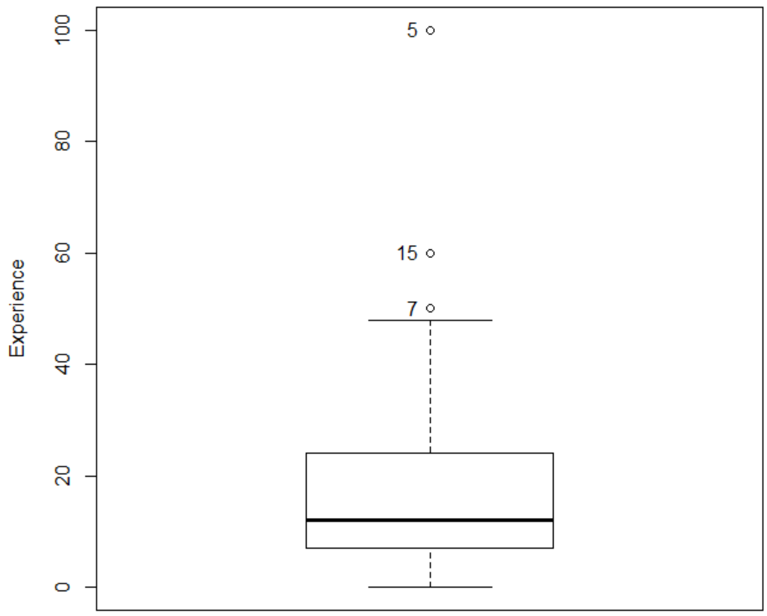

Figure 14 – Students' Experience in the Industry (Months)

The third thing of interest to us after age and industry experience is the number of semesters students spent in their current curriculum up until now. As we can see in Table 9, the average number of semesters prior to the BIM Sustain project is about 7, with numbers ranging from 1 to 22 – we should mention here that Building Science is a Master Curriculum, so a low number by these students does not mean that they are new to the university field. Again looking at the quartiles, we can see that most students find themselves between the third and the eleventh semester. We will look at this more closely in the following section, when we split the students into their professions so we lose the bias induced by the above mentioned master program.

	mean	**sd**[3]	**IQR**[1]	**min**	**25%**[1]	**median**	**75%**[1]	**max**	**N**[1]
age	26.34	3.40	4.5	20	24	26	28.5	34	35
experience	20.09	20.46	17.0	0	7	12	24.0	100	35
semester	6.94	4.95	8.0	1	3	5	11.0	22	35

Table 9 – Demographics of all Students

[3] sd = standard deviation|IQR = inter quartile range|25% = 1st quartile|75% = 3rd quartile|n = number of samples

In our test group, we had 24 male and 11 female students. The experience with the respective software solutions prior to the project will be discussed in the section about the software questionnaire. Unfortunately, as we already mentioned before, not all students handed in all three questionnaires. We decided to only use those results from students who participated until the end, diminishing the number from 47 starters to 35 students. Of these 35, three did not hand in one of the general or software questionnaire, so there are 32 students of whom we have complete data that will be used for the analysis later on.

Architects

As we can see, students from the architecture curriculum tend to be a little bit older than the average participant (see Figure 15), but also seem to have more industry experience (Figure 16). Please note here that we did not distinguish between the bachelor's and the master's program in the questionnaires. As we can see in Table 10, most participating architects are between 27 and 30 years of age, have one to three years of experience and have been studying for some time. There was one student who entered that he was in the first semester, but noted that he already owns a Master's Degree in architecture and took the course for some kind of retraining. Architects were the biggest group in our sample, their number being at 15. Building Science and Civil Engineering students both had the same number of people, 10.

	mean	sd	IQR	min	25%	median	75%	max	n
age	28.27	2.96	4.00	22	26.5	28.0	30.50	34	15
experience	23.47	17.26	25	2	11.0	24.0	36.0	60	15
semester	8.34	6.38	9.50	1	3.0	7	12.50	22	15

Table 10 – Demographics of Architects

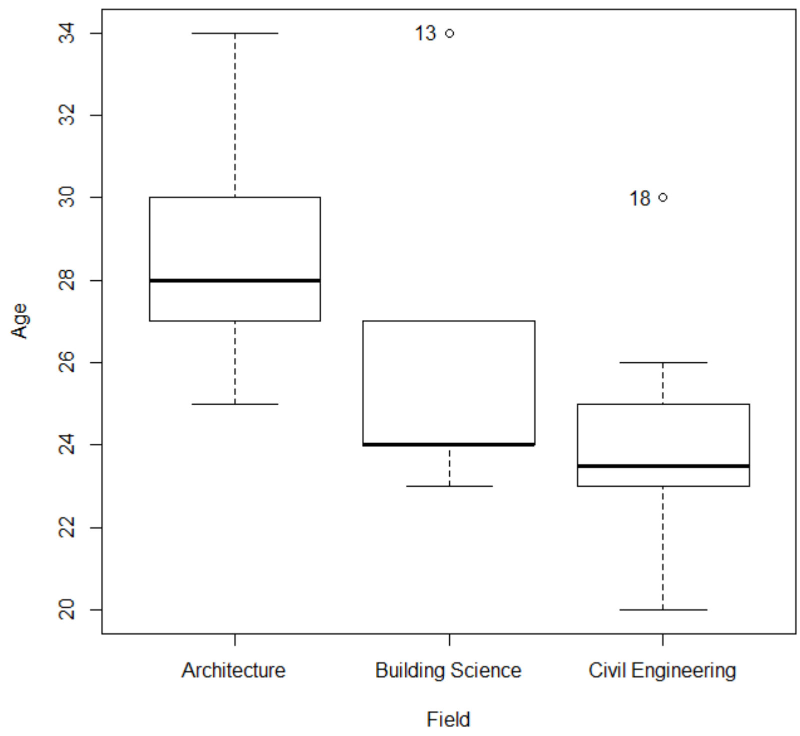

Figure 15 – Age of Participants by Field of Study

Civil Engineers

As we can see in Table 11 as well as Figure 15, Civil Engineers were the youngest of our participants. Most of them were between 23 and 25 years of age. Their mean experience in the industry was pretty much the average number of months reported in the BIM Sustain project (see Table 9), but we should note here that one student entered he had 100 months experience, so of course this number is deformed by such a high outlier. Looking at the box plot (Figure 16) and the quartiles we can say that most of the engineers have between seven and 21 months of industry experience and are between the fifth and eleventh semester in their curriculum.

	mean	**sd**	**IQR**	**min**	**25%**	**median**	**75%**	**max**	**n**
age	24.10	2.69	2.00	20	23.0	23.5	25.00	30	10
experience	19.90	29.17	14	2	7.0	9.5	21.0	100	10
semester	7.90	2.92	5.25	3	5.5	8	10.75	11	10

Table 11 – Demographics of Civil Engineers

Building Science

Age and experience of the Building Science majors can be seen as pretty much average in our field of students. What really stands out at first sight in comparison to the rest of the data is the low count of semesters spent in the curriculum (see Table 12 and Figure 17). As already mentioned, Building Science at Vienna UT is a Master's course of study only, so a student in the first semester has finished a bachelor's curriculum at VUT or some other university, so they have some experience although the pure figures might suggest otherwise. On the other hand, not everyone seems to have interpreted the question the same way; we believe that some students entered the total number of semesters they spent at university so far, so the maximum number entered is 11.

	mean	sd	IQR	min	25%	median	75%	max	n
age	25.70	3.23	2.75	23	24.0	24.0	26.75	34	10
experience	15.20	14.88	15	0	6.5	11.0	21.5	50	10
semester	3.90	2.51	0.00	3	3.0	3	3.00	11	10

Table 12 – Demographics of Building Science Majors

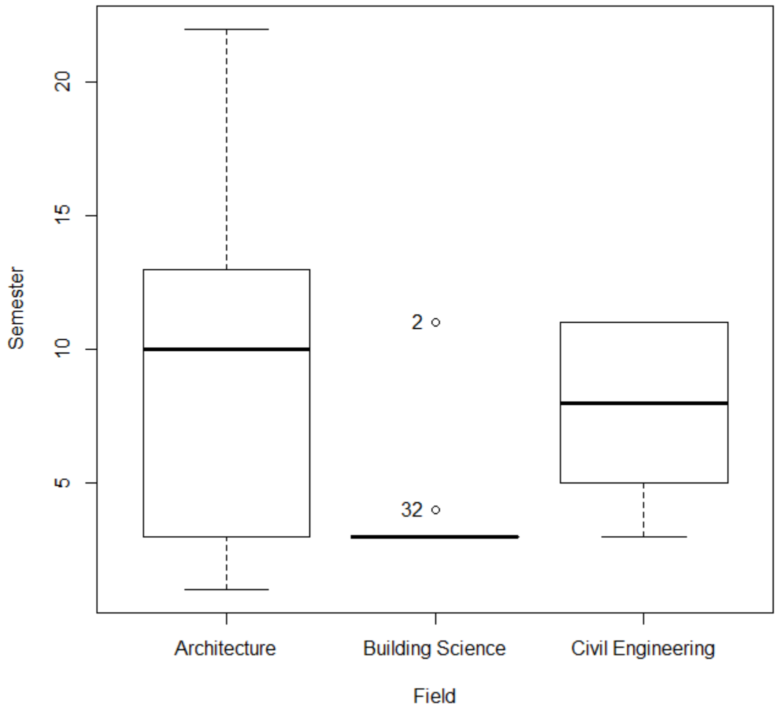

Figure 16 – Semesters Spent in Curriculum by Field of Study

Demographical Differences between the Professions

As already discussed briefly, the age is the biggest discriminator between the three professions in scope. Architects tend to be the oldest students, followed by building science with civil engineers being the youngest ones (Figure 15). Little surprising when knowing this, Architects also tend to have the most industry experience prior to the BIM Sustain project, their median for this field is more than twice as high as the median of the other professions (see Figure 17). When looking at the number of semesters, we have already mentioned that the numbers are little conclusive since we did not distinguish between bachelor's and master's programs in the questioning.

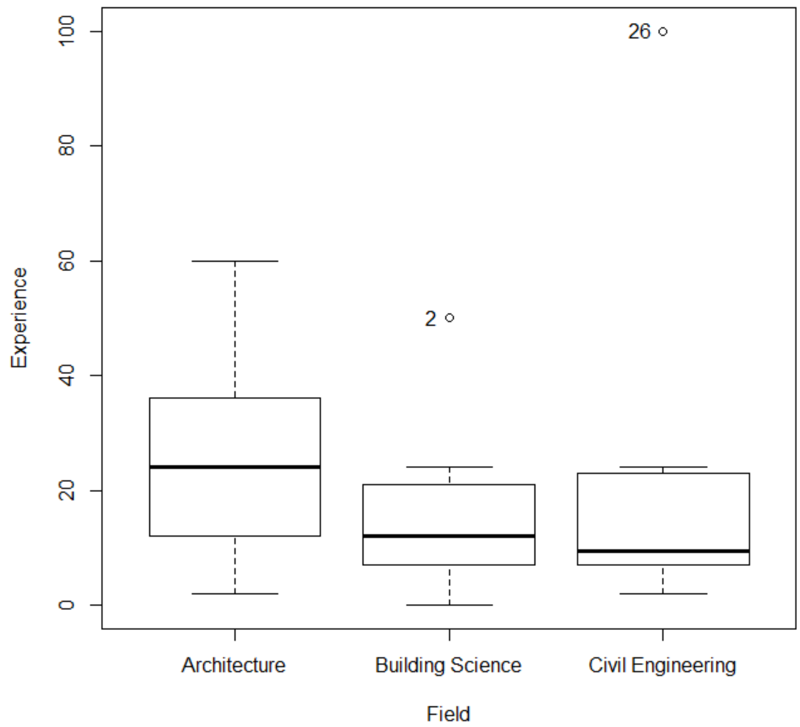

Figure 17 – Industry Experience (Months) by Field of Study

4.1.2 General Questionnaire

As we explained in chapter 3, our general questionnaire consisted of 12 questions making up 3 latent constructs, which we will look at separately here. Table 5 shows the three constructs of all 32 students. As mentioned before, not all students handed in all questionnaires, so the number is three students short of the prequestionnaires' count. We recall that students answered each question on a scale from 1 (wrong) to 5 (true). The score for a construct was calculated by simply taking the mean of its questions' scores, so a high score implies a high satisfaction with the collaboration, the outcome and the process, respectively.

As Table 13 below points out, the satisfaction in these three categories was not too bad. Every construct reached a score above the average of 3, satisfaction with the process was even rated as good. Since we expect some differences among the various stakeholders, we will look at each group and each construct individually now.

	mean	sd	IQR	min	25%	median	75%	max	n
Collaboration	3.73	0.98	1.5625	1.50	3.00	3.875	4.5625	5	32
Outcome	3.69	0.77	0.8125	1.50	3.25	3.750	4.0625	5	32
Process	4.07	0.59	0.7500	2.75	3.75	4.000	4.5000	5	32

Table 13 – Constructs from the General Questionnaire

Process Satisfaction

We tried to evaluate the students‘ satisfaction with the planning process as a whole by asking four questions. Cronbach's Alpha was already evaluated in chapter 3, we just want to see here if one specific question falls out of the pattern.

	mean	sd	IQR	min	25%	median	75%	max	n
Process	4.07	0.59	0.75	2.75	3.75	4	4.5	5	32

Table 14 – Satisfaction with Process by all Disciplines

Differences among the Disciplines

Other literature that deals with Building Information Modeling describes quite a difference in perception of the BIM process between the various disciplines involved in the planning of a building. So naturally, we expected to see the same thing in our data, which is why we want to compare the satisfaction with the process as a whole among architects, building scientists and civil engineers here.

	mean	sd	IQR	min	25%	median	75%	max	n
Architecture	4.14	0.61	0.750	3.25	3.7500	4.000	4.5000	5.00	9
Building Science	3.79	0.63	0.500	2.75	3.5000	3.750	4.0000	5.00	13
Civil Engineering	4.38	0.32	0.625	4.00	4.0625	4.375	4.6875	4.75	10

Table 15 – Process Satisfaction among the Three Disciplines

As we can easily see when looking at Table 15 above and Figure 18 below, there are some differences in the process satisfaction. A quick t-test (alpha = 0.05) showed, however, that only the results from Building Science and Civil Engineering differ significantly, but again, we must take into account that our sample size is very small. Nonetheless, students that had the role of the building scientist in our project reported the lowest value for process satisfaction, which leads us to the question where this might come from.

As we recall, this construct focuses mostly on the work done by the individual, whether they concluded their tasks efficiently and took up their role in the team appropriately. The low score could mean on the one hand that the students are just not satisfied with their work on the project, but on the other hand, this could come from a lot of rework that was necessary. Students with this profession had the task to calculate all the ventilation, lighting, heating and adjustment of the building. To be able to conduct these calculations, they of course need a valid model to work with – with the interface working poorly, a lot of rework becomes necessary. Since redrawing components and dealing with software errors is not part of the job description, it is easy to imagine that the students do not rate their time as being used efficiently or their role fulfilled in the best possible manner. When we look at where in the workflow the building scientists come into play, it is not surprising that they have to do a lot of rework: the model, which is created by the architects, is handed to the engineers for structural analysis as soon as the design is finished, and is then handed on for all the thermal calculations etc. Also, building scientists often had to use two or more software solutions (compared to one by the other players) to make all the calculations and simulations possible, so they had to do the rework twice, in some cases.

What does surprise us is that the highest satisfaction among the test subjects comes from civil engineering majors – we expected it to come from architects, since they work at the beginning of the workflow and thus should not have that much trouble with importing models as the other two professions. Civil engineers also have to conduct a lot of calculations and thus import and export the model a couple of times, so it is indeed unexpected that none of them rated the process below 4.0. It is also interesting to see that this group was very homogenous in this construct, with a standard deviation of only 0.32.

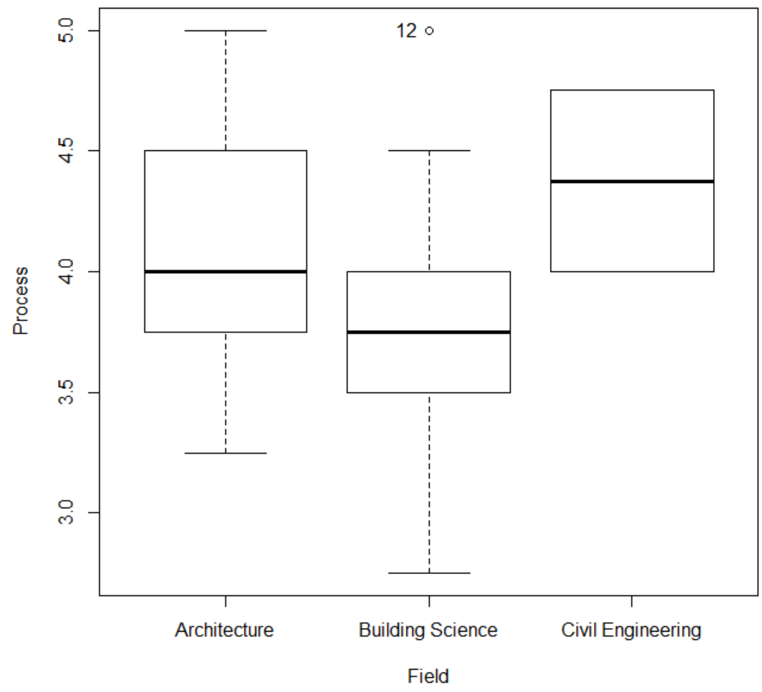

Figure 18 – Process Satisfaction by Field of Study

Outcome Satisfaction

This construct was to show us whether the participants were satisfied with the finished building design at the end of the process, and with the outcome reached as a team. Again, we want to take a look at the individual questions and all professions together at first (Table 16).

	mean	sd	IQR	min	25%	median	75%	max	n
Outcome	3.69	0.77	0.8125	1.5	3.25	3.75	4.0625	5	32

Table 16 – Satisfaction with Outcome by all Disciplines

Differences among the Disciplines

The initial design in the Building Information Modeling process naturally comes from the architect, so usually, architects should be satisfied with the outcome of the planning process since it is their idea that gets realized.

	mean	sd	IQR	min	25%	median	75%	max	n
Architecture	4.06	0.54	0.2500	3.25	4.00	4.00	4.2500	4.75	9
Building Science	3.38	1.00	1.2500	1.50	2.75	3.50	4.0000	5.00	13
Civil Engineering	3.75	0.44	0.4375	3.25	3.50	3.75	3.9375	4.75	10

Table 17 – Satisfaction with Outcome Among the Three Disciplines

As we can see in Table 17, architects report the highest outcome satisfaction by far. The case that their initial design was not realized is very rare and usually only happens when the other team members can't make it work, so the statics are impossible or the ventilation would not be doable, for example. This should almost never happen because the architect, although they are no specialist in the field, also knows about statics and what can be done as well as what can't be.

Something that can be seen in the box plot for this construct (Figure 19) very nicely is that answers given by architects were very unanimously given. The whole range only goes from 3.25 to 4.75, the box plot does not show any whiskers and thus indicates that most architects were of one mind. Other than that, it can be seen quite clearly that the building science majors show the complete opposite – their answers range almost over the entire possible scale of 1 to 5, and there are no real outliers since every respondent lies within the whiskers. What we see from the results is that on the one hand, the satisfaction with the process outcome lies only slightly above the average score possible at 3.38. The second thing we can see in Figure 19 is the already mentioned range of responses, which we believe is, among other things like the usual differences in personal perception, due to the different grouping together of students. Building Science is a program prior to which one might have studied architecture, so maybe the participants too had very precise ideas of the building they were planning, ideas that maybe were not shared by the group's architect.

The Engineers' score was somewhere between the other two disciplines, they also had the lowest standard deviation. Their plot looks much like one would imagine – the median is a little above the average of the scale, whiskers point more to the top end than to the bottom.

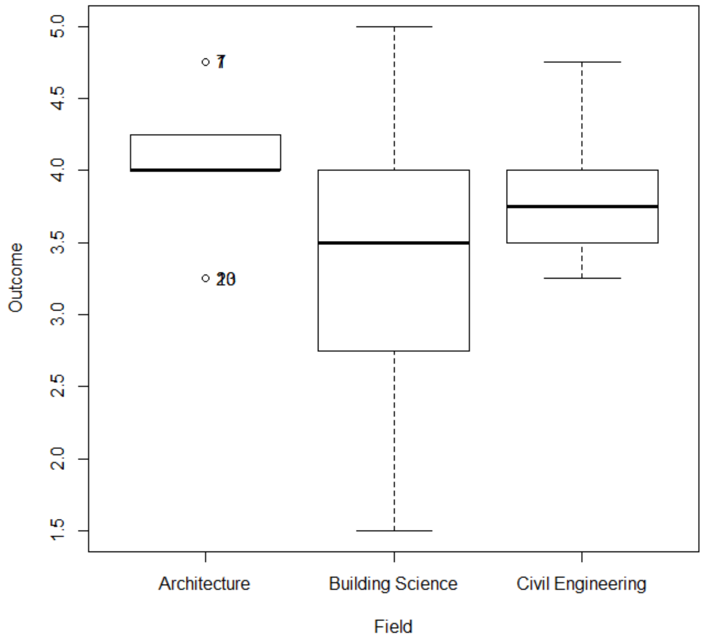

Figure 19 – Outcome Satisfaction by Field of Study

Satisfaction with Collaboration

This construct is the most interesting for us from the general questionnaire because one of our main research questions for this thesis and the BIM Sustain project as a whole is how well the collaboration between the various disciplines works and where the problems lie. To answer the second question, we again want to take a look at the individual questions first.

	mean	sd	IQR	min	25%	median	75%	max	n
Collaboration	3.73	0.98	1.5625	1.5	3	3.875	4.5625	5	32

Table 18 – Collaboration Satisfaction of all Disciplines

As we see in Table 18, the collaboration was not rated too well by the participants. The lowest score was reached by item 2, “Necessary information was exchanged by the team members in time”, which was also articulated in the focus group interviews. Civil engineers and building scientists both have to wait for the architect to finish their first draft of the design and for some steps in the workflow for other things too, so they cannot start their own work before the other players finish theirs. This can and did lead to a lot of stress, especially when the architects start their work very late towards the deadline – the other group members then have to squeeze tasks into very tight schedules, creating unnecessary stress.

Differences among the Disciplines

As the introduction to this construct hints, we expected to see the architects report the highest score for satisfaction with the collaboration. When looking at Table 19, however, our expectations are disappointed – architects actually answered with the lowest rating for this construct.

	mean	sd	IQR	min	25%	median	75%	max	n
Architecture	3.47	0.91	1.000	2.0	3.00	3.25	4.000	5	9
Building Science	3.75	1.056	1.750	2.0	3.00	4.00	4.750	5	13
Civil Engineering	3.93	0.99	0.875	1.5	3.75	4.00	4.625	5	10

Table 19 – Satisfaction with Collaboration by Field of Study

Since it is usually the architect who starts to work on a project, they are often the team leader, too. This often leads to communication running through them and giving them responsibility for keeping the time table, which might be a reason this group was not very satisfied with the collaboration in total. Other than that, we can see that the standard deviation is pretty high at around 1. What catches the eye when looking at the box plots (Figure 20) is that civil engineers seem to be much more uniformly satisfied with the collaboration within their team – their box and whiskers can be found between 3.5 and 5, only one outlier finds itself at the very bottom at 1.5. This is quite interesting because engineers are kind of in the middle of the whole workflow, so we suspect that they suffer the most from poor collaboration, leaving the conclusion that either our assumption is wrong, or that collaboration was really not such a big problem for them. We will look at this in detail when we discuss the results from the focus group interviews.

Building science students spread out the most, while most architects can be found between a score of 3 and 4. Although the score for collaboration is not as bad as we feared it would be, we still want to observe that all three participating professions rated it below 4 on average, leaving a lot of room for improvement. As we mentioned in the description of the project, students received hardly any formal training on how to conduct a Building Information Modeling Process properly, so it is still impressive that students were as successful as they were.

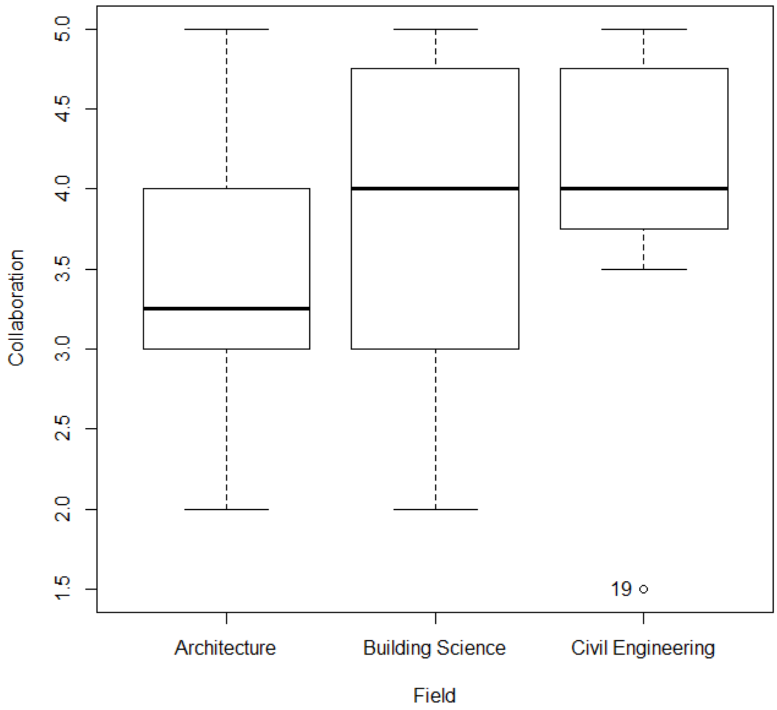

Figure 20 – Collaboration Satisfaction by Profession

4.1.3 Software Questionnaire

The software questionnaire too consisted of 3 latent constructs which were made up of 6 questions each in this case. As we saw in the analysis of the constructs, the value for Cronbach's Alpha reached by the third construct, interoperability, was too low for us to be able to use it in our analysis, so we will look at the six questions from this item separately. Before we go into detail, we again want to take a quick look at the questionnaire as a whole, taking all three disciplines into account.

	mean	sd	IQR	min	25%	median	75%	max	n
Ease of Use	3.19	0.91	1.42	1.33	2.42	3.33	3.83	4.67	43
Usefulness	3.79	0.85	1.50	2.33	3.00	4.00	4.50	5.00	43
IO 1	2.93	0.81	0.00	1.00	3.00	3.00	3.00	5.00	42
IO 2	2.53	0.96	1.00	1.00	2.00	3.00	3.00	4.00	43
IO 3	3.23	1.19	1.50	1.00	2.50	3.00	4.00	5.00	43
IO 4	2.35	1.00	1.00	1.00	2.00	2.00	3.00	5.00	43
IO 5	2.93	0.99	1.00	1.00	2.00	3.00	3.00	5.00	43
IO 6	2.95	0.95	1.50	1.00	2.00	3.00	3.50	5.00	43

Table 20 – Software Constructs of all Three Professions

We received 43 software questionnaires in total from 35 students, originating in the fact that some participants had to use more than one application (especially building scientists to make all calculations possible) and a sheet was filled out for each software solution in use. Again, the score can be on distinct points from 1 to 5. The first thing we notice here is that the overall score for constructs and questions is lower than the ones from the previously discussed General Questionnaire. Ease of Use and Usefulness do both not even come close to a good rating (which we see at about 4), and only one of the questions concerning interoperability is rated above 3. By simply looking at this data, we can already assume that the software is responsible for quite a lot of trouble in the building planning process.

Ease of Use

As we discussed in the methodological approach, ease of use is a quite important topic when evaluating software. We recall that this construct deals with how long it takes a user to become familiar with the software and how much training is necessary in order to work with the software appropriately. The Ease of Use was rated at an average score of 3.19, but as always, we are interested in the differences between the three professions.

Differences among the Disciplines

The low score by the building Science students immediately catches the eye – they rated the Ease of Use of their software solutions as below 3 on average, so they do not seem to be very satisfied. It was already discussed that a low score in Ease of Use is not only an indicator for an application to be cumbersome to work with and thus frustrates people. We also know that time spent in training is time not spent doing something productive, so a software solution that needs a lot of familiarization also has an economical downside for the company using it. At the end of this chapter, we will list the scores for all software solutions in use; here we just want to look at the discrepancies between the roles.

	mean	sd	IQR	min	25%	median	75%	max	n
Architecture	3.42	0.68	0.67	1.83	3.08	3.67	3.75	4.33	11
Building Science	2.98	0.83	1.17	1.80	2.33	3.17	3.50	4.67	15
Civil Engineering	3.24	1.10	1.83	1.33	2.17	3.67	4.00	4.50	17

Table 21 – Ease of Use by Field of Study

Looking at Table 21 and Figure 22 we can see that architects tend to be relatively satisfied with their software programs. Almost every student in this profession rated the Ease of Use as average or above, only one student scored below 2 out of possible 5. This does not really surprise us since the software suites used by architects have been around for quite a long time and have also been used by the participants throughout their field of study. A quick look at the students' experience with the software they used shows exactly that (Figure 21 shows the participants' experience prior to our planning process with the application they used in the project, rated from 1, no experience, to 5, a lot of experience). Here we can see that architects have had a lot more experience than the other two professions, a quick t-test (alpha = 0.05) prooves the obvious – there is a significant difference between the professions' level of experience. The next question that arises from that is whether there is a provable connection between experience and score achieved for ease of use and usefulness, a question which we want to answer in an own section a little later on.

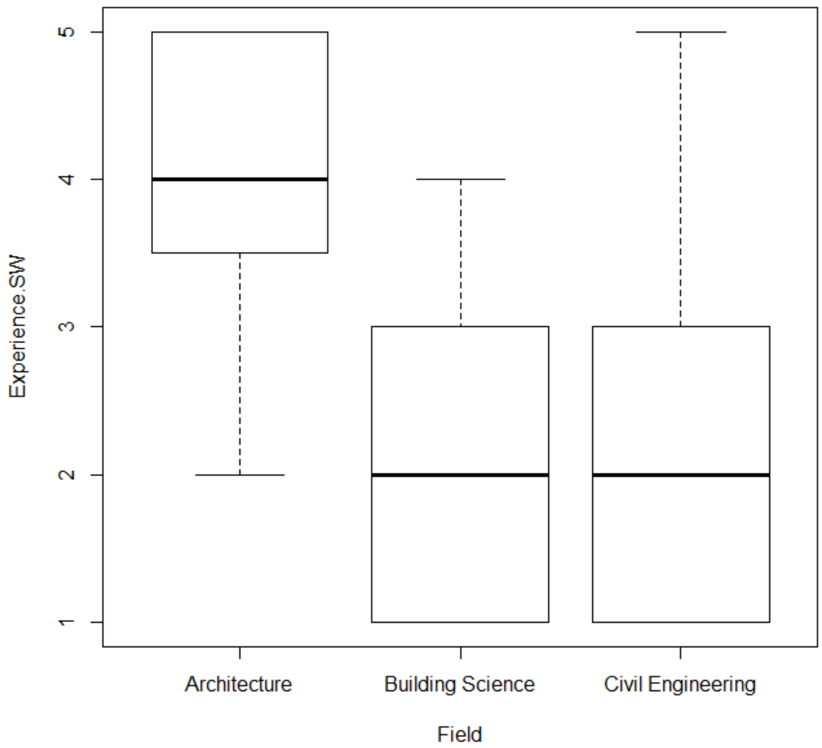

Figure 21 – Experience with the Software in Use Prior to the BIM Sustain Project

Figure 21 not only shows that architects report a better score than the other professions, but also that the ratings by engineers and building scientists are pretty spread out over almost the entire scale, only the two extremes (1 and 5) are missing. We believe that this can be traced back to the large variety of software solutions in use, which of course differ in their usability.

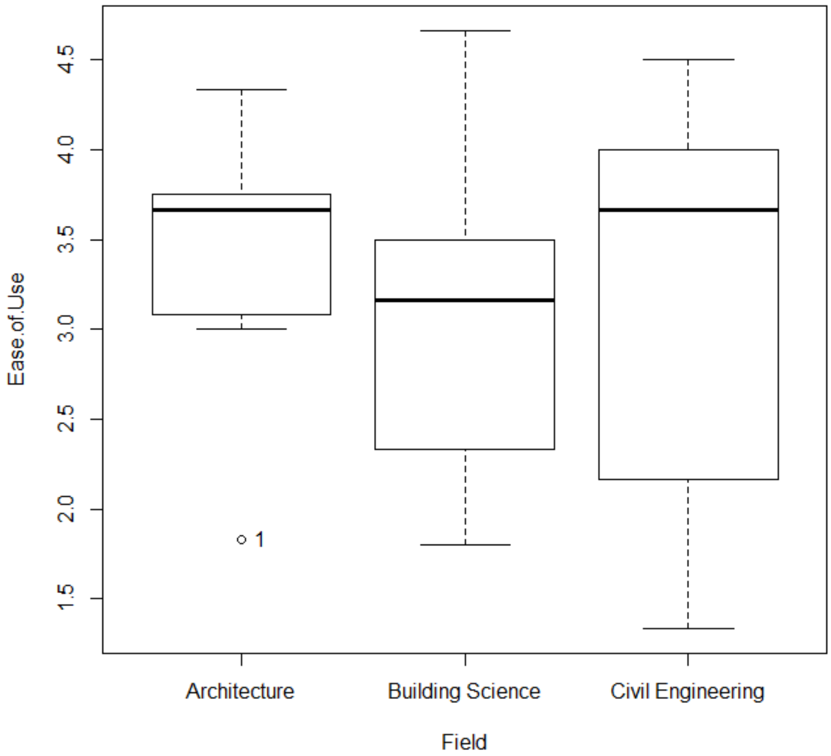

Figure 22 – Ease of Use by Profession

Usefulness

This construct mainly targets effectiveness, and whether the software in use supported productivity by the students. Usefulness, as already mentioned, is the second aspect of the Technology Acceptance Model and should always be looked at when looking at Ease of Use. Usefulness was rated better than Ease of Use when looking at all 43 questionnaires, but still below 4, so there is some room for improvement left.

Differences among the Disciplines

Every profession rated Usefulness above 3 on average, the surprising thing to see in Table 22 is that the engineers even rated the construct as good (above 4), no engineer perceived their application's usefulness as below 3. When looking at the corresponding box plot (Figure 23), it can be seen that the three groups in focus do not differ as much as in the previously regarded constructs. The mean for all three is between 3.5 and 4, the standard deviation below 1. What catches the eye is that civil engineers do not have a whisker to the bottom, so all of the respondents from this field of study were at least satisfied with their software's usefulness.

	mean	sd	IQR	min	25%	median	75%	max	n
Architecture	3.77	0.87	1.50	2.33	3.00	4.17	4.50	5	11
Building Science	3.57	0.89	1.67	2.33	2.58	3.83	4.25	5	15
Civil Engineering	4.01	0.79	1.67	3.00	3.00	4.17	4.67	5	17

Table 22 – Usefulness by Discipline

When recalling which questions were included in this item, such as “My tasks would be difficult to perform without this software”, it becomes quite understandable why engineers rate it so highly: their job includes a lot of complicated calculations that are very cumbersome to conduct by hand, so the software fulfills the definition of usefulness for their tasks very well. In all three professions, the two quartiles are quite far separated from each other, a fact that we again credit to the large number of different applications in use – some might have great usability, others might perform poorly.

The overall not too bad score for usefulness supports the idea of investing in Building Information Modeling. After all, introducing BIM to a construction business can be quite expensive as mentioned earlier in this thesis, so decision makers want to know their money to be put to good use. A score above average here allows the conclusion that the software supports the daily work of the stakeholders, making users more productive.

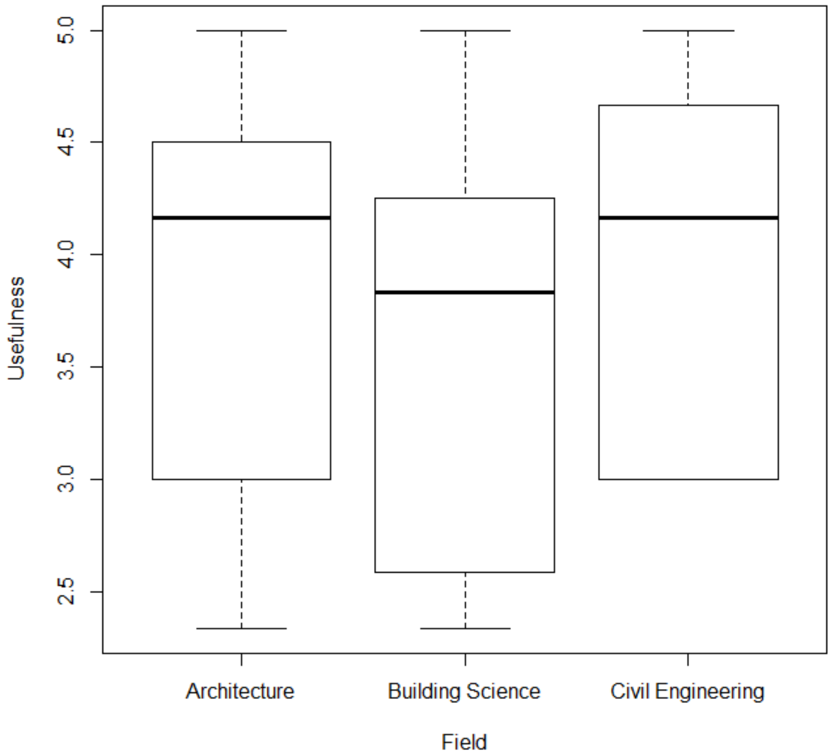

Figure 23 – Usefulness by Field of Study

Interoperability

Interoperability between the software solutions was, next to the collaboration among the professions, the second big question of the BIM Sustain project. We already know that the software interfaces lack behind in development, and that flaws in interoperability lead to a large loss in time and motivation. As we discussed earlier, this construct was custom designed for our research, and did not result in a satisfying value for Cronbach's Alpha, which is why we will look at each of the six questions separately. Generally spoken, we can see in Table 20 that only one question of this item set was rated above 3, namely question number 3, "With the software one can store to and load common data formats". This might seem like the applications fulfilled their interface-wise functions, but simply loading and storing a model is not enough to count as working well. We also asked if a lot of rework was necessary when working with the application, or if the export to other software causes problems, for example.

Differences among the Disciplines

IO1 - Data from other sources can be imported easily into the software

	mean	sd	IQR	min	25%	median	75%	max	n
Architecture	3.09	0.70	0.50	2	3.00	3	3.5	4	11
Building Science	2.86	0.95	0.75	1	2.25	3	3.0	5	14
Civil Engineering	2.88	0.78	0.00	1	3.00	3	3.0	4	17

Table 23 – Question 1 by Profession

As we can see, there was no big difference between the disciplines for this question – all three rated the importing abilities of their software solutions as average, what we can see is that only one building science major gave his application the best possible score of 5, and that almost all engineers rated it as 3 and can thus be seen as quite uniform.

IO2 - Exporting data for the use in other systems causes problems in this software (inverse)

	mean	sd	IQR	min	25%	median	75%	max	n
Architecture	3.82	0.87	1.5	3	3	4	4.5	5	11
Building Science	3.34	0.82	1.0	2	3	3	4.0	5	15
Civil Engineering	3.35	1.11	2.0	2	2	3	4.0	5	17

Table 24 – Question 2 by Profession

Please note that the scale of this question is inverse, so a high score actually reflects badly on the software at use. Building science and engineering majors seem to be pretty much on the same page in their ranking; only architects rated the software half a point worse on average. This is not surprising since architects are the first ones to export a model at the beginning of the workflow, so naturally it is safe to assume that they are the first ones to encounter problems.

IO3 - With the software one can store to and load common data formats

	mean	sd	IQR	min	25%	median	75%	max	n
Architecture	3.64	0.92	1	2	3	4	4	5	11
Building Science	3.40	0.99	1	2	3	3	4	5	15
Civil Engineering	2.82	1.42	2	1	2	3	4	5	17

Table 25 – Question 3 by Profession

As already mentioned in this section's introduction, question 3 is the best rated one from the topic of interoperability on average. As Table 25 shows, architects rated it the best, with engineers being the only group to rate it below 3. This group is also the only one to have included 1 (the lowest possible score) in their answers. The box plot (Figure 24) also shows that the architects' median was 4, compared to average experience by building science and partly poor rating from engineers.

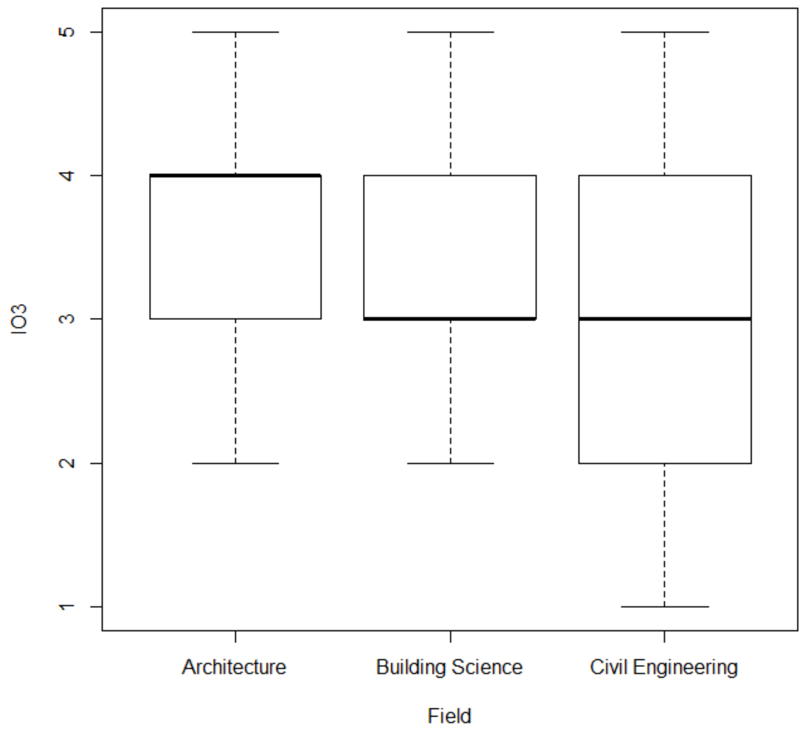

Figure 24 – Question 3 by Field of Study

IO4 - Using data from other systems in this software necessitates a lot of rework (inverse)

	mean	sd	IQR	min	25%	median	75%	max	n
Architecture	3.73	0.90	1	2	3	4.0	4	5	11
Building Science	3.57	1.09	1	1	3	3.5	4	5	14
Civil Engineering	3.76	1.09	2	2	3	4.0	5	5	17

Table 26 – Question 4 by Profession

We already talked a lot about rework in other sections of this thesis – time spent reworking is time spent not doing something productive, and frustrates people. Necessitating rework kind of is the opposite of the whole BIM-idea – when having to redraw a lot, the whole interoperability of the model does not work properly and it thus makes little sense to work with the common interface. As we can see from Table 26, all three disciplines report that a lot of rework is necessary and are distributed quite evenly across the answer sheet.

IO5 - The software helps to coordinate collaborative user processes

	mean	sd	IQR	min	25%	median	75%	max	n
Architecture	3.55	0.93	1	2	3	3	4	5	11
Building Science	2.87	0.99	1	1	2	3	3	5	15
Civil Engineering	2.59	0.87	1	1	2	3	3	4	17

Table 27 – Question 5 by Profession

The first thing that catches the eye here is that architects rated the software's ability to support the collaborative planning process way better than the other professions, which can be also seen quite clearly in the corresponding box plot (Figure 25): Building Science majors and civil engineers gave pretty much the same answers, architects lie one full point above them.

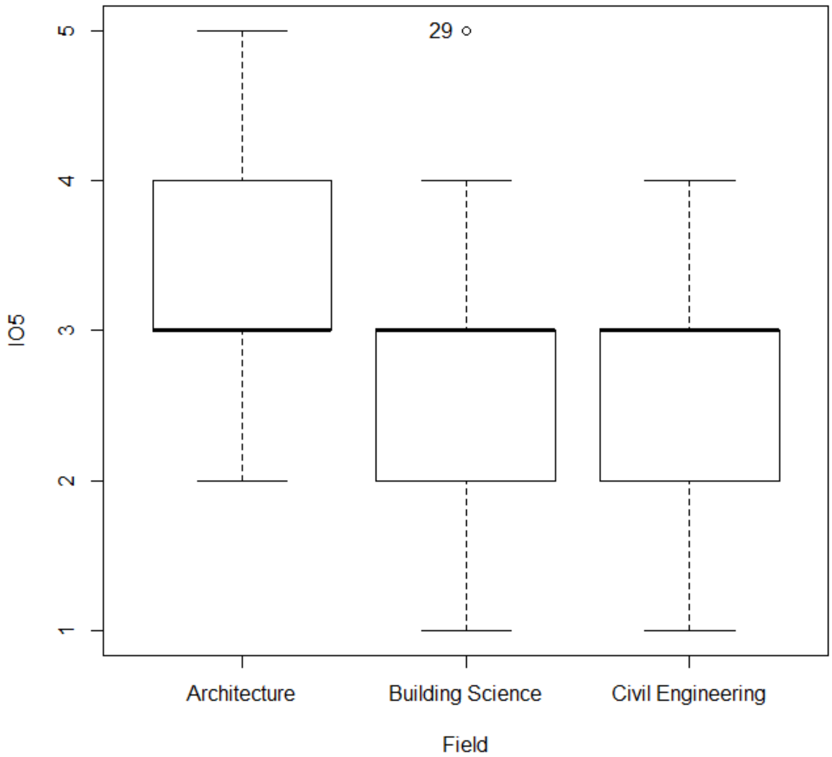

Figure 25 – Question 5 by Field of Study

IO6 - Overall, I find the software is highly interoperable with other systems

	mean	sd	IQR	min	25%	median	75%	max	n
Architecture	3.09	0.94	1.0	2	2.5	3	3.5	5	11
Building Science	3.00	0.85	0.5	1	3.0	3	3.5	4	15
Civil Engineering	2.82	1.07	1.0	1	2.0	3	3.0	5	17

Table 28 – Question 6 by Profession

Simply looking at the table, one would say that the three professions again experienced quite similar things in the project, so we want to look at the box plot for this question (Figure 26). Here we see that while the median is the same, 3, architects tend to move more towards the top of the scale, engineers more to the bottom, and building scientists are pretty much concentrated in the middle of the scale, except for some outliers towards the bottom. This graphic shows quite beautifully that the various software solutions are quite different from each other, and that the BIM process is indeed perceived in a different way by each profession.

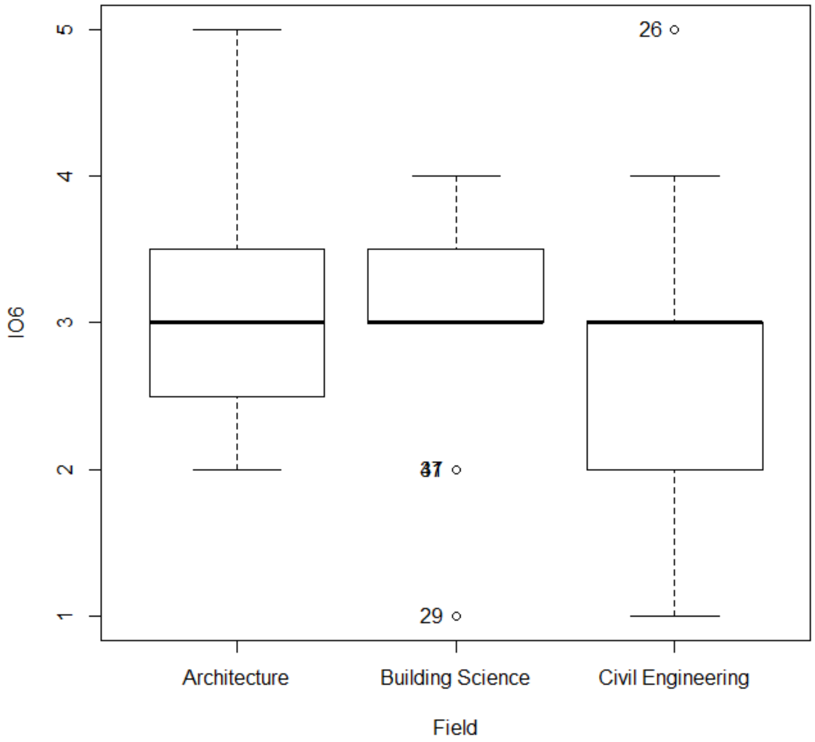

Figure 26 – Question 6 by Profession

4.1.4 The Role of Experience

In literature it is well known that the more experienced and trained a user is, the more success they have when using BIM (McGraw-Hill Construction, 2010). One of the questions for this thesis was whether we can say the same thing about our students, so we want to look at the connection between the experience with the BIM process, the experience with the software solutions and the score for the constructs in detail here. We already mentioned that architects had by far the most experience in the industry before starting work on the BIM Sustain project (see Figure 21).

We thus conducted some correlation analysis in R and came to the following results:

Construct	Correlation Coefficient with Industry Experience
Collaboration	-0.0186
Outcome	0.4124
Process	0.1570
Ease of Use	-0.1102
Usefulness	-0.0235
Interoperability 1	0.1301
Interoperability 2	-0.0565
Interoperability 3	-0.0716
Interoperability 4	0.3185
Interoperability 5	0.0508
Interoperability 6	0.0024

Table 29 – Industry Experience versus Construct Score

As we know, the closer the coefficient gets to 1 (or -1, respectively), the more the two variables correlate, so from Table 29 we can see that industry experience only seems to influence the satisfaction with the outcome, if anything at all.

Since our participants are all students, we have to take into account that not everyone has industry experience, and that experience gained in university projects might be valuable, too. To evaluate this, we looked at the correlation between the number of semesters spent in the respective field and the score reached in the questionnaires. As we can see in Table 30, no special connection can be made between these variables.

Construct	Correlation Coefficient with Semester Count
Collaboration	0.0483
Outcome	0.3241
Process	0.2068
Ease of Use	0.1621
Usefulness	0.1702
Interoperability 1	0.2690
Interoperability 2	0.0183
Interoperability 3	0.1077
Interoperability 4	0.1431
Interoperability 5	0.1225
Interoperability 6	-0.1090

Table 30 – Construct Score versus Number of Semesters Studied

The second interesting view we can take upon our data is the interaction of software experience and the scores for the constructs. In the following table, the correlation coefficient was calculated for the experience with the specific software application the subject used in the project and the results for the constructs.

Construct	**Correlation Coefficient with Software Experience**
Collaboration	0.0408
Outcome	0.6737
Process	0.4217
Ease of Use	0.4770
Usefulness	0.2545
Interoperability 1	0.3909
Interoperability 2	0.0590
Interoperability 3	0.4173
Interoperability 4	0.1078
Interoperability 5	0.3722
Interoperability 6	0.1800

Table 31 – Construct Score versus Software Experience

Correlation between software experience and perception of the various attributes (Table 31) seems to be higher than with the industry experience, which does not really surprise us: when spending less time with cumbersome jobs like redrawing and importing, the whole process is perceived as more satisfactory, so as we suspected earlier, software functionality seems to have an influence beyond the fields of usability and interoperability.

4.2 Results of the Content Analysis

The results of the content analysis of the three focus group interviews are as follows and will be discussed in the next section. As already mentioned in the section about methodology, the objectivity of the results is increased by using two operators for the content analysis. The two operators are the authors of this thesis. The results below are visualized data of the content analysis after transcription, unitizing, categorization and coding.

Colors used will stay consistent throughout all content analysis results diagrams and are as follows:

Focus group architecture – blue
Focus group civil engineering – red
Focus group building science – green

4.2.1 Overview of the Contents of the Focus Group Interviews

Sequence of topics in the focus group interview of the architects

- Explanations of approaches to the project and collaboration within the groups
- Major problems with the different software
- Discussion about utility and impact of the software
- Problems using the software
- Communication within the groups, quality of the work of other group members
- Suggestions for improvement
- Benefit of the software presentations and of software support
- Use of IFC
- Discussion about the advantages and disadvantages of 3D versus 2D

Sequence of topics in the focus group interview of the civil engineers

- Short accounts of process and collaboration
- Very detailed discussion about problems with the software
    - Workflow
    - Experience/support
    - IFC
    - Advantages and disadvantages
- Requests for the developers, suggestions for improvement
- Discussion about different features and problems of various software
- Collaboration and social aspects
- Lessons learned

Sequence of topics in the focus group interview of the building scientists

- Negative experiences with collaboration
- Difficulties with organization and the task definition
- Lessons learned
- Support and problems with the software
- Suggestions for improvement
- Positive experiences and conclusion

The sequences above show a first look at the similarities and differences between the three focus group interviews. The first topic is very similar in all interviews because of the initial question. Afterwards the architects and civil engineers immediately start talking about software and problems with it while this topic is only in fourth place for the building scientists. Also interesting to note is that the architects are the only group having a general discussion about BIM and its value while the other two professions stick to talking about the specific project at hand. Another similarity is that all interviews start off with negative remarks after the initial question and only gradually mention some positive experiences later on. Even though the guiding questions are formulated in a neutral way (see Appendix E – Focus Group Guidelines), the overall atmosphere in the interviews towards the project is rather negative.

4.2.2 Results after first complete iteration of the content analysis

Results for the main categories

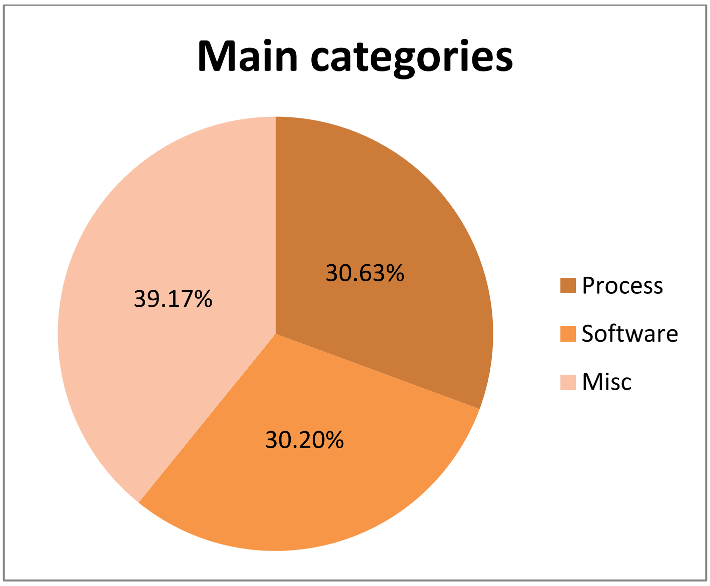

Figure 27 – Relative Frequencies of the Three Main Categories, First Iteration, Overall

Figure 27 provides a first overview of the results after the first iteration of the content analysis of the focus group interviews of the architects, the civil engineers and the building scientists. The three main categories as described in the methodology section about the focus group interviews are **Process**, **Software** and **Misc**. Surprisingly the two important categories **Process** and **Software** comprise a similar amount of statements, which means both topics were equally important in the interviews. Since the focus of the experiment as well as this work is on both the process and the software involved in Building Information Modeling this is a satisfying result. The strongest category being about miscellaneous topics, which do not yield as much useful information for our analysis as the other two main categories is a little concerning however. This means that some of the content of the interviews does not provide us with relevant information and is rather discussion among the participants or with the interviewer about topics which we are not particularly interested in. It was important to us, however, that participants were able to speak as freely as possible, which leads to some of the discussion not being of immediate use. It is important to remember that the sub-category *Moderation* has not yet been filtered out in the diagram seen in Figure 27. The filtering does however also reduce the overall content of the interviews and thus does not improve the total of meaningless information.

Sub-categories

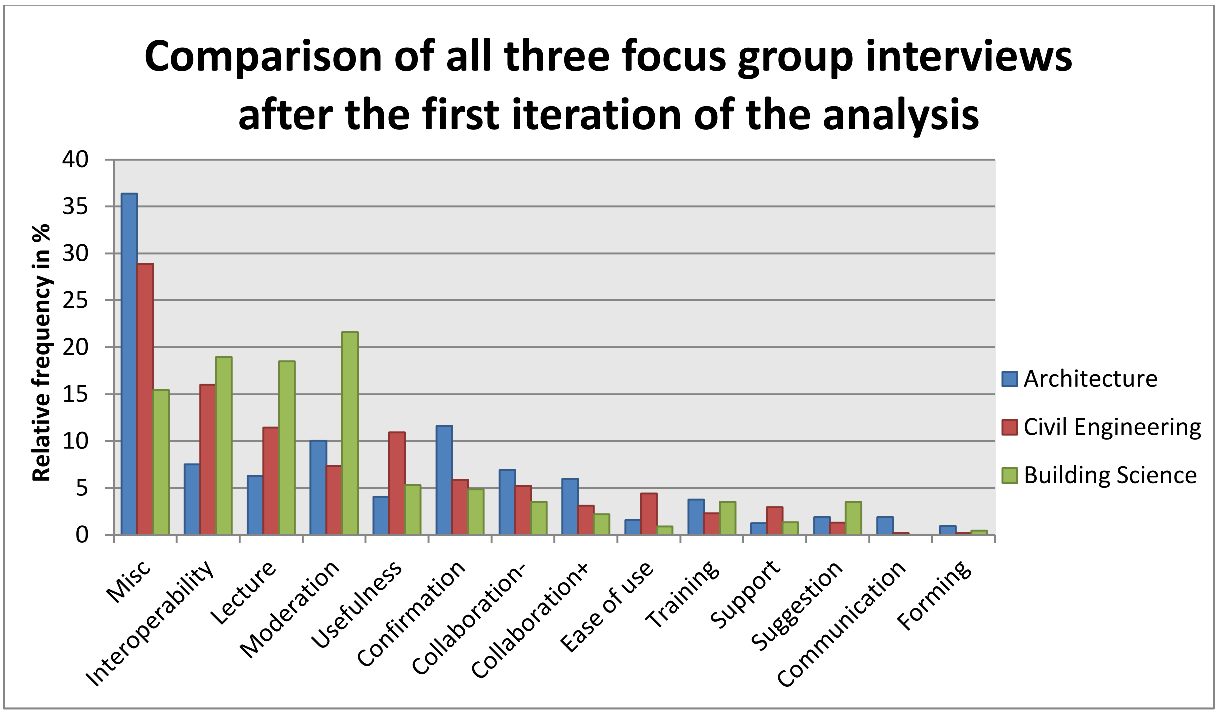

Figure 28 – Relative Frequencies of all Categories after the First Iteration

Figure 28 shows the relative frequencies of categories in all three focus group interviews after the first complete iteration of the content analysis and without any filtering. The relative frequency is calculated by adding up all units which were coded with a specific category and then dividing it by the total number of units for this interview.

In this table it is very apparent that the category *Miscellaneous* dominates the outcome. This is not satisfactory as the category does not provide as much useful information as the other two and should not be the biggest category overall. In the coding results of the focus groups architecture and civil engineering *Miscellaneous* even represents the single largest category. Only in the building science results it is a little less strong than the two meaningful and important categories *Interoperability* and *Lecture*.

Before further improving the results already a few observations can be made. It is obvious that the lecture's main topic, interoperability, is also a major talking point in the interviews. Coming in second overall it seems that students had lots of comments regarding interoperability. As discussed in the methodology section where the categories were described in more detail, interoperability in this case has an almost exclusively negative connotation. Very few and thus negligible comments about interoperability were positive.

The topic lecture is almost as important as interoperability in the focus group interviews and comes in third in this first iteration of the content analysis. The contents of this category and what the students talked about will be discussed in more detail with the final iteration of the content analysis.

Also important to note is that *Moderation* is in fourth place regarding relative frequency. Even though this category is filtered out in the final iteration and results of the content analysis, it is important to draw consequences from this observation. The interviews were structured, but the interviewer acted as an active listener and posed questions only if desired topics (see methodology section about the focus group interviews) were not talked about by the interviewees on their own. A high relative frequency for the category moderation points out that the structuring did not work as well as intended. This is especially true in the interview with the building scientists which needed a lot of moderation to cover all the desired topics. A reason for this could be that the interview was held in English, due to the international curriculum of the program at Vienna University of Technology. English was not the first language for many if not all the participants in the interview, thus hindering the development of a lively discussion.

The categories *Communication* and *Forming* are almost invisible in Figure 28 which suggests there were not enough statements which fit either category. In fact, a total of only 7 units were assigned the category *Communication* and only 5 the category *Forming*. Having very few statements in a category diminishes its significance and we consequently eliminated both as mentioned in the methodology section.

To improve the results and increase their significance we decided on a set of rules and performed a second iteration of the categorization and coding phases of the content analysis. Details about the rules and the revised category scheme can be found in the methodology section of this work.

4.2.3 Results after the second and final iteration of the content analysis

Main categories overall

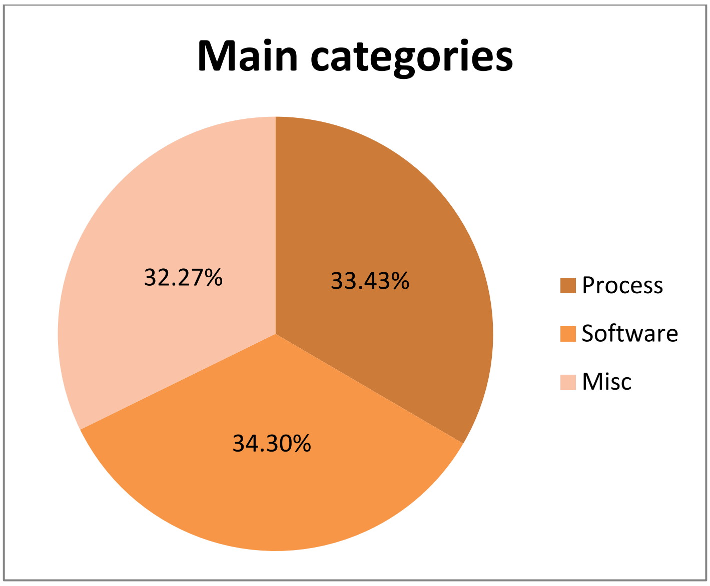

Figure 29 – Relative Frequencies Main Categories, Final Iteration, Overall

What is immediately apparent in Figure 29 above is that distribution of the content across the three main categories is very even. Almost exactly one third of all units were assigned sub-categories of each of the three main categories **Process**, **Software** and **Misc**. Especially the similarity of distribution between **Process** and **Software** is important here, as both topics are equally important in the experiment and in this thesis. The almost identical distribution of statements between these two main categories means that an equal amount of information can be drawn from them for our analysis thus not giving more weight to one category or the other. The share of the category **Misc** is reduced in comparison to Figure 27 due to the filtering of the sub-category *Moderation*. Even with *Moderation* filtered, almost a third of the data is about topics we are not interested in as much as in the ones which were assigned to the main categories **Process** and **Software**.

Architecture

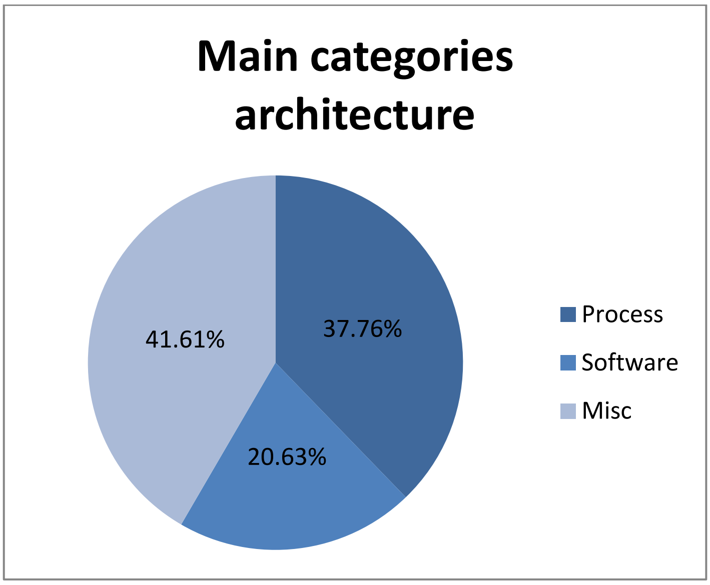

Figure 30 – Relative Frequencies Main Categories, Final Iteration, Architecture

The overview for the main categories in the focus group interview of the architects in Figure 30 shows that their main talking points were the process and miscellaneous topics. It is interesting to note that not many statements were made about software. This phenomenon can easily be explained by looking at the workflow of a Building Information Modeling project. The architect works on an initial model in a creative phase where they can basically invent anything within the limitations of the project. Then they draw this model in their single software which many of the architecture students were already quite familiar with as can be seen in the results section of the pre-questionnaires (see chapter 4.1 above). This preliminary experience and the use of only a single software lead to much fewer problems for the architects than for the other two professions. This is evident in Figure 30 where the category **Software** only comprises 20.63% of the statements.

The main category **Misc** comprises the sub-categories *General Discussion*, *Technical Discussion* and *Misc*. Many statements in these categories are simply digressions from the topic of discussion and thus do not yield useful information. Consequently, **Misc** being the biggest main category in the interview of the architects is slightly concerning and suggests the need for a refined structure for the interview.

Regarding the category **Process** the architects talk a lot about the collaboration with their group members and about problems which arose. Since the other two professions depended on the architects' models, the architects were often blamed for problems with the import as well as deadline issues.

Civil Engineering

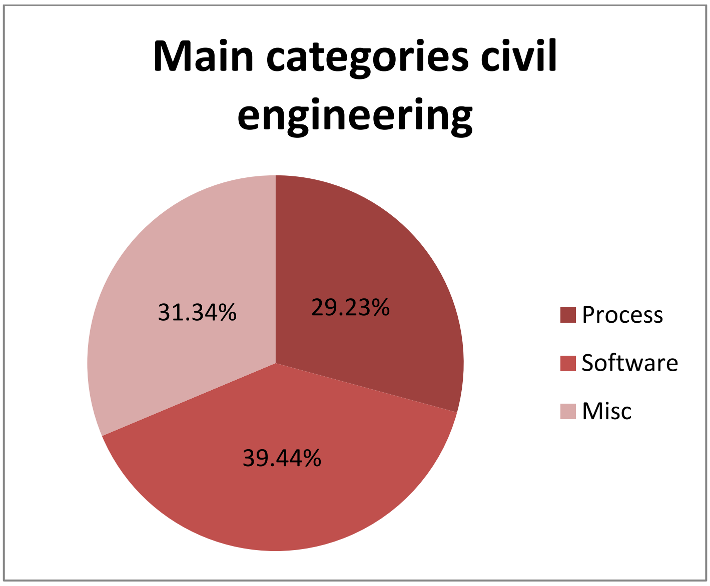

Figure 31 – Relative Frequencies Main Categories, Final Iteration, Civil Engineering

The overview for the main categories of the focus group interview of the civil engineers in Figure 31 shows a much different picture than the one for the architects in Figure 30. The smallest main category in the architect's interview is the biggest one by far in the interview of the civil engineers – **Software**. There are multiple reasons for this occurrence, the main one being the workflow position of the civil engineers behind the architects. The architects export their model which was drawn in the architectural software via an interface and the civil engineers are supposed to import said model in their software. Not only do the civil engineers use different software solutions for different calculations, but they are also not as experienced with each program as the architects are with their single software (see chapter 4.1.1 above). This inexperience can lead to problems with importing the model. Additionally, the import and export interfaces of the software solutions used in this experiment often did not work perfectly or even to a sufficient amount. Many statements by the students criticized the interfaces and mentioned there was a lot of rework or even complete redrawing necessary to be able to complete the specified tasks for the lecture.

> Example criticism of interfaces: *„Yes and also with the software, I have to say, they always talk their heads off. Easily transferring the model just does not work."* [xi]

Again, the **Misc** category, comprising the sub-categories *General Discussion*, *Technical Discussion* and *Misc* constitutes a large part of the overall distribution of statements. As will be discussed later, especially technical discussion among the students about their used software, issues with it and possible solutions or workarounds was prevalent. Once more, the statements in these categories are somewhat off-topic. They are, however, interesting from a qualitative point of view and provide an idea of the students' problems and their approaches to find solutions.

Although **Process** is the weakest of the main categories in the interview of the civil engineers, they do talk a lot about the collaboration with their fellow group members and especially criticize the architects. Additionally, deadline issues are mentioned and the project size is rated as too big.

Building Science

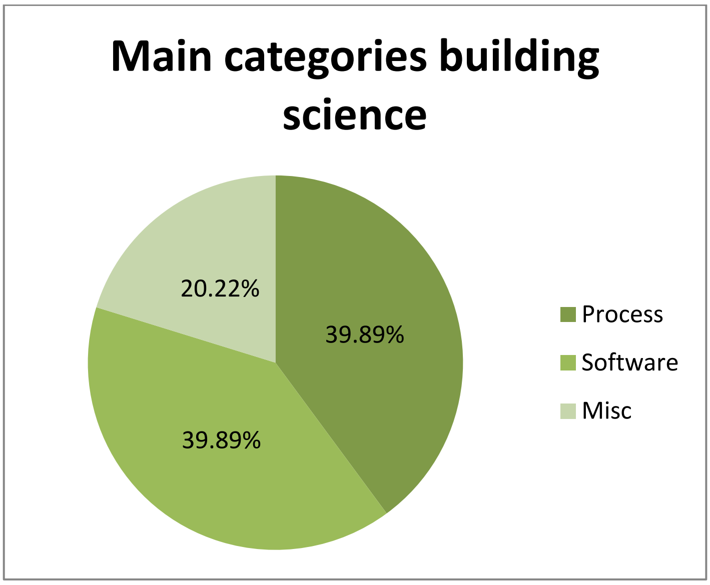

Figure 32 – Relative Frequencies Main Categories, Final Iteration, Building Science

Figure 32 shows an overview of the main categories of the focus group interview of the building scientists. Once again, this figure is very different from Figure 30 which shows the data for the architects' interview and from Figure 31 which is the overview for the civil engineers. Exactly the same amount of statements was coded with sub-categories from the two main categories Process and Software.

Because of the interview being held in English, which is not the first language for most if not all interviewees, digressions occurred less frequently. Answers were mostly short and to the point, in sharp contrast to the interviews of the architects and the civil engineers where the interviewees often talked for longer periods of time and also about topics which they were not specifically asked about by the moderator.

Statements in the main category **Software** for the building scientists are similar to those of the civil engineers. Many had problems with importing the models they received from their architects and many were inexperienced with some if not all of the software solutions they had to use for their calculations.

Regarding the **Process** complaints were made about too little time for the project. Especially the same deadlines for all professions were criticized as the building scientists depend on the architects completing their work before starting their calculations. A total of seven different results were asked of the building scientists, which they felt was too much.

4.2.4 Detailed sub-category results

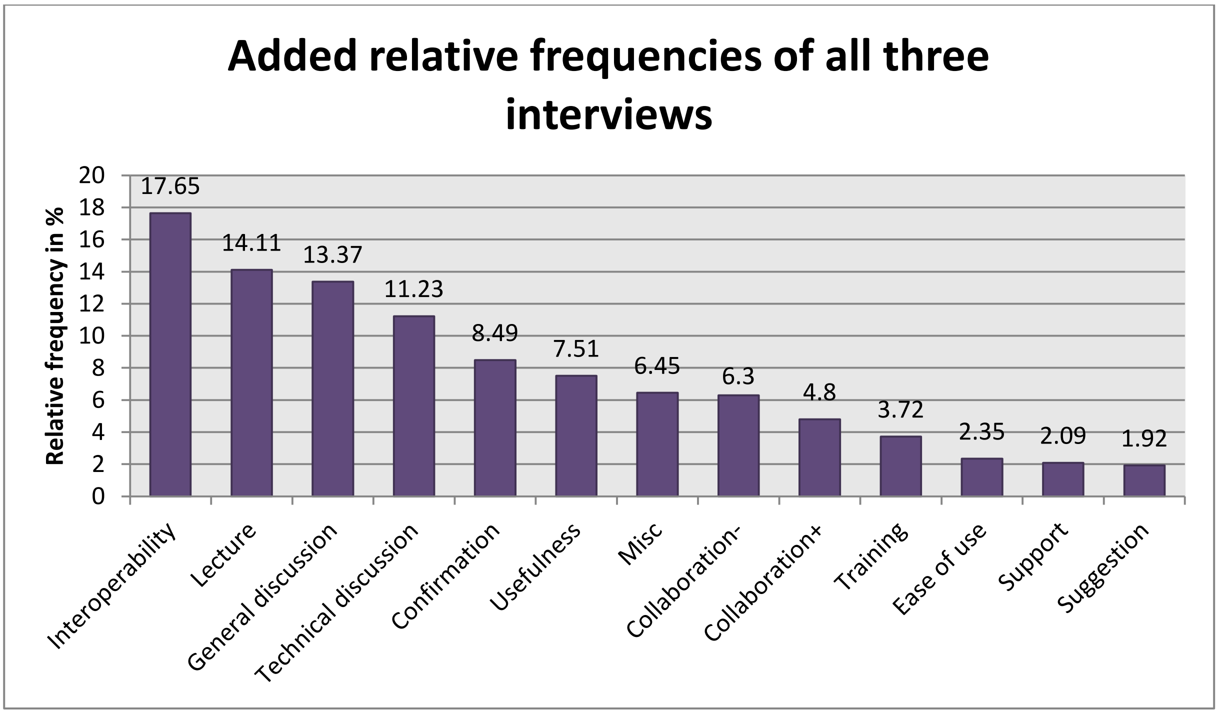

Figure 33 – Added Relative Frequencies of all Three Interviews

Figure 33 shows the added relative frequencies of the 13 final sub-categories across all three interviews. The frequency for one category is calculated by adding the frequency of this category for each interview and then dividing the result by the number of interviews. This calculation eliminates a possible bias towards interviews with more single thought units which would be present if just the total of statements for each sub-category would have been divided by the overall total of units.

The categories, sorted by frequency, show a quite linear progression of importance. The most immediate observation here is that interoperability was the most important topic overall. This is not surprising as this is also the subject where most problems were encountered by the students. The civil engineers and the building scientists in particular had many issues with interoperability which led to a large amount of frustration, additional work and thus the need to talk about these problems in the interviews, as will be discussed in more detail in the following sections.

Following behind *Interoperability* is the category *Lecture* which comprises all statements about the actual lecture in which the experiment was conducted. Here students mainly criticized the size of the project in relation to the available time. All three professions were agreed that there was not enough time for them to realize the project in a manner they would have liked. In the end many resolved to deliver anything at all, sometimes meaning not having the best possible result, rather than missing a deadline.

The two categories *General Discussion* and *Technical Discussion* follow closely after the category *Lecture*. This is due to the students of each profession being in the same room together and being able to discuss the projects from the point of view of their profession. Because of this, a lot of discussion about specific technical problems or topics regarding either architecture, civil engineering or building science took place among the students as they had the chance to exchange their experiences, problems and solutions.

The high amount of confirmations during the interviews suggests that students agreed often with each other. This gives more weight to the statements of individual interviewees as they can be taken as representative for their profession since the other students present in the interview did not contradict but rather confirmed them. Overall there were very few instances in which students' contradicted the statement of others; the opinions were very homogeneous in each individual interview. The picture is a little different when one looks at all three interviews together, as often blame for problems with collaboration or other issues was shifted to one of the other two professions.

The category *Usefulness* includes positive as well as negative units. Because the negative portion far outweighs the positive portion, both were included in a single category. This means the 7.51% relative frequency for *Usefulness* does not judge usefulness but rather just means the topic. The difference between positive and negative statements in this category will be discussed in more detail in a section below.

The final definition of the category *Misc* states that all thought units which would not fit in any meaningful category and thus had no value for this analysis would be assigned this category. After the refinement of the main category **Misc** and its division into *General Discussion*, *Technical Discussion* and *Misc* this category now holds 6.45% of all thought units which have no further value. This improves our results, as many units previously assigned to this category are now in either of the categories *General Discussion* or *Technical Discussion* which, although off-topic regarding the questions of the focus group interview, still provide additional insight.

The two categories *Collaboration-* and *Collaboration+* provide very interesting insight into the process of the project and inter-profession teamwork within the groups. It's important to distinguish between positive and negative remarks about collaboration as there are significant amounts of units in each category. Combined, the category *Collaboration* would make the 5th place overall in the progression of importance of the categories. The category with negative remarks containing 1.5 percentage points more than the category with positive remarks indicates an overall dissatisfaction with teamwork within the project groups. This fact is not really confirmed by the results of the questionnaires which show a value of 3.73 for the satisfaction with the collaboration. The differences between the two categories *Collaboration+* and *Collaboration-* vary between the three interviews and will be discussed individually for each interview in the sections below.

Training includes all thought units which were about the in-lecture training received by the students as well as experience with the software. At the beginning of the course, there were training units during which representatives of the software companies presented their software and provided an introduction to working with and using it. This is rated by students as a good idea overall, although it was not enough. Additionally, the quality of the introductions varied and while some were useful for the project at hand, others were too shallow and did not help the students a great amount.

Ease of Use is criticized in some thought units but only makes up 2.35% overall. Because *Interoperability* and *Usefulness* are the topics which most students had problems with, *Ease of Use* is only slightly important in the interviews. The low frequency of *Ease of Use* can also be attributed to the attitude of most students when approaching a piece of software for their profession. Software in the fields of architecture, civil engineering and building science has to be very potent and include a lot of functionality. Thus, students do not expect that software is easy to use, especially when they initially start to use it.

Support was coded when interviewees talked about the software support directly related to the software they used during the project. Hence thought units in this category mean software support was contacted with an issue. The relatively low frequency of Support does not mean there was little use of this communication channel. In fact, many students did contact software support about problems they had and also received answers and help.

Last but not least is the category *Suggestion.* Unfortunately only 1.92% of all thought units are about suggestions the interviewees made. Suggestions can be about the lecture and the project as well as the software the students used. The low frequency here indicates that students were not encouraged enough to suggest improvements for either the process or the software in the interviews.

4.2.5 Detailed sub-category results for each interview

Architecture

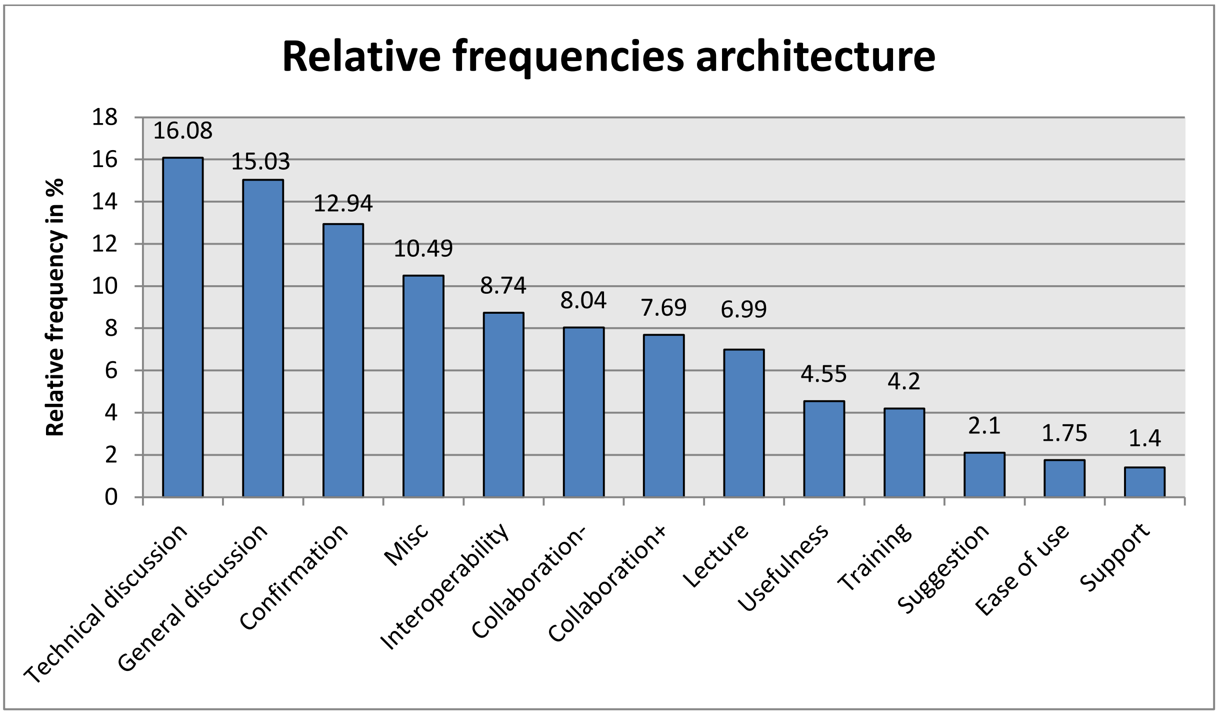

Figure 34 – Relative Frequencies Architecture

The focus group interview with the students who assumed the role of an architect in the experiment has a length of 01:14:05 hours and its transcript comprises 25 pages. The relative frequencies of categories assigned to thought-units can be seen in Figure 34 above. As already apparent in the overview of the main categories for the architecture interview in Figure 30, the sub-categories of the **Misc** main category dominate this interview. In this case, the sub-categories *Technical Dis*cussion and *General Discussion* are the most prominent sub-categories which can be attributed to the tendency of digressing in the interview. The students talk a lot about general topics in their profession and also about technical issues with their projects and software.

> Example for General Discussion: *„You get a degree in architecture and you arrive at a small desk where you have a monitor and then you do two weeks, and that's your work nowadays."* [xii]

The sub-category *Confirmation* with 12.94% relative frequency indicates a high amount of agreement between the interviewees. Many statements by students are confirmed by others who share their opinion, and the views of the interviewees are very homogeneous.

The last category with more than 10% in relative frequency is the sub-category *Misc* with units which could not be assigned to any other category. These statements are of no further value for the analysis and point to discussion which is off-topic or irrelevant to the interview.

Example for Misc: *"You can speak in German."*

Interoperability is in fifth place with 8.74% relative frequency. This is quite a low value and can be attributed to the architects being much more experienced with their software than the other two professions. Additionally, most architects only used one piece of software and could thus tailor the model to work well with this particular software.

The two categories *Collaboration*+ and *Collaboration*- provide interesting insight. The difference between their values is only 0.7% which is less than the difference between them in the overall relative frequencies of all interviews seen in Figure 33. The small difference points to the architects being more satisfied with the teamwork in their respective groups than the other professions.

Example for Collaboration+: *"Erm, no that actually worked really well, we got along well and still do."* [xiii]

A simple reason for this is that in most groups the architects were the ones to design the initial model. This means they often had a lot of creative freedom and could create the building they wanted to create. On the other hand, the civil engineers and the building scientists were forced to take over the model and do the calculations on it, even if they did not agree with parts of it. This would be somewhat different in a real-world project, as the reward would be monetary. In the lecture, the final model was judged by professors which probably created ambition for many participants to deliver a model they were comfortable and satisfied with. Having little to no influence on the design of the building would thus be frustrating for the civil engineers and the building scientists, leading to a lower satisfaction with the collaboration. Of course there were some groups which handled the design process differently and where all team members were involved.

Example for Collaboration-: *"Yes. Yes, because my other two colleagues were not too familiar with their software. […]. And that creates problems."*[xiv]

Put together, the sub-categories *Collaboration*+ and *Collaboration*- make up 15.73%, which means that collaboration in the project groups was in fact the second-most important topic in the interview of the architects.

In the sub-category *Lecture* the architects talk about positive and negative aspects of the lecture, which was held for the first time and was thus an experiment itself. Similar to the other professions, especially the project size is criticized.

Example for Lecture: *"It's like I would say like too big."*

But also the use of BIM itself is questioned by one student who states that everything could still be done in the way it was done for a very long time and that BIM does not save any time or costs and does not improve the project or collaboration.

“Because it is exactly the same with BIM, I mean, can’t people in the building industry work with normal plans? What do we need BIM for? That’s something extra. For me it is something extra.” [xv]

Regarding *Usefulness* students are especially criticizing the handling of penetrations in the ceilings by the export and import interfaces where even small inaccuracies could lead to many errors. Additionally, curved walls caused a lot of problems, if they were even possible at all in some software solutions.

„The precision was somewhat of a problem for us as well. Especially the round walls again.” [xvi]

The *Training* sub-category includes thought units which are about experience with software as well as the training by professionals or software developers in a few units at the beginning of the lecture. What is important to note here is that the architects generally appreciate the training part of the lecture, but also would like to receive more training. The inexperience of other group members with their respective software is also a concern for many architects.

“I think one of the biggest problems we had was that almost no one was really proficient with their program. We received three hours of training and then had to solve problems together. That’s impossible.” [xvii]

Very few suggestions are made by the architects in their focus group interview. This is certainly an issue that has to be worked on in future interviews as the suggestions by the interviewees are an important part of the results of this experiment. Suggestions are incorporated in the guideline for BIM processes and also forwarded to software developers to enable them to improve their software based on immediate feedback by users. One of the students proposes to develop their own software because a well-known architect did this after not being satisfied with the existing solutions.

“Frank Gehry developed his own software because he knew he needed it. He wanted his problems solved, moved to (dissol?) systems from (katia?) and developed his own software. I think that’s also a way to do it, right?” [xviii]

Even less units were coded with the sub-categories *Ease of Use* and *Support*. Units which were added to Ease of Use are about different issues with the software the interviewees used and criticize its low ease of use. As an example, the labeling of errors with numbers which have to be looked up elsewhere is apparently very time-consuming.

„Yes I think sometimes there were errors and the debugging took up a lot of time. Also that there was only a number which we had to input somewhere else to actually see which error it was.“ [xix]

Software support is only mentioned in one exchange during the interview where one student mentions that the civil engineer of their group worked closely with software support for Revit to resolve issues. Another responds with a negative remark, stating that the support could only tell them that there was no solution for their problem with round ceiling penetrations.

Civil Engineering

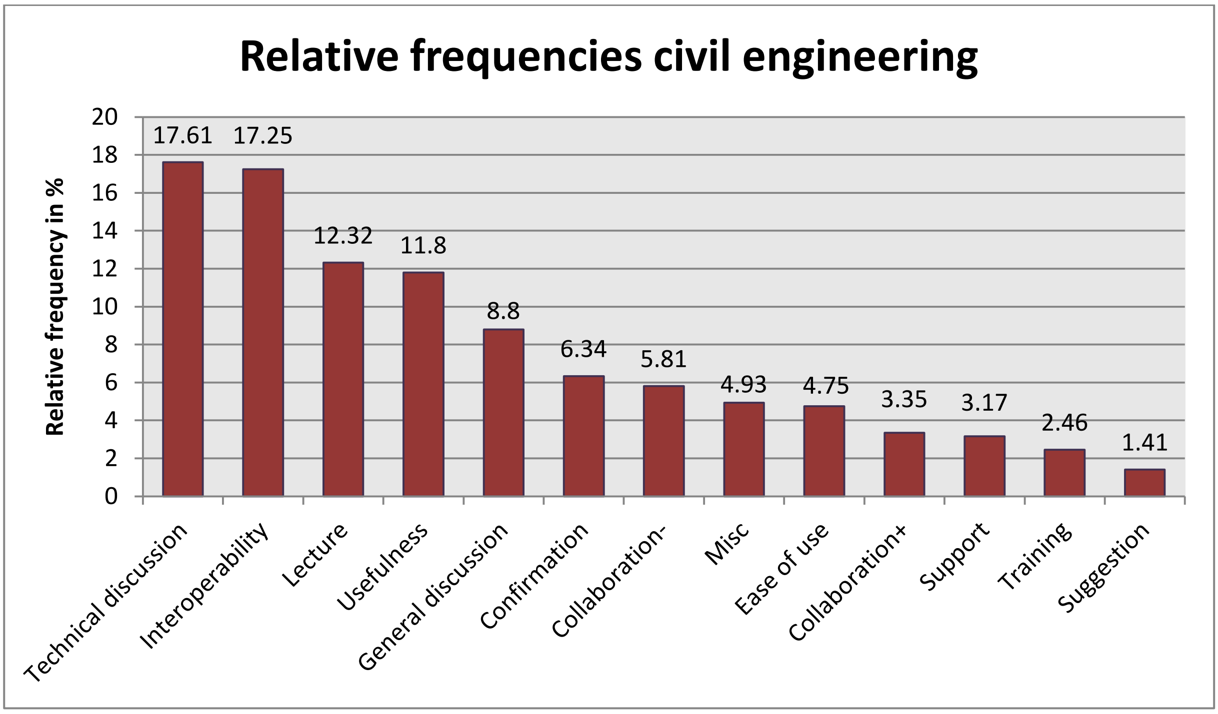

Figure 35 – Relative Frequencies Civil Engineers

The focus group interview of the civil engineers has a total length of 01:28:52 hours, making it the longest interview of the three. The transcript comprises 40 pages and is also by far the biggest. This means there is a lot of information to be gained from this particular interview.

The civil engineers are very vocal in their interview and a lot of discussion especially among the interviewees takes place. The number one topic as outlined in Figure 35 above is technical discussion, comprising 17.61% of all units. A lot of the technical discussion is about specific calculations, methods the civil engineers used to solve tasks, and about problems they had with their software.

Interoperability is a very important part of the focus group interview of the civil engineers and makes up 17.25% in relative frequency. The civil engineers had to use different software solutions for their calculations and there were thus more possibilities for errors and issues. Especially round ceiling penetrations caused many problems which were difficult to fix. Also inaccuracy on the part of the architects generated frustration for the engineers.

> *„Yes, and you as the civil engineer or building scientist end up having problems because the architect said he did not want to model this accurately enough."* [xx]

Regarding the lecture, the civil engineers especially criticize the size of the project in comparison to the time available for their tasks. Not enough support from the respective institutes at university regarding software and problems was another point which is raised.

Because of several new pieces of software which the engineers had to become familiar with and use, they feel that there should have been more help provided from the professionals at university. Additionally, the distribution of ECTS points for the lecture in each respective study program is found to be unfair and bad for the project. Since the lecture yielded different amounts of ECTS points for the students of different programs, and thus differed in importance, some put in less effort than others, dragging their groups down.

> Example for Lecture: *„That's true, for us it's 8 ECTS and for them it is 6 or less, which means it's more important to us than to them."* [xxi]

Usefulness is a big topic in the interview and makes up 11.8% in relative frequency. Many issues arose when the civil engineers used their different software solutions to implement the calculations they were tasked with. A lot of problems were unsolvable with the current software versions and workarounds or remodeling had to be used. Apart from missing or poor functionality also troubleshooting is supposedly very difficult in many programs.

> Example for Usefulness: *„The biggest problem was the software. It was hard to even get some kind of model"* [xxii]

Although *General Discussion* is still a big category, much more miscellaneous discussion is held in technical terms. Very similar to the architects for example, the civil engineers tend to digress from the current topic and talk about their studies. Here, several units provide insight into the way the students see their profession and which position they think it takes in the BIM process.

> Example for General Discussion: *„You also have to know how to deal with people"* [xxiii]

The many units which were coded with the sub-category *Confirmation* point to a homogeneous opinion between the participants in the interview. This is also reflected from a qualitative point of view – often statements are confirmed or reinforced by others.

Again, the two sub-categories *Collaboration*- and *Collaboration*+ are very interesting. On one hand, negative remarks about collaboration with other team-members account for a relative frequency of 5.81%. On the other hand, only 3.35% of all thought units were coded with *Collaboration*+. This discrepancy is quite remarkable as it indicates a high dissatisfaction with the teamwork in the groups. Especially the skills of students of the other professions are criticized and also difficulties due to language barriers and different nationalities are mentioned by the civil engineers. This is not true for all groups, however, as some interviewees report a good workflow and a productive collaboration.

> Example for Collaboration+: *„We met in person really often, sometimes even more than twice a week."* [xxiv]

The next category when ordered from highest to lowest by relative frequency is the sub-category *Misc* with units which could not be assigned to any other category. These statements are of no further value for the analysis and point to discussion which is off-topic or irrelevant to the interview.

Ease of Use is a bit overshadowed by *Usefulness* because the students talked about the more important functionality of the software rather than focusing on ease of use. Nevertheless some interesting statements about ease of use occur in the interview. The students concur that the software is especially hard to use in the beginning as it is very unintuitive, but also agree that this is understandable since the programs are so complex and offer a lot of functionality.

> Example Ease of Use: *„Or if it just crashes."* [xxv]

The software support is generally criticized as being of too little help. Even though the students appreciate the possibility of support from the developers, they also say that often not even support could help with their problems. The civil engineers also wish for more available support material, for example online tutorials which could help get a better feeling for the software and its functionality.

> Example Support: *"Well, there is no SCIA help or I don't know, F1 button or a pdf file with 5000 pages."* [xxvi]

Concerning the training the students received at the beginning of the lecture the civil engineers state that it was a good idea, but much too short.

> Example Training: *„What's more is that, for the Sophistic group I think, the introduction was really, really short."* [xxvii]

Amounting for only 1.41% of all thought units, the category *Suggestion* is very small. This is problematic since obtaining suggestions from the students is a big goal of the experiment and important also to the software developers. Of course it is much easier to criticize than to come up with constructive suggestions, but even considering this, the 1.41% is a very low percentage. Suggestions worth mentioning are the extension of the training at the beginning of the lecture to a week-long workshop and the implementation of more detailed error codes in the software. In this workshop a complete project should be shown, from beginning to end-results, so that students get a better understanding of their tasks and the work they will be doing during the lecture.

> Example for Suggestion: *„Another improvement regarding the software would be error messages which are more meaningful than 'Error -100'."* [xxviii]

Building Science

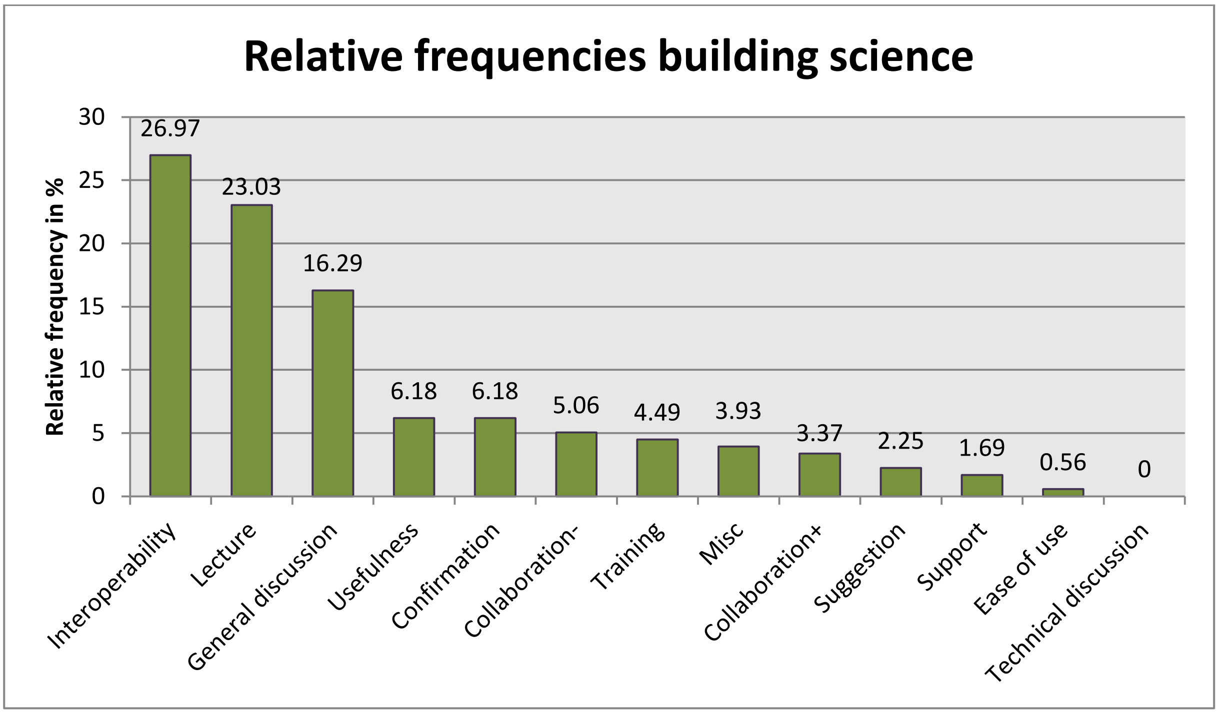

Figure 36 – Relative Frequencies Building Science

The focus group interview of the building scientists is the shortest of the three interviews with 00:56:07 hours and its transcript only comprises 16 pages. The relative frequencies for the developed sub-categories can be seen in Figure 36 above. The most immediate observation here is that there are three very dominant sub-categories in the interview which are *Interoperability*, *Lecture* and *General Discussion* with *Interoperability* and *Lecture* together accounting for exactly 50% of the interview. The interview was held exclusively in English because of the internationality of the study program Building Science at Vienna University of Technology.

Similar to the other two professions, *Interoperability* is a very important topic for the building scientists. They too had to use several different software solutions for their seven diverse tasks and there were thus many possibilities for issues.

Example Interoperability: “The problem is the BIM function isn’t working <yeah> at all.”

Lecture, with 23.03% relative frequency, is very prevalent in the interview as well as *Interoperability.* Concerns of the interviewees include the size of the project and the limited time available to complete their tasks. Most importantly, the building scientists complain about having the same deadline for their tasks as the architects, since they depend on the architects creating their model to do necessary calculations and adding features to the model.

> Example for Lecture: “Because the architect has the same deadline that we have, and that’s not fair because we have to take his modifications and apply it (no problems?)”

General Discussion in the focus group interview of the building scientists is mainly about comparisons with real-world projects and companies where buildings like the one in the lecture would be designed. This is also the third of the high-frequency sub-categories which with 16.29% comprises more than 2.5 times as many thought units as the next sub-category in the order.

Statements which were coded with the sub-category *Usefulness* are mainly about problems with the functionality of the software. Especially because the building scientists had to use a lot of different software products, many issues arose. Students were not able to correctly identify the sources of errors and sometimes features necessary for specific tasks did not work at all.

> Example Usefulness: “Nothing is working as it should.”

The high amount of confirmations, making the sub-category *Confirmation* the 5th strongest, again indicates a very homogeneous group of interviewees. As can be expected, the students can relate to each other, having the same role in the projects and facing similar problems with other team members as well as their respective software.

The two sub-categories *Collaboration*+ and *Collaboration*- are once again very interesting. The difference between the negative category *Collaboration*- and the positive category *Collaboration*+ equals 1.69 percentage points in relative frequency pointing to an overall dissatisfaction with the teamwork within the groups. This observation is not supported by the results from the questionnaires which show a value of 3.75 out of 5 for the building scientists’ satisfaction with the collaboration. Of course negative points are much easier expressed and more prevalent on one’s mind, possibly leading to an overrepresentation of the category *Collaboration*-.

> Example Collaboration: “Yeah, it was going at first the architect made a rough design, sent it to me, and til the last presentation before Christmas it wasn’t really finished so it had to do them, to do the calculation for the ventilation and now the process form the architect is finished but I have to rework everything.”

Regarding training, the building scientists mention that they do not have enough experience with most of the programs they had to use. Again this inexperience caused many problems and the students feel they could have solved those issues faster or would not even have had them in the first place, had they had more experience. The introductory lessons at the beginning of the lecture are considered very helpful, but were apparently not held for all of the different software.

> Example Training: “Of course we were learning those software last year, but every course took us a month, and through the month we made a small amount of work with the software […]”

The next category after *Training* when ordered from highest to lowest by relative frequency is the sub-category *Misc* with units which could not be assigned to any other category. These statements are of no further value for the analysis and point to discussion which is off-topic or irrelevant to the interview.

Suggestions revolve around moving error detection from the import to the export so that they can be fixed right away in the exporting software as well as initially reducing the project size and increasing it incrementally over several lectures and developing an all-in-one software which comprises all the necessary features for tasks related to building science.

> Example Suggestion: “So yeah, maybe you should start like this, step by step, in the first year, you have a small building, getting some support, fixing this error is…is also easier to isolate the errors […]”

Software support is barely mentioned and the few statements that concern support are not positive. One student sent their model which she was not able to import to the software support who told her they were able to import it. After some time she just redrew the whole model herself in the software she wanted to import it into, because the import simply did not work.

> Example for Support: “I couldn’t import into Tass at all so I contacted the support team from Tass and I sended them my gbxml file and which was really interesting that they could import it in their Tass and they said yeah its working but I said no its not working for me and we yeah wrote a whole day each other and at the end I drew it myself so that’s not the point.”

Ease of Use and *Technical Discussion* both account for less than 1% of relative frequency of the focus group interview of the building scientists and are thus negligible. It is interesting to note, however, that, even though the building scientists worked with a higher amount of software products than the other professions, they do not talk about ease of use but rather usefulness in regards to the software. A reason for this could be that the students were at least somewhat familiar with the programs they had to use because of previous courses in their study program. The value of 0% for Technical Discussion is interesting as well. Because of the interview being in English, there was not much digression and the interviewees mainly stayed on topic and answered the questions posed by the moderator.

Comparison of all three interviews

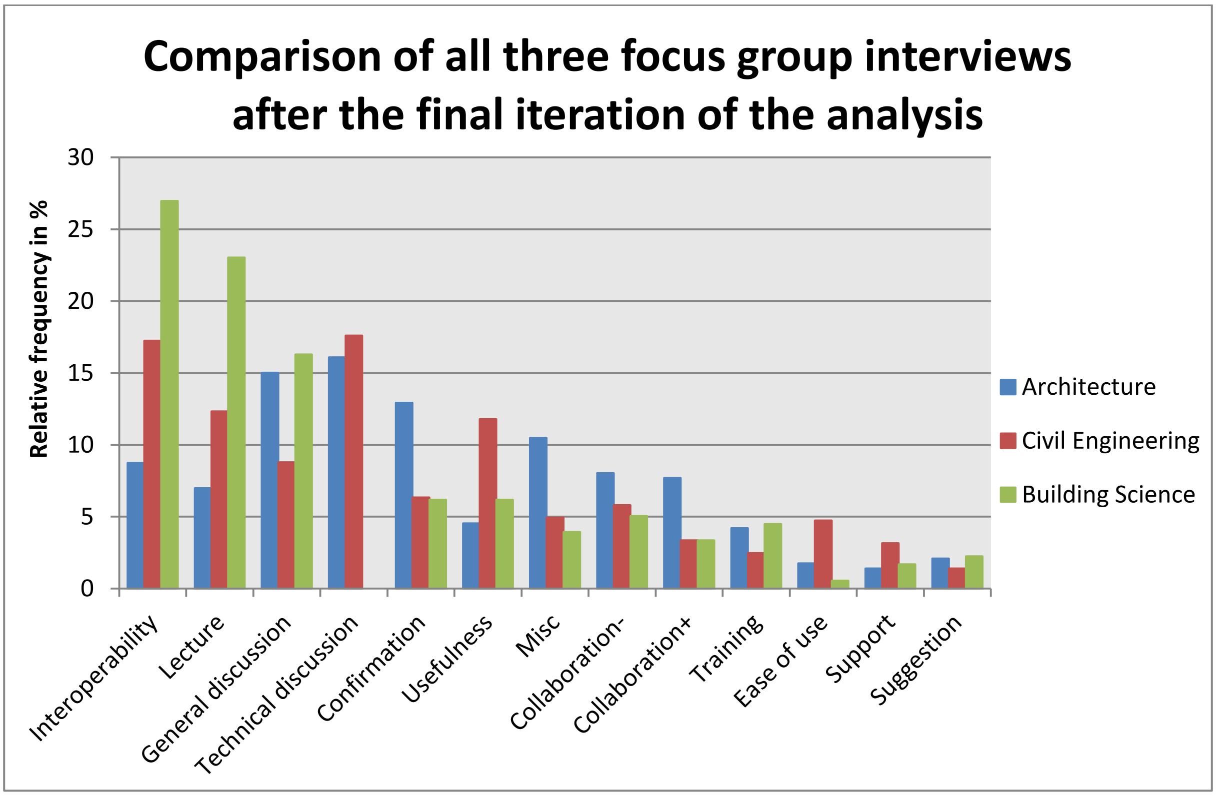

Figure 37 – Relative Frequencies, all Interviews

Figure 37 above shows the final results of the content analysis after the second iteration. As detailed in the methodology section, in the second iteration a revised category scheme was used and the category Moderation was filtered. This leaves a total of 13 sub-categories of the three main categories **Process**, **Software** and **Miscellaneous**. The ordering in Figure 37 is by added relative frequency of all three focus group interviews which leads to the same order as in Figure 33.

The first observation here is that interoperability, a central part in the experiment and in this thesis is also the most important topic in the focus group interviews. There is however a significant difference between the three professions. With 26.97%, building science has the lead in relative frequency of interoperability, while civil engineering and architecture do not even reach this value when combined. This can be explained by the building scientists using a lot of different software products, leading to more problems with interoperability for them than for the other two roles in the project.

Following closely behind interoperability is the category *Lecture,* where the distribution between the three focus group interviews is very similar to interoperability with building science taking a major share and civil engineering and architecture contributing with considerably less relative frequency. The reason for this is related to the reason for the distribution of relative frequencies for interoperability. Because of their using many different programs for their tasks in the projects the building scientists also report more issues regarding deadlines and time-management in general. The architects had the same timeline as the other two professions which did, however, depend on the work by the architect, leading to a lot of frustration for both civil engineers and building scientists.

General Discussion about studies, projects and profession of the respective focus group interviewees takes third place when ordering by relative frequency. Students seize the opportunity to discuss general topics with their peers as there are usually not many opportunities to do so with many of them present and in a mindset for discussion.

Technical Discussion is notably completely absent in the focus group interview of the building scientists but very prevalent in the other two interviews. Software is only fourth in the sequence of major topics in the interview of the building scientists and then interoperability dominates the discussion. The architects and the civil engineers both start talking about software much earlier in their interviews and thus also digress to more technical discussion about possible solutions. Also the language barrier plays a role here, as it is harder to talk about technical details in a language other than one's first language.

The category *Confirmation* shows that the interview of the architects is the most homogeneous with a lot of agreement. This can however also be attributed to single interviewees who tend to agree a lot. Overall, the three interviews all have a high rate of confirmations which indicates high consensus between the students of each respective profession.

Usefulness, being part of the main category **Software**, is most prevalent in the interview of the civil engineers. Both the building scientists and the civil engineers talk a lot more about software than the architects. This is especially reflected in the category *Interoperability*, but can also be seen in *Usefulness* and *Ease of Use* for example. The architects mostly worked with software they were already quite familiar with, whereas the other two professions had less experience with the software they used as the results of the pre-questionnaires point out.

The next category after *Usefulness* when ordered from highest to lowest by relative frequency is the sub-category *Misc* with units which could not be assigned to any other category. These statements are of no further value for the analysis and point to discussion which is off-topic or irrelevant.

Collaboration- is stronger than *Collaboration+* in all three interviews. The difference is a lot less in the focus group interview of the architects however. As already mentioned this can be explained by looking at the sequence of the workflow, where the architects had the initiative and could be creative in designing their model. The other two professions depended on the skill of the architects and also on their work ethic, as the deadlines were the same for all professions while the civil engineers and building scientists could only start with their tasks after the architects finished theirs.

The sub-category *Training* has similar relative frequencies in all interviews, although the frequency for civil engineering is a little lower. While the architects and building scientists also talk about experience and the training with the software more, the civil engineers do not look as much for problems with themselves, such as too little skill with the software.

Ease of Use is much stronger in the interview of the civil engineers, where a lot of discussion about the different software and its properties takes place. Problems are located with the software rather than with the user and not attributed to not enough skill or inexperience, but to faults of the developers.

Support is seen by all three professions as positive but could not always be of help. Sometimes even support had to admit they were unable to solve a problem or that a specific feature was not yet implemented. Nonetheless, the students are glad to have access to customer support by the software developers.

Unfortunately the sub-category *Suggestion* is in last place overall when ordered by added relative frequency. A lot more complaints are voiced by the students than constructive suggestions. This is an issue where the structure of the interviews or the manner in which they were conducted might have to be changed. Suggestions are an important part of the experiment and also of the thesis, so it is regrettable that so few were gained.

4.2.6 Breakdown by positive and negative remarks for certain sub-categories

For some of the categories it is interesting to split them into positive and negative. Units which were coded with the sub-category support for example can be both positive and negative. There is no information whether the coded unit contains a positive thought about support or a negative one. The only category where this was done initially was *Collaboration* because we felt it was necessary to distinguish between positive and negative experiences similar to the questionnaires. To get further insight, we decided to re-code additional categories and divide them into a positive and a negative category. This was done for the following sub-categories:

- Ease of Use →
  - Ease of Use+
  - Ease of Use-
- Usefulness →
  - Usefulness+
  - Usefulness-
- Support →
  - Support+
  - Support-
- Lecture →
  - Lecture+
  - Lecture-
- Interoperability →
  - Interoperability+
  - Interoperability-

The categories were re-coded by both operators and the already introduced parameter *Cohen's Kappa* was again calculated to measure inter-operator agreement. Since the sub-categories which were not further divided were already described in detail in the sections above, the following section will concentrate on the five changed categories *Ease of Use, Usefulness, Support, Lecture,* and *Interoperability.*

One aspect which has to be taken into account is that people generally remember bad experiences better than positive ones. In an interview where the goal is evaluation of a product and a process, it is therefore natural that negative remarks prevail. This fact has to be considered for every comparison of positive versus negative thoughts in this section.

Ease of Use

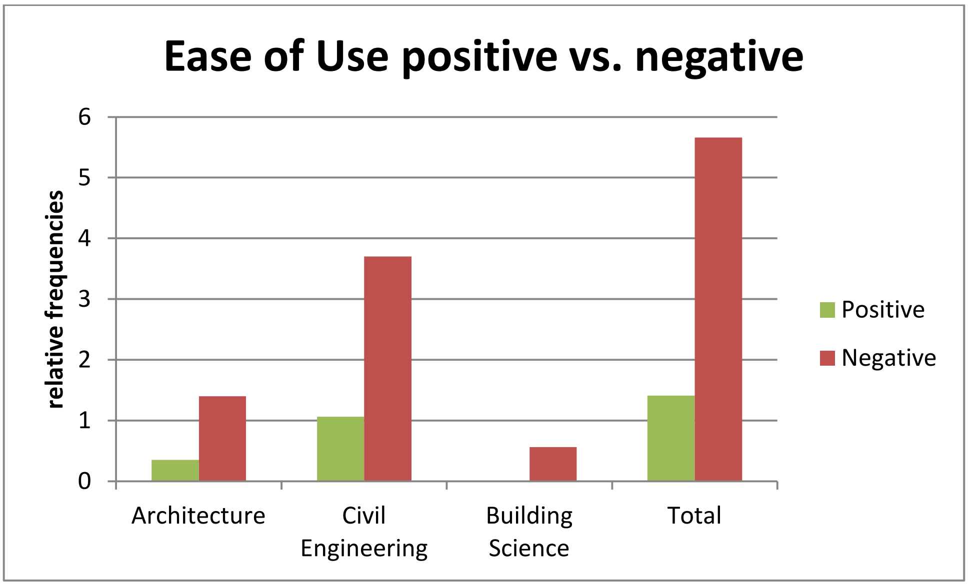

Figure 38 – Ease of Use Positive versus Negative

Figure 38 shows the comparison of units which were coded with either *Ease of Use*+ for positive thoughts about ease of use, or with *Ease of Use*- for negative thoughts about the topic. The ordering here is arbitrary and will be held consistent throughout all following figures, which regard the comparisons of positives versus negatives in several sub-categories. It is evident that negative thoughts outweigh the positive ones by far. This does not bode well for the rating of ease of use of the software used in the experiment. Reinforcing this observation, the numbers suggest that ease of use is not very high for the software solutions which were used in the project. An obvious reason for this is the high complexity and the high amount of functionality provided by these programs. Since the building planning process is highly complex there need to be a lot of features built into these programs, diminishing ease of use significantly and expectedly. Nonetheless there is always room for improvement and especially the error handling is unsatisfactory from an ease of use point of view for many students.

Usefulness

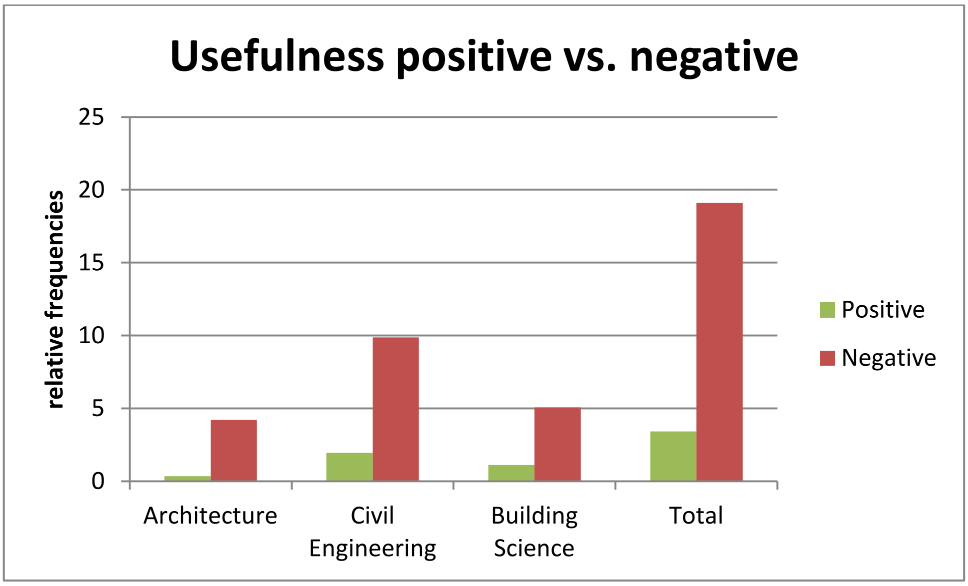

Figure 39 – Usefulness Positive versus Negative

As Figure 39 indicates, the difference between positive and negative thoughts in the sub-category *Usefulness* is even higher than for *Ease of Use.* Students are very dissatisfied with the usefulness of many of the used programs and especially the civil engineers are very vocal about this.

Support

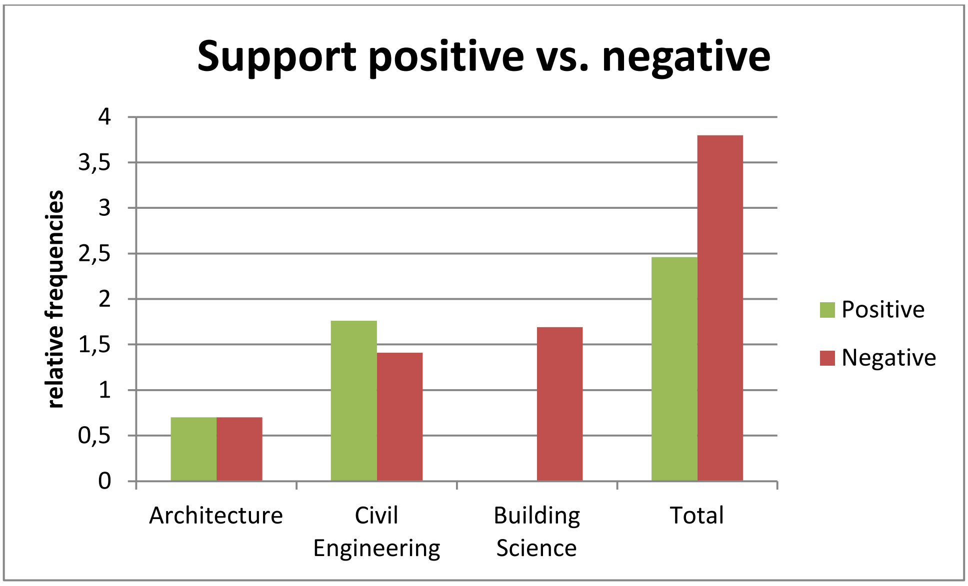

Figure 40 – Support Positive versus Negative

The sub-category support, visualized in Figure 40, is by far the most positive of the five examined in this section with civil engineering being the only instance where positive thoughts actually outweigh negative ones. Since the students had many issues with their respective software, many of them contacted support and received valuable advice which helped them solve their problems. Complaints are voiced, however, about not getting enough support and in some cases about not having access to or about the inexistence of written or video material with further help.

Lecture

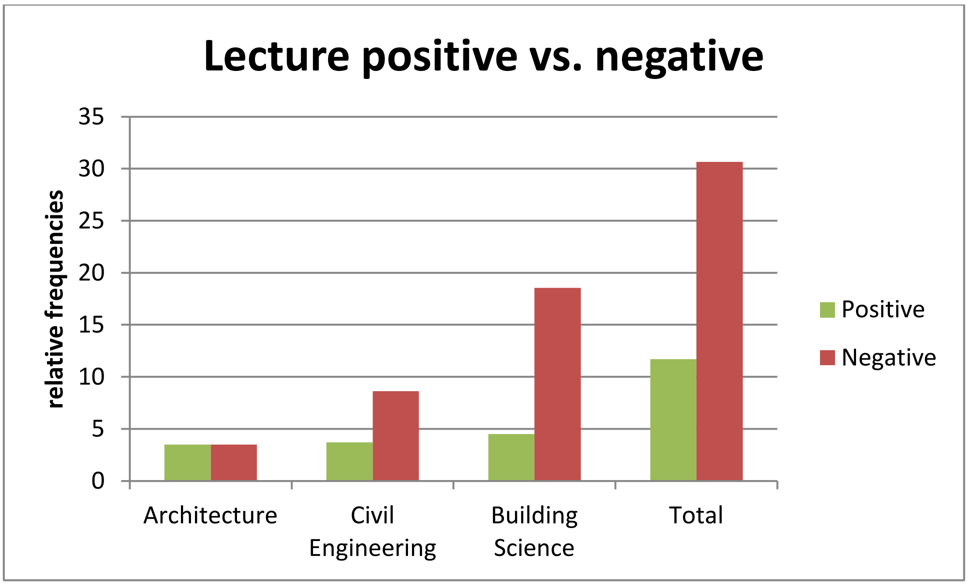

Figure 41 – Lecture Positive versus Negative

Experiences of the students regarding the Lecture differ strongly from profession to profession as evident in Figure 41. In the focus group interview of the architects positive thoughts and negative thoughts balance out, while in the other two interviews negative remarks strongly outweigh the positive ones. The architects have a more positive view of the lecture because they did not have as many problems with the software, one reason being that they used less different programs than the other two roles. Also their position at the beginning of the workflow and the same deadline as all their team members lead to a more positive experience for the architects.

Interoperability

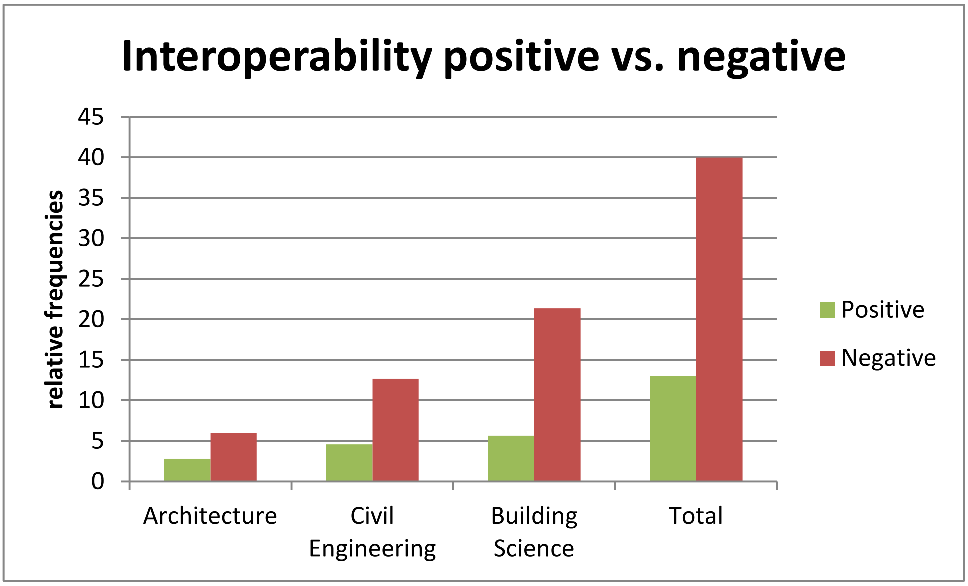

Figure 42 – Interoperability Positive versus Negative

Interoperability as one of the main topics of this thesis is also interesting when split into positive and negative thoughts. Figure 42 shows that negative thoughts outweigh positive ones by far. The architects have the least amount of negative thoughts which corresponds to previous findings that they did not have as many problems with their software and interoperability as the other two professions. The amount of positive thoughts is only slightly higher in the interviews of the civil engineers and the building scientists, indicating more overall talk about interoperability. The amount of negative thoughts is much higher, however, which points to a high dissatisfaction with the interoperability features of the software for the civil engineers and the building scientists.

5 Conclusions

In this master thesis we evaluated data from a pilot experiment at Vienna University of Technology consisting of questionnaires and focus group interviews on BIM-supported planning processes. After discussing the results in the previous chapter, we now want to address the research questions formulated in the introduction.

5.1 Problems with the BIM Process

Regarding the BIM process there are many issues which came up during the experiment and were mentioned by the students in the questionnaires and the focus group interviews. Some of these issues are very impactful and hinder the formation of a fluid and positive collaborative process. One of the goals of this work is to identify these problems and offer suggestions for improvement.

The most obvious problem here is that there are many very different professions collaborating on a BIM project. These professions all have diverse tasks of their own and very different information needs to do their work efficiently and effectively. Additionally interferences occur when several disciplines work on the same model at once. These interferences not only cause extra work, but also create the need for a lot of communication between the stakeholders.

The questionnaires show that satisfaction with the collaboration, the outcome and the process is rated as above average but not great by the students. This means that there is room for improvement. As we know, the BIM process has two sides – the software on the one hand, and the human interaction on the other, both depending on each other. It is thus important that the interdisciplinary process works well in order to achieve a good outcome.

In the focus group interviews the reasons for the ratings in the questionnaires are voiced by the interviewees. Contrary to what can be found in literature, the architecture students mentioned that BIM would be great for smaller projects, but was too immature to be used with large building designs. The standardization of BIM enables users to create frameworks which can easily be re-used in a new project. An architect can design a certain window for example and use the same window in another building without having to redesign it completely. This was seen as a major advantage of BIM over the traditional designing processes by the students. As the task in the lecture was a rather large project, this reasoning explains why the participants were not completely satisfied with collaboration, outcome and process.

One of the major topics of the BIM Sustain project was the collaboration between the three involved disciplines. Since all participants work on the same model at the same time it is crucial that they work well together. For this to be possible, each profession needs a thorough understanding of the others' work. To understand each others' needs, communication between the team members is of great importance.

As evident in the focus group interviews, communication often did not work well within the groups. Not only language and physical distance created barriers, but also differences in experience, expectations and willingness to invest time and effort into the project lead to problems. Another factor contributing to the problem at hand is the absence of appreciation of the other team members' work. During the focus group interviews, the other two disciplines were often seen as perpetrators and the own role was hardly ever identified as being responsible for issues.

Not only is the understanding of the other disciplines' work often very low, but also no real team work can be established because of the group members being self-involved. Own results and deadlines are perceived as more important than the possible resulting workload for others to compensate for this selfishness.

There is of course no perfect solution to each of the aforementioned problems. The following statements are therefore to be seen as suggestions for improvement of the BIM process for all stakeholders. First of all a consciousness for the diversity of needs of all stakeholders has to be created. Only if each involved party knows about the needs of the other parties everyone can work together properly. It is important that certain aspects are considered by all disciplines, for example the accuracy of the model. A method to increase this consciousness is to have representatives of each discipline take part in an interdisciplinary workshop. Such a workshop would take place before the initiation of a project and the participants would receive a lecture about the needs and prerequisites of each profession. As a result everyone knows what their part has to look like in the end for a successful, efficient and effective workflow to be possible.

The assumption that Building Information Modeling is better suited for smaller projects points to a gap in experience between the students in this experiment and the building design industry as a whole, which is developing BIM specifically to help with larger projects. Consequently this means that gaining experience is very important to use BIM successfully. Trainings, workshops and projects at university can help to increase experience quickly and enhance productivity in the planning process.

Teams which reported good communication did not only use one channel but communicated in many different ways. Examples are regular personal meetings, Skype conferences, troubleshooting via Teamviewer and phone calls which were all used by one group. This group reported having few problems and a great atmosphere between the team members. Our suggestion is to use as many different kinds of communication as possible to increase not only the amount of information shared but to also include information which could not be shared via text alone for example. Additionally support from other team members helps to prevent the escalation of issues and reduces time spent on re-work and other cumbersome tasks.

5.2 Problems Identified with BIM Software

In the beginning of this project, the question was posed if software really causes problems in the BIM process, or if users just rant about it because it is an easy victim. To assess the truth behind all the complaints one can hear at the coffee machine, we used several techniques to evaluate the software solutions in use in our project, which were 3 each for architects and civil engineers, and 4 applications for building science majors.

Looking at the questionnaires, we can identify that the overall ease of use seems to be relatively low in the software solutions at hand - although most of the students rated is as above 3 out of possible 5, we see this as not that good since we have to consider that the subjects already have experience with similar software from their studies. This plays a role here because the time needed to familiarize themselves with the application at hand should have been diminished by that, leaving us no other explanation than that the software indeed is hard to use.

The second aspect concerning the software solutions we took a closer look at was the usefulness - usefulness was rated as better than usability, but still only civil engineers rated it above 4, and not much above it - the score was 4.0098. Usefulness tackles questions such as whether the software supports the work it is designed for well, and whether it would have been difficult to conduct one's tasks without it.

Software for technical tasks, as the applications in our project are, should reach a high score in usefulness since its purpose is to simplify the complex calculations necessary when planning a building, such as statics, earthquake simulations or the thermal balance of the structure. When the user has the opinion that an application does not support them enough to the extent that they cannot say that they task would be more difficult without it, this conveys a very clear message. What is the point of investing in expensive BIM software if one's employees do not benefit from it, decision makers will ask?

Another very important aspect when talking about software in the context of Building Information Modeling is the problem of interoperability, which is the golden thread in this thesis. As we know, interoperability is necessary because a lot of different professions with different applications work together here. Architects, civil engineers, building scientists, but also facility managers and emergency services are supposed to use the information provided in the common model. With an interface not developed very well, there is information missing, leading to false assumptions or mistakes made by users further down the workflow. Another problem that occurs quite often is that one model cannot be imported into a specific application, making a lot of rework necessary to be able to continue working on it. Effort spent on rework costs time and thus money as well as user motivation, all of which are things that are of special importance in the very competitive building industry.

Interoperability was rated very poorly by the test subjects, only one question reached a score above 3, the rest lies between 2 and 3 again out of possible 5. Students reported that a lot of rework is necessary as well as that it is difficult to import data from other sources. The applications were denied to support the collaborative user process very well, and also the exporting to other systems seems to have caused a lot of trouble. Students generally do not think of the software solutions as highly interoperable with other systems, all of which turn our attention towards the interfaces between the applications that are supposed to carry the interoperability: if the common data format lacks in power and functionality, it is impossible for the corresponding applications to work with each other as intended.

So how can these problems be addressed? The obvious answer here is that first of all, the usability has to come into focus more when developing BIM software. Usability Engineering and User-Centered Software-Development have been around for some time now, but seem to have been neglected in this kind of applications. This is quite common - the more specified software is, the smaller the target audience is, the less useful it is - but it also usually becomes more powerful. Sometimes it seems to me that one hast to choose whether one wants a powerful software or one that is easy to use. In this thesis we pointed out that although the users are quite well educated in their field, ease of use and usefulness still play a great role.

To increase these two qualities, the software development process has to change – users have to become part of it, and software designers have to see usability as an important part of their applications. As we pointed out, there is a lot of time spent by users with simply trying to find features and functionalities within the applications, and trying to get anything to work at all. Time spent learning the software is time not spent doing anything productive, so decreasing the learning effort is of financial interest for the industry. The user, of course, cannot take part in the development process, so they can only counteract the problems by becoming specialists for the applications. Once a user knows the software they have to work with well enough, ease of use does not play such a big role any more, and also the perception of usability seems to improve.

Talking about the software interfaces, which caused a lot of problems during the design project at hand, the very clear conclusion is an appeal to the software companies to get together at a table and design (or rather enhance) the interfaces, which has already been mentioned. Again looking at what the user can do, we mentioned increasing awareness for the other professions' needs – software interoperability can also benefit from that. One of our student groups reported they sat together before the actual work on the project started and talked about each other's software solutions. They looked at the interfaces between the applications and at the prerequisites a model has to fulfill in order to be imported into the next worker's software solution. With that knowledge, every student could bear in mind what their model had to fulfill in the end while working, thus producing a file at the end of their work cycle that could easily be imported into other applications. This group also reported having very little problems with interoperability.

When talking about respect and awareness for each other's needs, we should also mention the complaints voiced by students that every profession seems to think they are the most important player. Consequently, there seems to be a lot of conflict within the teams, because with this mindset, participants simply did their thing and exported the model. What happened afterwards was of no interest to them – an attitude which is of course very poisonous for the climate within the group. Apart from that, when people start working as lone wolves rather than as a party of the team, rework and cumbersome importing-related problems turn up. These problems don't just affect the player who has to deal with the poor model, but consequently affects the performance of the whole team, not only by downgrading team spirit. If users cannot be taught to play as a team, they can at least be forced to pass on valid models. Right now, error messages are thrown when trying to import the model, leaving the responsibility to the worker who has never seen it. By moving the inspection whether the model fits the interface's demands to the export, everyone is forced to deal with, and fix, the errors that they themselves caused. For this to work of course, again, the interface has to be defined very clearly and the definition has to be honored by all software vendors. One might think now that we just want to shift workload from one stakeholder to another without actually diminishing cumbersome tasks, which is not true. When everyone has to deliver a valid model not only is the solution to the problem (namely, the lacking accurateness in one's work) shifted to the place in the workflow that causes it, but this user also most likely the one to be able to solve it efficiently. Having to fix someone else's mistakes usually takes some time to read into it and, last but not least, frustrates people.

5.3 Influence of Training and Experience

In literature it can be found that the more experience users have with Building Information Modeling, the better they perceive its benefits, as we discussed in chapter 2. Naturally, we expected to see the same results in our students. Although they are relatively young (compared to subjects in the industry) and naturally tend to not have a lot of experience, there is quite a range in this aspect among our participants. But not only industry experience plays a role for us – in the pre-questionnaire, we also evaluated the students' length of study. After all, the curriculum is supposed to prepare students for later work in the building industry, so experience gained in group projects and individual projects should have an influence on the performance regarding BIM as well.

The aforementioned aspects of experience can be seen as concerning the design process, but as we know, software plays a big role in the BIM process. To evaluate this, we had the test subjects fill out their experience level with all 10 software solutions in use. They had to evaluate themselves on a scale from inexperienced to very experienced. At the end of the project, we matched the scores for the all constructs against the level of experience reported for the specific application the student used.

Our results show that industry experience definitely plays a role in the perception of the process and the satisfaction with the outcome, which is what we expected and what can be found in literature to the topic as well. The number of semesters spent in the curriculum seems to be influential in some aspects, too, but not as much as the industry experience. Every item in the questionnaires except for one question about interoperability has a positive correlations coefficient with the time spent at university. Our conclusion from this is that experience at least influences the perception of the design process. We can't really tell if the outcome is better with experienced users since we cannot measure its goodness objectively. This might sound like a problem now, but it is exactly what we are interested in – earlier in this thesis we talked about workplace motivation and that a happy individual will conduct their work better and do than simply mark their time at the office, so perception is quite important for us. Secondly, when we want to evaluate someone's work, who is more capable to do so than the experts who conducted it?

As we already know, the BIM process has two main aspects from the user's point of view – the collaborative process itself, during which they interact with agents of other professions, and the software that is used to enable the interoperability. From this knowledge we can draw that the way the software is perceived has a huge influence on the way the whole BIM process is perceived. If the interaction with the applications during the design process is very cumbersome and holds a lot of unpleasant experiences for the user, the otherwise positive aspects of the work will be clouded by this experience. Enhancing the user's experience with the software thus makes a difference in perception of the whole process, but we wanted to know if this dependence is bidirectional.

Looking at the scores for the constructs, we can see that software experience has a positive correlation with every single questionnaire item – the higher the users rated themselves in terms of software experience, the higher their score for the items was. The correlation coefficient between software experience and the questions was even higher than the one with industry or university experience, which is interpreted by us in the way that the user's interaction with the software has the greatest influence on their happiness.

What we can conclude from this is that experience plays a great role for the success of the BIM initiative, and that everyone involved profits from know-how gained prior to a project, so the satisfaction curve seems to go up with more time spent using BIM. From a financial point of view, time and money invested in training your employees and letting them gain experience is money well spent because projects in the future will benefit from it. It also seems to make sense to specialize in one or two software applications and use them in all or most of one's projects, so not only ever more experience can be gained, but also the outcome gets better every time. Talking about training, we believe it is a good idea to invite experts for a specific software solution to share their know-how and tricks with not so experienced users, thus speeding up the learning process and helping them to achieve desired results more quickly.

5.4 Negative and Positive Perceptions

As the results in chapter 4.2.6 indicate, for the most part the perceptions of positives and negatives of the process are quite similar among the three participating professions. There are some differences, however, which originate from the different positions in the workflow the three roles are in respectively.

The architects are at the beginning of the workflow and create the initial model. In this installment of the lecture, the deadlines for the individual tasks were the the same for all professions even though the BIM planning process necessitates a specific chronology for some tasks. Students which assumed the role of the architect in the project were thus somewhat independent from their group members while the others had to wait for the architects to finish their models. This freedom is reflected in the discussion, where the two most prevalent topics for the architects are *Technical Discussion* and *General Discussion*. A lot of discussion in the interview is about the general usefulness and perception of BIM in regards to the profession of architecture as well as about specific problems with the models. This indicates there is not a lot of need to talk about the process, pointing to a high satisfaction with it. The results from the questionnaires paint a similar picture. Process satisfaction for the architects has a mean of 4.14 which is very high. Also the outcome satisfaction shows a high score with 4.06. Only the satisfaction with the collaboration is slightly lower with 3.47. The relative frequencies for the categories *Collaboration+* and *Collaboration-* in the focus group interview of the architects are very similar, and *Collaboration-* is only slightly ahead with 8.04% against 7.69%. The category *Lecture*, where discussions about the process took place, makes up for only 6.99% in relative frequency pointing to little interest in the process for the architects.

Moving on to the civil engineers, the situation changes in comparison to the architects. The engineers depended on the model designed by the architects, without which they were not able to do their calculations. This dependency coupled with the same deadlines for all professions in the project lead to a lot of frustration which is voiced in the focus group interview. Interestingly, the process satisfaction determined through the questionnaires is the highest for the civil engineers with a value of 4.38. This value even tops the 4.14 of the architects, which was already very high. Satisfaction with the outcome, however, is quite a bit lower with a mean of 3.75. Although the negative experiences voiced in the focus group interview would point in another direction, the satisfaction with the collaboration is surprisingly the highest for all three professions with a value of 3.93. This value is not supported by the findings in the focus group interview. There, the category *Collaboration-* is much more prevalent with a relative frequency of 5.81% than the category *Collaboration+* with 3.35%. It is hard to tell why the perception of the collaboration for the civil engineers differs between the questionnaires and the focus group interview, but it is possible that the group dynamic of the interview reinforced the proclaiming of negative experiences, even though the overall perception was positive. Aside from collaboration, the civil engineers did overall talk more about the process in the interview, also indicated by the high relative frequency of 12.32% for the category *Lecture*. This puts *Lecture* in third place of all categories when ordered highest to lowest by relative frequency. This means that the different position of the engineers in the workflow, adding dependency from the architects, enhances the need to talk about the process and the workflow. Although the focus group interview would suggest a very low satisfaction with the collaboration, the process and the outcome, the actual values from the questionnaires are unexpectedly high.

The building scientists were in a similar situation as the civil engineers regarding their position in the workflow. They too had to wait for the architects to finish their model leading to deadline issues and lots of last-minute work. Additionally, many of the building scientists are not fluent in German, leading to communication issues as well. It is thus not surprising that process satisfaction is the lowest for the scientists, with a value of 3.79. In turn also their satisfaction with the outcome is lower in comparison to that of the architects and of the civil engineers, reaching only a value of 3.38. A reason for the lowest values in these two categories of the questionnaires could also be that students with the role of the building scientist had to deliver up to seven different results. This meant using a lot of different software and potentially a lot of rework leading to frustration and dissatisfaction with the BIM process as a whole. Satisfaction with the collaboration reached a score of 3.75 for the building scientists, which is again higher than the value for the architects. It seems that even though the scientists often felt disadvantaged due to their position in the workflow and the ensuing deadline problems, they were still more satisfied with the collaboration than the architects. When compared with the relative frequencies for the categories *Collaboration+* and *Collaboration-* in the focus group interview, this observation is somewhat put into perspective. *Collaboration-* makes up for more than 66% more in relative frequency than *Collaboration+*, so seemingly the satisfaction with the collaboration is very low in the interviews. Similar to the interview of the civil engineers a reason for this could be that the voices stating negative experiences are simply the loudest. Also in contrast to the architects and similar to the civil engineers the category *Lecture* makes up for a high amount of relative frequency (second overall with 23.03%). Since *Lecture* is equal to the overall process for the students this indicates a high need to discuss the ongoings in the process and thus a low satisfaction with it. This observation is supported by the lowest value of satisfaction with the process in the questionnaires and by more than four times as much relative frequency coded with the category Lecture- for negative expressions than with Lecture+ (18.54% versus 4.49%). As already mentioned, several factors like language barriers as well as possible cultural differences could have led to this dissatisfaction.

According to the focus group interviews one of the biggest issues that caused dissatisfaction with either process, outcome or collaboration is lack of communication. Groups which reported a high volume of communication between team members also reported a higher cohesion in the teams and overall increased satisfaction. There are many ways for communication to take place, especially in today's technologically advanced society. Examples for good communication were use of phone calls, Skype or Teamviewer for remote visual support, all of which are synchronous means of communicating. Asynchronous methods like e-mail work too, but add a lot of delay and cannot transmit nearly the same volume of information as spoken communication in a synchronous way. According to one group, personal meetings are the best way to increase teamwork and to communicate effectively. If a superficial ranking had to be made, personal meetings would be at the top, followed by synchronous spoken communication, while asynchronous written communication would end up at the bottom. To increase the chances for a successful project the means of communication should be chosen according to this ranking, where a lesser ranked method should only be used if no higher ranked methods are possible.

5.5 Discussion of Software Problems and Interface Problems

As already quite evident from previous observations and from what is said during the focus group interviews, there were many problems with the software the students used. Only very few solutions worked well and especially import and export via the interfaces was tedious at best. Below, available data for each individual software is compiled, which includes statements in the focus group interviews as well as constructs in the questionnaires, segregated by software. It has to be noted that there are not many entries in the questionnaire for each individual software, since there were only 38 students in total. The scores for the software are taken from the constructs Ease of Use, Usefulness and of the question 6 in the Interoperability construct, which is “Overall, I find the software is highly interoperable with other systems”. Tables depicting the scores for the various software solutions can be found in the Appendix.

5.5.1 Allplan

In Allplan it is hard to change round walls because this leads to inaccuracies. Also, even though there is a proprietary interface between Allplan and Scia, similar to Revit and Sofistik, this does not work at all, according to some students. Another issue comes up with ceiling openings, which are not recognized correctly by Allplan. One building scientist compliments Allplan’s many features, because a lot of tasks can be solved by using this program alone.

5.5.2 Archicad

Archicad’s filters to deliver data to the civil engineers or the building scientists were useful. Inaccuracies occured if the architect did not specifically account for them and correct them, meaning knowledge about how the other professions use the model was required. The export from Archicad to Tekla worked well at first, but the model had to be translated and after the translation some information, especially about ceiling openings, was missing. Also axes were defined wrongly and had to be corrected after the import into Tekla. What worked well with the transport to Tekla was the definition of pillars, which was transfered correctly.

The transfer from Archicad to RFEM via IFC worked well with a filter provided by the lecture team.

5.5.3 Plancal

Import into Plancal worked very well according to one student.

5.5.4 Revit

While one group worked together on the same Revit model where import and export worked well, it didn't work for another team which had to do a lot of redrawing. Another student states that not only errors were not displayed, but that Revit does not work at all for BIM. One student suspects the program is useful for small projects like similar townhouses since the tutorials were focused on this as well. The interface between Revit and Sofistik supposedly works well, since it is a proprietary interface. Round walls, however caused problems and file locks and ensuing crashes lead to many lost hours for another student.

5.5.5 RFEM

When importing into RFEM, script is not transferred. Transfer via the proprietary interface between Tekla and RFEM works very well, with no problems. Problems arose when students used round ceiling openings, because RFEM was not able to calculate them correctly. Another issue came up with sharp edges, which were not calculate-able in RFEM either. As already mentioned, import from Archicad into RFEM worked well.

5.5.6 Scia

One student had issues with drawing triangular shapes in Scia.

5.5.7 Sofistik

As already mentioned, Sofistik sets file locks which lead to unwanted behaviour for one student, because the program then crashed and subsequently damaged the file. The combination Sofistik and Tekla did not work at all. One student feels that they need to have a lot of experience with Sofistik to be able to use it correctly and efficiently. On a positive note the proprietary interface between Sofistik and Revit worked very well.

5.5.8 Tekla

In Tekla, round designs do not work, for example round walls. Also, the interface between Tekla and Sofistik does not work at all. The import from Archicad to Tekla has some issues, especially with ceiling openings and wrongly defined axes, while the transfer between RFEM and Tekla works well in both directions because of the proprietary interface. When transferring back from Tekla to Archicad, information about changes is lost.

Our thesis shows that Building Information Modeling has a lot of potential to enhance the building planning process. To exploit this potential, however, several improvements are necessary, concerning the process as well as the software involved. Hopefully, the conclusions drawn in this work will give both the construction industry and the software industry some stimulation to increase the usefulness of BIM, both in regard to software and interdisciplinary collaboration. We hope that our research as part of the FFG project helps to enhance all participants' experience in the planning process and defines a new state of the art.

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Appendix A – Interoperability Construct

This construct was created specifically for this experiment and thus has not been field-proven or even field-tested before, so the low Alpha of 0.6550 comes as no surprise. Nonetheless, this poses some difficulties when wishing to evaluate the questionnaires. When offered such a result for a construct, it has to be reworked, meaning that we tried to eliminate one or several questions in the hope of finding a smaller, but more consistent set of items, a task which we approached systematically. The original construct consisted of the following six statements:

1. Data from other sources can be imported easily into the software.
2. Exporting data for the use in other systems is causes problems in this software. (inverse)
3. With the software one can store to and load common data formats.
4. Using data from other systems in this software necessitates a lot of rework. (inverse)
5. The software helps to coordinate collaborative user processes.
6. Overall, I find the software is highly interoperable with other systems.

Our first try was to eliminate one question at a time, hoping for one of the items to be the black sheep, resulting in the following Alpha scores:

Question eliminated	Cronbach's Alpha
1	0.6101
2	0.5637
3	0.6685
4	0.6320
5	0.5788
6	0.6153

Table 32 – One Question eliminated

As we can see, no single question can take the blame; the scores get even worse, except if we leave out question 3. Unfortunately, the increase is still way too low to meet our goal of 0.7, so we carried on and removed two questions at a time.

Questions eliminated	Cronbach's Alpha
1, 2	0.4837
1, 3	0.6324
1, 4	0.5811
1, 5	0.5334
1, 6	0.5381
2, 3	0.5362
2, 4	0.5513
2, 5	0.4464
2, 6	0.5167
3, 4	0.6446
3, 5	0.5919
3, 6	0.6658
4, 5	0.5394
4, 6	0.5728
5, 6	0.4981

Table 33 – Two Questions eliminated

The elimination of two questions at a time could not lead to a satisfying increase in alpha scores, too, the best combination being the abandoning of questions 3 and 6 with a score of 0.6658.

Questions eliminated	Cronbach's Alpha
1,2,3	0.4254
1,2,4	0.4753
1,2,5	0.3672
1,2,6	0.3742
1,3,4	0.6059
1,3,5	0.5771
1,3,6	0.6215
1,4,5	0.4970
1,4,6	0.4565
1,5,6	0.3891
2,3,4	0.5053
2,3,5	0.3553
2,3,6	0.5497
2,4,5	0.4365
2,4,6	0.5002
2,5,6	0.3401
3,4,5	0.5396
3,4,6	0.6395
3,5,6	0.5765
4,5,6	0.3907

Table 34 – Three Questions eliminated

Cronbach's alpha still did not increase to any value close to being acceptable. The best combination of only three questions is a combination of 1, 2 and 5.

Questions eliminated	Cronbach's Alpha
1, 2, 3, 4	0.3607
1, 2, 3, 5	0.2213
1, 2, 3, 6	0.3941
1, 2, 4, 5	0.4425
1, 2, 4, 6	0.3218
1, 2, 5, 6	0.1268
1, 3, 4, 5	0.5688
1, 3, 4, 6	0.5743
1, 3, 5, 6	0.5862
1, 4, 5, 6	0.1505
2, 3, 4, 5	0.2370
2, 3, 4, 6	0.5783
2, 3, 5, 6	0.3499
2, 4, 5, 6	0.3020
3, 4, 5, 6	0.4589

Table 35 – Four Questions eliminated

Combining just two survey items at a time does not seem to make any sense either (highest Alpha was 0.5862), so after trying out all possible combinations of questions and still reaching no satisfying value for Cronbach's Alpha, we decided to leave out the construct of interoperability for the detailing interpretation of the results, so we will look at each question individually in the results part of this thesis.

The most probable cause for the low Alpha score is that the six questions in the interoperability category are not consistent enough with each other, meaning that they are trying to cover too broad of a subject. For example question 5, "The software helps to coordinate collaborative user processes", might be misunderstood by some participants. What we were aiming for was whether the program facilitates on the one hand, or complicates on the other hand the collaborative process of designing a building – but that is not always the software's fault. Some users might have interpreted their overall dissatisfaction with the whole process into this question, while others might have thought the software is supposed to actively support the communication between the stakeholders, while the purpose should be at least not to hinder it.

Another possible source for the lack in consistency is that the software solutions differ in the aspects that are researched here quite widely. Some students might have had the luck that their interface worked really well with the other students' solutions, while others might have had the complete opposite, so the data in focus might just be too widely spread over the spectrum to get consistent answers with this small set of observations. For example, question 3, "With the software one can store to and load common data formats", shows a standard deviation of 1.21, quite a high value for a range of 1 to 5. Question three is also the only one whose elimination from the construct showed an increase in the alpha score, as mentioned above. All except for one question have a standard deviation above 1, the first being at 0.93. We discussed the individual questions and their statistics in detail in the results part of this thesis (Chapter 4.1.3).

As we mentioned earlier, two different data formats were used in the project, gbXML and IFC. Different groups used different interface standards, some of which might have worked better than others. This can also be seen as a reason for the problems we experience with this set of questions, since for example questions 2, "Exporting data for the use in other systems causes problems in this software" and 3, "With the software one can store to and load common data formats", aim directly at the students' experience with the software interfaces.

Appendix B – Construct Scores by Software

Allplan

Construct	Score
Ease of Use	3.67
Usefulness	4.42
Interoperability 6	3.50

Table 36 – Construct Scores for Allplan

Archicad

Construct	Score
Ease of Use	3.83
Usefulness	4.22
Interoperability 6	3.33

Table 37 – Construct Scores for Archicad

Plancal

Construct	Score
Ease of Use	2.63
Usefulness	3.27
Interoperability 6	3.40

Table 38 – Construct Scores for Plancal

Revit

Construct	Score
Ease of Use	2.93
Usefulness	3.33
Interoperability 6	2.64

Table 39 – Construct Scores for Revit

RFEM

Construct	Score
Ease of Use	4.17
Usefulness	4.17
Interoperability 6	3.00

Table 40 – Construct Scores for RFEM

Scia

Construct	Score
Ease of Use	3.00
Usefulness	4.17
Interoperability 6	3.67

Table 41 – Construct Scores for Scia

Sofistik

Construct	Score
Ease of Use	1.50
Usefulness	1.67
Interoperability 6	3.83

Table 42 – Construct Scores for Sofistik

Tekla

Construct	Score
Ease of Use	4.17
Usefulness	3.92
Interoperability 6	3.50

Table 43 – Construct Scores for Tekla

Appendix C – General Questionnaire

Measured by a 5-point Likert scale: (1) wrong (2) rather wrong (3) partly (4) rather true (5) true

1. I am satisfied with my performance in the planning process. (SP1)[4]
2. My personal results for my tasks in the project are satisfactory. (SO4)
3. Necessary information was exchanged by the team members in time. (SC2)
4. My approach to accomplish my tasks was practicable. (SP2)
5. The goals I defined for myself are fulfilled by the results. (SO3)
6. All participants in the team worked satisfactory and made their contribution. (SC3)
7. I fulfilled my tasks efficiently. (SP3)
8. The results are in accordance with my initial expectations. (SO2)
9. The team members communicated effectively and efficiently. (SC1)
10. I carried out my role and position during the project appropriately. (SP4)
11. I am satisfied with the results reached as a group. (SO1)
12. The team members cooperated well and supported each other. (SC4)

[4] (SP1) = Question 1 in the given Construct | (SP1-) = Answer scale is inverse

SP…Satisfaction with Process | SO…Satisfaction with Outcome | SC…Satisfaction with Collaboration

Appendix D – Software Questionnaire

Measured by a 5-point Likert scale: (1) wrong (2) rather wrong (3) partly (4) rather true (5) true

1. I often need to consult the manual or support when using the software. (EU1-)[5]
2. Overall, I find the software is highly interoperable with other systems. (IO6)
3. Using the software enhances my effectiveness on the tasks. (UF4)
4. I find it easy to make the software to do what I want it to do. (EU2)
5. The software helps to coordinate collaborative user processes. (IO5)
6. The software increases my productivity. (UF3)
7. Interacting with the software requires a lot of mental effort. (EU3-)
8. Using data from other systems in this software necessitates a lot of rework. (IO4-)
9. With the software it is easier to do my tasks. (UF5)
10. Overall, I find the software tool easy to use. (EU6)
11. Using this software improves my performance in conducting my tasks. (UF2)
12. With the software one can store to and load common data formats. (IO3)
13. It is easy to remember or discover how to perform tasks using the software. (EU5)
14. Exporting data for the use in other systems causes problems in this software. (IO2-)
15. Overall, I find the software useful for my tasks. (UF6)
16. The software is inflexible and rigid in handling. (EU4-)
17. Data from other sources can be imported easily into the software. (IO1)
18. My tasks would be difficult to perform without this software. (UF1)

[5] EU...Ease of Use | UF...Usefulness | IO...Interoperability

Appendix E – Focus Group Guidelines

Duration:

Start:

End:

Language:

o English

o German

Group:

o Architects

o Civil Engineers

o Building Science

Announcement:

Thank you for participating in this group discussion with the aim to evaluate the BIM project. We will audio record the discussion for scientific purposes. The data will be used only anonymized and will not be distributed outside the research team. This group discussion gives you the possibility to exchange experiences with your colleagues of the same role but from different groups.

Questions:

Initial question: 'How did you experience the building planning process of the BIM project?'

Follow-up questions: (in case of speaking breaks or if not mentioned!)

- How did you experience the cooperation of the different project members of your team in the building planning process?
- What went wrong or was difficult to handle, what went especially good?
- How was the teamwork – where there conflicts?
- How was the coordination and communication (media)?
- Was the work load divided equally, how did you manage division of labor?
- Could you fulfill the tasks and keep the deadline?
- Where there a lot of loops, how did you manage model changes?

Appendix F – Abbreviations

BIM – Building Information Modeling

FFG – Österreichische Forschungsförderungsgesellschaft

GBXML – Green Building Extended Markup Language

IFC – Industry Foundation Classes

ISO – International Organization for Standardization

TAM – Technology Acceptance Model

Vienna UT – Vienna University of Technology

Appendix G – Translations

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i. Translated from original: *„Also im Scia ändern ist superleicht.“*

ii. Translated from original: *„Ich finde es auch nicht gut, dass man da im Sofistik was*

ii. Translated from original: *„Ich finde es auch nicht gut, dass man da im Sofistik was ändern kann, oder dass mir das automatisch was ändert.“*

iii. Translated from original: *„Na aber er gibt das Feedback in's Revit zurück. Und sagt: 'da hat es ein Problem gegeben, mit dem Bauteil', und das musst du dir nochmal anschauen.“*

iv. Translated from original: *„Aber ich könnte keine Software lernen, ohne ein Projekt zu haben. Also ich lerne auch die Sprache nicht im Wörterbuch mit A bis Z.”*

v. Translated from original: *„Bei mir war Fehler, als ich in meine Kern in Decke Öffnungen gemacht hab, und die Öffnungen waren nicht sichtbar, und ich hab gefragt und keine Ahnung.“*

vi. Translated from original: *„Was hast du für eine FE-Netz Größe eigentlich eingestellt jetzt?"*

vii. Translated from original: „*Euer Architekt hat ARCHICAD gehabt oder?“*

viii. Translated from original: *„Ja was vielleicht auch nützlich wäre, wär wenn man das Projekt so macht, dass die Architekten einen Abschluss haben und das Projekt nachher angeschaut worden ist und fertig."*

ix. Translated from original: *„Das ist richtig.”*

x. Translated from original: *„Schneeballeffekt.”*

xi. Translated from original: *„Ja und selbst auch bei den Programmen, man muss schon sagen, also sie sprechen immer von dem ‚Blauen‘. Dass man einfach das Modell rüberspielen kann, das ist einfach nicht so.“*

xii. Translated from original: *“Du kriegst ein Diplom in Architektur und gehst zu ein kleines Tisch (hin?) und dann hast du Bildschirm und sagt dass du (darfst?) zwei Wochen lang, und das is deine Arbeit heute.“*

xiii. Translated from original: *„Ahm, nein das hat eigentlich alles sehr gut funktioniert, wir ham uns ja gut verstanden. Oder tuns immer noch.”*

xiv. Translated from original: *„Ja. Ja weil die anderen zwei Kollegen haben sich mit den eigenen Programmen nicht so gut ausgekannt. […]. Und das macht Probleme.”*

xv. Translated from original: *„Weil es ist genauso mit dem BIM, ich meine, könnten die Bauleute nicht mit normalen Plänen arbeiten? Wozu braucht man BIM? Das ist etwas extra. Das ist für mich extra.“*

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xvi. Translated from original: *„Die Genauigkeit war bei uns auch ein bissl ein Problem. Also speziell jetzt nochmal die Runden Wände."*

xvii. Translated from original: *„Das is glaub ich, eins der größten Probleme die wir mit dem ganzen Projekt hatten, is dass fast keiner wirklich sein Programm beherrscht hat. Wir sind hergekommen, haben drei Stunden Schulung bekommen und haben zusammen da Probleme lösen müssen. Und das geht net.".*

xviii. Translated from original: *„Frank Gehry hat seine eigene Software entwickelt, weil er wusste er braucht diese, er muss diese Probleme gelöst haben und is zu (dissol?) systems gegangen von (katia?) und hat sich seine eigene Software geschrieben. Ich glaub das is halt schon irgendwo auch der Weg, oder?"*

xix. Translated from original: *„Ja ich denk, teilweise waren auch einfach Fehler, Fehlersuche, die einfach viel Zeit gekostet haben. Und dass du halt irgendeine Nummer hast die du irgendwo wieder eingeben musst, damit da dann irgendwie gezeigt wird, welcher Fehler das jetzt wirklich ist."*

xx. Translated from original: *„Ja, und am Ende triffts nachher dich als Statiker, als Building Science, und der Architekt hat ja gemeint, ja das mag er jetzt nicht so genau machen"*

xxi. Translated from original: *„Das ist wahr, also bei uns ist das 8 ECTS und für sie ist es 6 oder weniger als bei uns und für uns ist das dann wichtiger als für sie."*

xxii. Translated from original: *„Eigentlich die Hauptproblematik war einfach wirklich nur die Software, wo man einfach geschaut hat, dass man überhaupt ein Modell einmal zusammenbringt"*

xxiii. Translated from original: *„Man muss auch wissen wie man mit den Leuten umgeht."*

xxiv. Translated from original: *„Wir haben uns so oft getroffen, vielleicht mehr als zwei Mal in der Woche manchmal."*

xxv. Translated from original: *„Oder wenn's einfach abstürzt."*

xxvi. Translated from original: *„Also es gibt keine SCIA Hilfe oder so, keine Ahnung "F1" (.?), pdf Datei 5000 Seiten."*

xxvii. Translated from original: *„Was bei uns noch dazukommt, bei der SOPHISTIC Gruppe glaube ich – dass die Einführung ziemlich, ziemlich kurz"*

xxviii. Translated from original: *„Was noch eine Verbesserung wäre zum Programm, Fehlermeldungen, die mehr sagen als wie ‚Fehler -100'."*