

CIB 2013 World Congress

BIM-supported planning process for sustainable buildings – Process Simulation and Evaluation through Exploratory Research

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Abstract

One of the consequences of increasing complexity of planning and construction process is a large number of disciplines participating in planning process, all of whom use wide spectrum of specialised visualisation, simulation or calculation tools. With the maturing of BIM tools and their increasing presence on the market, the hope for possibility of maximisation of process-integration through joining all of the different building-representation models in one single joint model came up. The planning practice reality however demonstrated a number of upcoming problems with BIM implementation on technical- (heterogeneous data, interfaces, large data volumes) but even more so on process-level (question of responsibilities and work-load distribution, lacking standards or conventions on building-representation). The optimal data management, transfer and synchronisation within very inhomogeneous software context, such as employed within construction projects, require enormous organization, coordination and communication effort in the earliest design-phases. The BIM implementation implies therefore on necessity of fundamental rethinking of the traditional design process; for which the knowledge is still largely lacking.

In this paper we will present the first results of the exploratory research carried out at the Vienna University of Technology. We simulated a BIM-supported multi-disciplinary planning process with students of architecture, structural engineering and building physics, using several BIM-software tools. First insights on process-quality, such as team-, process- and technology satisfaction, as well as conflict- and stress levels will be presented. We were able to identify numerous technical problems related to the data transfer and inconsistencies in translation, which resulted in participant dissatisfaction and significant increasing of work-loads.

The first results imply on the importance of traditional process-design techniques such as face-to face communication, coordination and work-load allocation between the team-members in order to conduct efficient BIM-supported process; as well as on urgent need for advancement of the tools in terms of data transfer- and exchange. In the next step, using mandatory protocols and timesheets, a detailed statistical analysis of the people-process-technology issues will be conducted, as well as comparison of „Open-Platform-BIM“ to „One-Platform-BIM“ model.

Keywords: BIM, Collaboration, Integrated Planning, Exploratory Research, Experiment

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1. Current issues in BIM-adoption and utilization

With upcoming requirements for sustainable building, the need for more integrated planning practice, which would enable simultaneous collaboration of various disciplines in order to share and create new common knowledge, arises. BIM (Building Information Modelling) has often been recognised by research and practice as suitable tool for support of collaborative planning, facilitating communication and information exchange between diverse planning process participants; and eventually to leading to maximization of efficiency- and quality and reducing time effort (Sebastian and van Berlo, 2011). Especially promising seems BIM in terms of life-cycle oriented planning and optimisation. BIM is largely understood as object-oriented digital representation of a building or built environment that enables interoperability and data-exchange in digital form (Kiviniemi et al 2008). In this context BIM addresses primarily the process of model-building and information exchange (Succar, 2007). BIM is believed to bear large potential towards integrated design (Prins and Owen, 2010) inducing a shift from AFC fragmented practice that still largely dominates the AFC industry (Fellows and Liu 2010). Rekkola et al (2010) argue that “integrated design” is still handled rather loosely in the practice – often is the creation of BIM model sufficient for the project to be referred to as “integrated project”, regardless of actual interdisciplinary data sharing and model use. BIM, in our understanding is much more about how (design of design process), that about what (building model and its properties). Since the AEC industry is project-oriented, the small markets are characterised by high fluctuation of the employees and of the related know-how loss. Owen et al (2010) point out the need for enhancement of skills of project members, which are often highly specialised in own fields of expertise, but seldom trained to work in integrated project environment. The organizations also seldom support this kind of professional development. The introduction of the new BIM-tools therefore mostly means more than simple CAD-tools shift, since the adoption is mostly related to the reorganization of the processes and management strategy of the project-based organization. In the practical BIM operation and use a number of problems on different levels can be met. On the technological level the questions of the interfaces in the data transfer of the interdisciplinary models arises, as well as of the heterogeneous data-structure of the different software the art of model building and management of ever larger data-volumes. On the semantical level, it can be noticed that each discipline needs individual information; the professional languages differ strongly as well as the means and methods to represent a building (Bazjanac and Kiviniemi, 2007). The spectrum reaches from diverse lists for project management and quantity surveys, over reduced slab model for structural engineering for earthquake simulation, to complete spatial representation of architectural model in the full geometric complexity. The optimal management, filtering and reliable synchronisation of these very differentiated information in the context of in the building industry still dominant heterogeneous software-structure requires high effort in organisation, administration interdisciplinary communication and know-how. A standard solution offering the complete software package for this large spectrum does not yet exist, and it is a question if such solution is viable for every building and consequently every design process is of prototypic nature.

The high fragmentation of the design and construction process disables the management of complexity the linear planning process of highly specialised disciplines proves as not

suitable for the achievement of sustainable buildings. The necessity for change in the way the buildings are designed, constructed and operated is being continually reported by the practice. The emerging of highly developed BIM tools together with maturing of promise a paradigm change from the linear, fragmented process towards more integrated practice that would not only bring benefits for the planning and construction but even more so for the optimisation of operation. A life-cycle oriented approach brings whole-life value enabling knowledge management and -transfer from life-cycle phase to phase and integrating building services and automation systems (Owen et al, 2010). The BIM-based Software-packages that would fully support and enhance the integrated, interdisciplinary planning practice and holistic life-cycle oriented data integration are still rather seldom. One-stop architecture and structural engineering, MEP (mechanical and electrical engineering), energy optimization, cost- and life cycle cost calculation are not available for the needs of Central European planning practice and building policy. Caused by the different project-constellations and mostly changing project-stakeholders with each new project, new combinations of software tools are to be met with each new project. For a successful implementation life-cycle oriented planning and management strategies, enabling smooth data exchange without information losses, standing in close relation with further development of open formats for data-exchange is a pre-requisite.

The BIM research was mainly focused on the problem-solving of the software-interoperability and efficient data exchange, only recently has the academic community realised that the successful BIM-adoption towards more integrated design and delivery is not only related to the handling of technical, but even more over so of the issues related to the need for the re-organisation of the design process itself (Succar, 2010, Pentilää 2008). This relates to the inter-organisational organization and standardization of the work-flows, role descriptions and related responsibilities of the stakeholders, as well as to the general commitment towards collaborative planning attitude. Rekkola et al (2010) argue the lack of knowledge beyond technological issues, in domain of workflow and business practices, where actual benefit of BIM is. In their case study of university building project, they identified problems and benefits of BIM-supported integrated process by creating categories: people (competence or knowledge problem), process (work-flows, timing, contracts, roles) and technology (software). They argue that a) for enhanced integrative practice a participative process is necessary and b) that the slow BIM-adoption in the practice is caused by the difficulty of interrelation (triangulation) of the people-process-technology problems.

2. Towards a research model

The over-all understanding for of BIM- related benefits for planning networks and for built environment is still not well understood, due to the complexity of the tools, but more over to the related transformation of planning process and inter-organisational procedures. Therefore, we argue that closer research of examining interrelations within the triangle: technology (operability) - people - process is necessary. In order to evaluate BIM performance regarding technology-people-process framework within an integrated planning process we conducted an experiment with students, simulating a multi-disciplinary planning process for sustainable building, using different BIM-software settings. Several experiments on BIM-performance either in real-time projects or simulating planning process with students

have been conducted, however always primarily focusing either on technology performance (interoperability, building model semantics) or on people-process issues.

Plume and Mitchell (2007) conducted in 2004 an experiment with 23 in a design studio setting students testing the IFC-model performance in multi-disciplinary collaboration (architecture, landscape architecture, MEP, statutory planning, sustainability and construction management.) They focused primarily on operational issues, such as building model (representation of a building model in different tools) and IFC –server data sharing issues. They conclude that the original architectural model needs significant adoption for the use of other disciplines or their tools. Further issue that needs attention is model management – tracing of the changes and updates carried out on the common model

Sacks, Kaner and Eastman (2010) carried out the “Rosewood experiment”, comparing the BIM-supported versus the traditional 2D CAD the planning and fabrication process of the pre-cast façade. BIM proved to be more efficient by 57%, however IFC proved not mature enough causing data inconsistency in transfer between architectural and engineering system. Losses in translation are to be assigned to object-semantic, a similar problem addressed by the Plume and Mitchell.

Sturts Dossick and Neff (2011) observed the collaboration of several teams on three real projects using a BIM-technology supported design process, focusing on people and process issues. They concluded that technology can even hinder the innovation of the design process through a too rigid corset of work-flow and knowledge exchange, hindering the exchange of tacit, informal knowledge. Their concept of “messy talk” – the informal, unstructured information exchange as often practiced in architecture and construction engineering is tested within student experiment, where geographically distributed teams work using BIM on a project in a virtual environment. They conclude that “...messy talk requires both the flexible, active, and informal setting described in the 2011 study as well as mutual discovery, critical engagement, knowledge exchange, and synthesis.” (Dossick et al 2012).

3. Empirical Research through Experiment

Through exploratory research – an experiment within an interdisciplinary design class involving 40 students, the collaborative, multi-disciplinary BIM-supported planning for an energy-efficient office building is simulated. The experiment is a part of an on-going research project “BIM-Sustain: Process Optimisation for BIM-supported Sustainable Design” involving three institutes of Vienna University of Technology and seven BIM-software vendors. The close collaboration of academy and industry in this setting enables development of the customised strategic concepts for the BIM-tools within multi-disciplinary planning process and immediate impulses for improvement of software-tools. The multi-disciplinary teams taking part in the experiment consisting of: architect, structural engineer, building physicist (BS) were formed by the means of a pre-questionnaire, which questioned skill-level, experience and preference of the software. Upon the results of questionnaire a matrix of software-combinations used by each team was compiled (Figure 1).

	Architect	Structural Engineer		Building Science (Simulation in TAS)	
	CAD	CAD	FEM	CAD	Calculation
1	Allplan	Allplan	Scia Engineer	Allplan	Allplan
2	Autodesk Revit Architecture	Autodesk Revit Structure	SOFISTIK		PLANCAL
3	GRAPHISOFT ARCHICAD 16	TEKLA	Dubal	PLANCAL	PLANCAL
4	GRAPHISOFT ARCHICAD 16	Allplan	Dubal	PLANCAL	PLANCAL
5	Autodesk Revit Architecture	Allplan	Scia Engineer	PLANCAL	PLANCAL
6	GRAPHISOFT ARCHICAD 16	Allplan	Dubal		PLANCAL
7	Allplan	TEKLA	SOFISTIK		PLANCAL
8	Autodesk Revit Architecture	TEKLA	Scia Engineer	Allplan	Allplan
9	GRAPHISOFT ARCHICAD 16	Autodesk Revit Structure	Dubal	PLANCAL	PLANCAL
12	GRAPHISOFT ARCHICAD 16	Allplan, TEKLA	Dubal		PLANCAL
13	GRAPHISOFT ARCHICAD 16	TEKLA	SOFISTIK		PLANCAL

Figure 1: Software-combinations used by the teams

In the course of the experiment (design class) basically two work-flow models can be identified: One-Platform BIM (proprietary) and Open-Platform BIM.

The Open-Platform BIM (Fig. 1, Groups 3-11) uses different, for each discipline relevant (typical, custom) software and works with central architectural building model, exchanging the data using the IFC. The One-Platform BIM (Fig. 1, Groups 1 und 2) work with one software family Nemetschek Allplan (2012) or Autodesk Revit (2012) using proprietary standard.

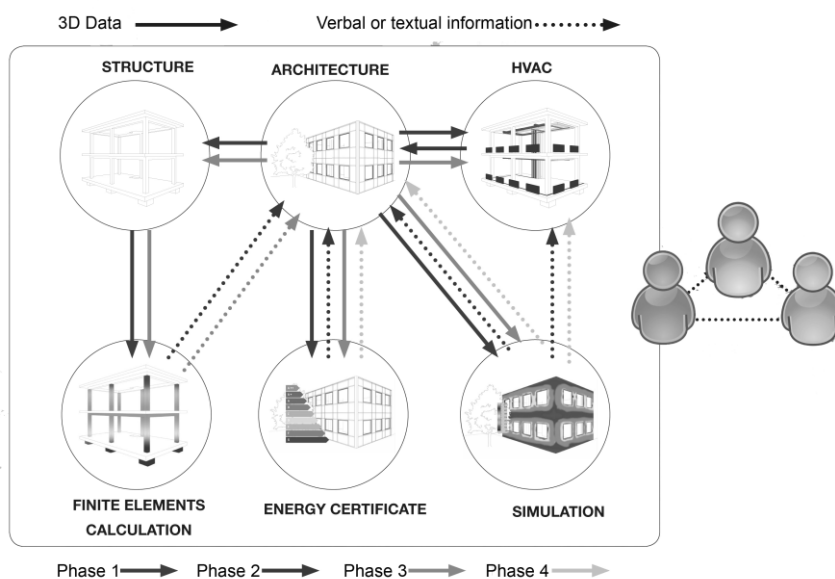


Figure 2: Multi-disciplinary teams, related building models and data transfer

The teams are producing the architectural-, structural, thermal and ventilation (as representative of MEP) models, as well as thermal simulation and energy certificate in collaborative manner (Figure 2). The groups were given an assignment consisting of a functional programme, site-plan with orientation and set origin, layer-structure and colour scheme for latter room-stamps. The time-schedule of the design-class is strictly organized; the experiment is taking place for one semester. We have organised three presentations, where in the first one the architectural model is presented, in the second presentation the structural and thermal and in the final presentation the optimised, full model containing all

the information. Between the presentations the crits as well as tutorials provided by software vendors are taking place. The experiment is examining the efficiency of the two BIM-models, communication effort, and work-allocation (work-flows) as well as satisfaction and conflict levels. Through the mandatory protocols and time-sheets the problems related to the technology (data transfer inconsistencies or losses, semantics) but also to the process-people related problems (conflicts, communicational difficulties, lack of work-flow definitions or responsibilities etc.) can be tracked. Additionally an e-learning platform has been set up, with a forum for tutor feedback as well as for student-communication, scheduling and posting of tasks is taking place.

4. First findings

The first data on satisfaction was gathered at the point close to the second presentation of structural and thermal models – basically one data exchange step has taken place – export from architectural model towards RFM and thermal simulation software. In the student workshop through rough questionnaire answered by 19 students (three architects, two engineers, 14 BS), a) satisfaction with BIM-technology, b) satisfaction with teamwork, c) satisfaction with process (work-flows), d) conflict-level and e) stress-levels were questioned on the scale ranging from 0 (low) to 6 (high).

Table 1: Results of the first questionnaire

Question	Mean Value	Median Value
Satisfaction with BIM	1,89	2
Satisfaction with teamwork	3,84	4
Satisfaction with process	2,37	2
Stress level	4,16	5
Conflict Level	1,37	1

The general BIM-technology dissatisfaction resulted through data transfer problems, reported especially by the BS students, using TAS simulation software, where data exchange uses gbXML standard. Mostly all of the architectural models had to be newly drawn in TAS due to the data loss or wrong interpretation by TAS. It was reported by the students that the time effort for the adaption of the imported model was equal to the time effort for creation of new model (two days).

When passing architectural geometry into structural analysis software two types of IFC-Files are used: Coordination View and Structural Analysis View (BuildingSmart 2012). Software for Finite Element Method (FEM) Simulation requires the Structural Analysis View of an IFC-File. But only a few CAD-Programs support the export of this type (Tab. 3), as well as not every FEM-Program supports the import of the physical model (Coordination View –Tab. 2). As a consequence, an intermediate step is needed to transfer the model from architecture to structural model: an import into a program which can import and export both types of files, a step which goes along with a loss of information (Figure 3). Due to this incompatibility it was

i.e. not possible to import an Allplan-Model as an IFC-File into the FEM-Software Sofistik (2012), because both programs support the type which cannot be read by the other one.

Table 2: Compatibility with IFC – Coordination View

CAD		FEM	
Archicad	↔	Dlubal RFM	←
Allplan	↔	Scia Engineering	↔
Revit	↔	Sofistik	
Tekla	↔		

Table 3: Compatibility with IFC – Structural Analysis View

CAD		FEM	
Archicad		Dlubal RFM	↔
Allplan		Scia Engineering	↔
Revit	↔	Sofistik	↔
Tekla	↔		

The IFC 2x3 (structural analysis view standard) still leads to variety of problems: especially more complex geometry such as sloped or rounded walls, roof elements and openings are very likely to cause problems or even disappear when being imported.

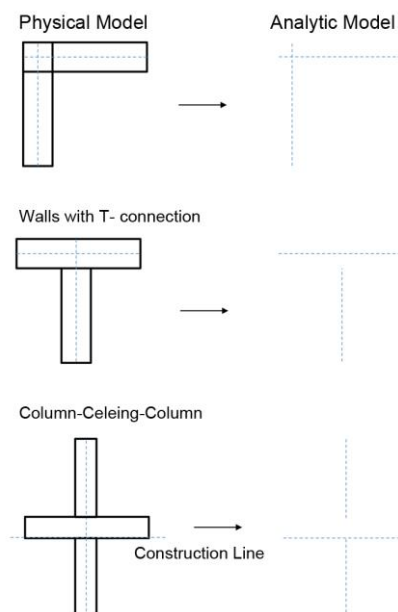


Figure 3: Results from export from architectural model, import in RFM simulation

For example, problems were identified with Tekla Structures (2012): stairs become boxes, openings disappear, and round elements become rectangles. Findings from data transfer from Allplan to Scia (2012): when round walls are used, the model takes long period of time to get imported in Scia (hours). To illustrate further problems, we assembled a scene containing several pertinent elements, exported an IFC file and imported this into different structural analysis programs. Figure 4 illustrates the architectural model; Figures 5 and 6 the interpretations by different FEM software - a completely different result when importing the exact same IFC file.

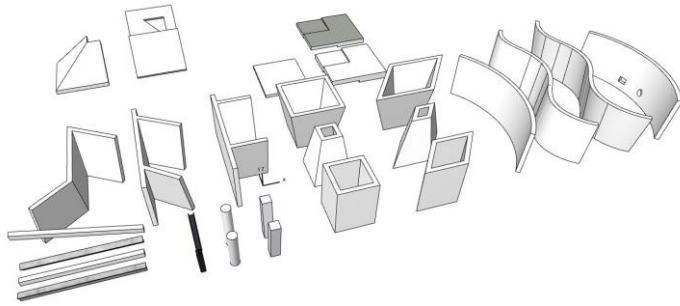


Figure 4: Architectural model from ArchiCAD16a

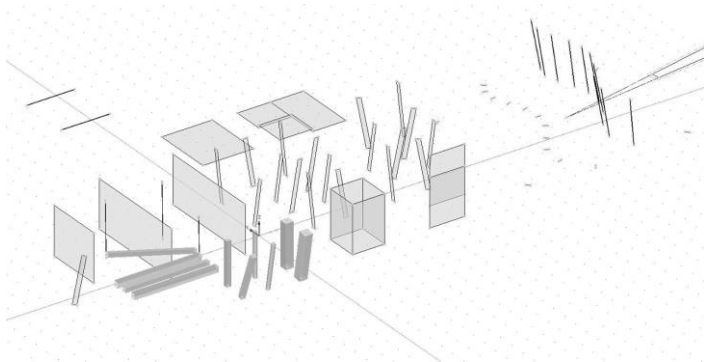


Figure 5: Import in Dlubal REFM

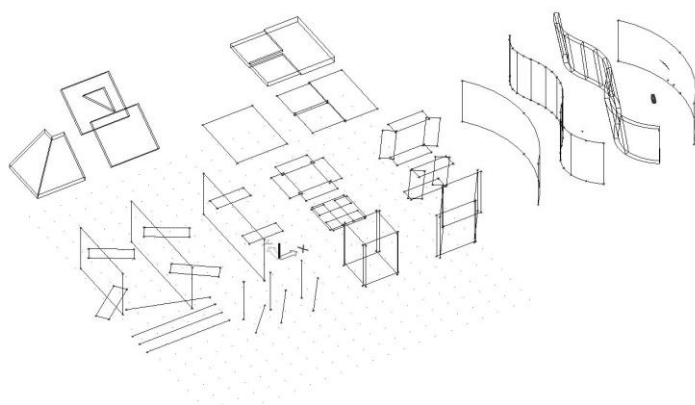


Figure 6: Import in Scia

5. Conclusion

This paper presented the first results of an experiment: simulation of BIM-supported multi-disciplinary design of energy-efficient office building, using various kinds of BIM-tools for architectural, structural, ventilation and thermal simulation modelling. For both structural engineering and thermal simulation, the data transition becomes difficult as soon as there is complex geometry involved, such as round walls, which have caused problems in all software-combinations. A problem of semantics of building models is a constant issue – architects use different room-stamps than BS, the pillars are drawn from slab to slab whereas structural engineers work with one continuous pillar from top to bottom slab. Further difficulties originate from incompatible software-combinations such as Allplan → Sofistik, or Archicad → Sofistik (see Tables 2 and 3). Such constellations can lead to significant problems in the current BIM-supported planning practice, if e.g. an architectural office using Archicad has to work with the structural engineers using Sofistik, since the data transfer will not be possible and purchase of additional software or of additional “BIM-services” will lead to increase of the planning costs.

In terms of comparison of One-Platform BIM versus Open-Platform BIM, it can be concluded that One-Platform BIM constellation, as closed system, does not exist on the market yet. The One-Platform BIM Software (Nemetschek Allplan and Autodesk Revit) both leave the original platform in order to conduct structural calculation and simulation; however offer proprietary interface to these software or even plug-ins (Revit to Sofistik). Even with proprietary interfaces the complex geometry causes problems in transfer through very long transfer-time (Allplan to Scia). The Open-Platform BIM, using IFC interface has proved as time-efficient and exact in transfer, if there is a standardised setting used for IFC transfer from architectural in structural model, and under condition that simple geometry is involved.

Our findings when compared to the student experiment executed in 2004/05 by Plume and Mitchel show that Archicad has made significant progress (at that time it was not able of producing a functioning IFC); however the question of the building-model semantics for different disciplines and the difference in the grade of required detailing for each model has not been solved yet. Our findings basically confirm the findings of the Rosewood experiment – we experience similar data losses and wrong interpretations at export-import of IFC; Rosewood experiment works with the same version of IFC. Further development of IFC is urgently necessary.

The **satisfaction with the BIM-technology** at current intermediate stage is has been reported as low, due to the very difficult data-transfer, inconsistency and data losses, especially so for the thermal simulation, where models had to be redrawn. **Processes-satisfaction** has been found as weak: work-flows are poorly organised among team-members, there are many problems in allocation of responsibilities. In many teams it is expected from the architect to undertake all of the major adaptations of the architectural model in order to make it fit for the transfer (the consultants are not ready to adopt the imported models). Teams often report that some team members are often not available.

On the level of **people-related problems**, despite the reported low conflict level, team-satisfaction is only average. We were able to observe a lack of team affiliation with most of the teams, often a bonding between the two disciplines can be observed and the third one is not playing along. This phenomenon might be referred to the lack of an organised kick off meeting. Some of the problems originate in the lack of professional knowledge (e.g. design of an office building or energy efficient facade) and in generally to lack of experience and knowledge of collaborative planning. In some cases the lacking of the team-building/bonding, and following the aim to „just finish the project“ led even to an increase of fragmentation of the design process (architect defines everything, the consultants only optimise in following steps), which is exactly the opposite of the expected BIM-effect. We can confirm the argument by Sturts, Dossick and Neff (2011) – BIM-technology is advantageous for exchange and presentation of explicit knowledge, but does not support the tacit knowledge of how the buildings are designed. Our first findings also imply that BIM-technology does not support integrated practice by itself, for the support of the collaboration other means are necessary such as well organised formal (kick-off meeting) and opportunities for informal communication (von Both and Zentner 2004).

Finally, BIM as presently used, hardly changes the work-flow between architects and structural engineers, not only due to technical interface limitations but even more so due to a logical contradiction. FEM models require a far lower level of detail than the architectural model delivers, so any automatically converted model necessarily needs to be post-processed manually by the engineer in order to simplify the model for reasonable meshing and resulting calculation times. When importing a coordination view IFC into calculation software, the discretization of architectural models into FEM-suitable meshes is carried out within the import and is hence forced to accept the model geometry “as it is”. For example, a small rounded wall opening, let’s say for a drainage pipe, will produce a complex mesh in the FEM model when being imported. For the structural system however, this opening is irrelevant, but still causes enormous effort in calculation and will hence be deleted by the engineer. Once simplified, such a wall element cannot be re-exported into the central model, because otherwise the opening would be missing. Vice versa, once the architectural model changes and is re-imported, the opening is back. The possible solution is either the radical improvement of FEM-software performance concerning calculation time for meshing; or enabling of the FEM software to directly manage the referential architectural model. The problem of bi-directional model-management remains one of the greatest challenges, not only because of the technical issues but mostly because of the process issues: definition of rights (who may change what and when?) related to change management. As first future step, detailed statistical analysis of the mandatory protocols and time-sheets will be carried out in order to gain more knowledge on performance of One-Platform BIM versus Open-Platform BIM, as well as of communication effort, work-allocation, satisfaction and conflict levels. In 2013 we will conduct the second experiment, where we will be able to use the first findings and propose framework for data-exchange procedures as well as careful design of communication. Finally we will compare the results of the two experiments, evaluate the benefits and verify the framework.

Acknowledgements

This paper is a result of an on-going research project "BIM-Sustain" funded by FFG (Austrian Research Funding Agency) and following BIM-software vendors: A-Null, Artaker, b.i.m.m. Gasteiger, Dlubal REFM, Sofistik, Construsoft Tekla and Nemetschek Allplan. We gratefully acknowledge the work of the academic partners: Institute for interdisciplinary Construction Process Management, Prof. C. Achammer, Institute for Management Sciences, Prof. S. Kösegy, Dr. M. Filzmoser and Institute for Building Physics and Ecology, Prof. A Mahdavi, L. Skoruppa and K. Kiesel, and to all the students taking part in this project of Vienna University of Technology.

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