Kovacic et al. Visualization in Engineering 2013, 1:13
http://www.viejournal.com/content/1/1/13

Visualization in Engineering
a SpringerOpen Journal

RESEARCH ARTICLE **Open Access**

The "BIM-sustain" experiment – simulation of BIM-supported multi-disciplinary design

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Abstract

Background: The AEC practice using BIM technology in Central European (CE) context is still very young; the previous experiences demonstrated a number of upcoming problems with BIM implementation on technical- (heterogonous 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 and in general lack of experience and knowledge on integrated practice).

The optimal data management, transfer and synchronization within inhomogeneous software context, as is often the case within inter-firm construction projects, require enormous organization, coordination and communication effort in the earliest design-phases. The BIM implementation implies therefore necessity of fundamental rethinking of the conventional design process, which in CE context is still predominantly based on sequential, segmented practice.

Methods: At the Vienna University of Technology a BIM-supported multi-disciplinary planning process with students of architecture, structural engineering and building physics, using several BIM-software tools was simulated. From the qualitative and quantitative evaluation of this BIM-supported multi-disciplinary collaboration will enable the compilation of guidelines for efficient use of BIM in design and planning process for the planners and standardization bodies.

Results: First insights on process-quality, such as team-, process- and technology satisfaction, as well as conflict- and stress levels will be presented in this paper. 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.

Conclusion: The first results imply at the importance of process-organization techniques such as face-to face communication, coordination and work-load allocation between the team-members in order to conduct the efficient BIM-supported process; as well as at 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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Background

The consolidations for realization of sustainable built environment result in increasing complexity of planning and construction process. The increasing number of partaking disciplines uses wide spectrum of specialised visualisation, simulation or calculation tools. The practice calls for more integrated design and planning process, which would enhance simultaneous collaboration of various disciplines for sharing and creation of new common knowledge. Building Information Modelling (BIM) is believed to bear large potential for inducing a shift from the conventional, fragmented practice, which still largely dominates the AEC (architecture, engineering and construction) industry (Fellows and Liu 2012), towards more integrated design practice (Prins and Owen 2010). BIM as method is supportive of collaborative planning, facilitating communication and information exchange among various planning process participants (Rizal and van Berlo 2010). However, 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), than about what (building model and its properties).

This paper will focus on introduction of BIM-supported planning in the CE and particularly Austrian AEC (architecture, engineering and construction) market, where the application of this technology is still novel, as well as the integrated planning approach. Austrian market is characterised by a large number of very small planning offices (average size of architectural office of 2,7 employees (Forlati et al. 2006)) as well as construction companies largely coming from the small- or medium size sector. The traditional design and planning process is carried out by small scaled, highly segmented large number of experts working in sequential manner, using various kinds of tools and software. Therefore the standards, but also the knowledge for BIM-supported planning process is largely lacking.

The further problem that most of the Austrian offices are facing is the high fluctuation of the employees and of the related know-how loss; which is a common characteristic of the most of the small project-oriented firms. Owen et al. (2010) point out the need for enhancement of skills of project members, which are often highly specialised in their 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.

Seen in this light, 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 multi-disciplinary models arises, as well as of the heterogeneous data-structure of the different software, and of 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 models for structural engineering for earthquake simulation, to complete spatial representation of architectural models in the full geometric complexity.

The optimal management, filtering and reliable synchronisation of such highly differentiated information in the context of in the AEC industry, still dominated by the heterogeneous software-structure, requires high effort in organisation, administration interdisciplinary communication and know-how; especially in a market that lacks a tradition and knowledge of integrated planning practice. A standard solution offering the complete software package for this large spectrum does not yet exist, and it is questionable if such solution is viable, due to the prototypic nature of construction projects.

The BIM-based software-packages that would fully support and enhance the integrated, interdisciplinary planning practice and life-cycle data integration are still rather seldom. The one-stop-shop tools for modelling of architecture, structural and MEP (mechanical and electrical) engineering, energy simulation, life cycle costing and assessment are still not available according to the requirements of planning practice and building policy. The intra-firm project-constellation and mostly changing project-stakeholders with each new project, represent challenges for interoperability of new software-tools combinations with each new project. A pre-requisite for a successful implementation of life-cycle oriented planning and management is therefore a smooth and efficient data exchange without information losses.

If the early BIM research was mainly focused on the problem-solving of the software-interoperability and efficient data exchange, the current research efforts are focusing on the change of the planning practice towards integrated design and delivery, which is not only related to the handling of technical, but even more over so to the process-related issues (Succar 2009; Penttilä and Elger 2008; Gu and London 2010). The process-reorganization addresses both the intra- and inter-firm project organization and standardization of the work-flows, role descriptions and related responsibilities of the stakeholders, as well as the general commitment towards collaborative planning attitude. Rekkola et al. (2010) argue, that the actual BIM-benefit lies in the domain of workflow and business practices therefore process-knowledge, beyond the technological issues. Within a case study of university building, 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.

Therefore, the greatest challenge especially within markets still dominated by sequential design and planning method, either for holistic concepts such as Building Life-cycle Management (BLCM) (von Both 2011) or Integrated Design and Delivery Solutions (IDDS) Modell (Prins and Owen 2010), remain with the people (planning process stakeholder) and process – the process of model building of an integrated, interdisciplinary building model requires close cooperation and coordination of the planners, contractors, industry and facility managers, a highly skilled project team as well as detailed conventions on an inter-organizational level (et al. 2010, Plume and Mitchell 2007; Arayici et al. 2011).

Methods

Although a large bulk of literature is implying on the benefits of BIM (Azhar 2011; McGraw-Hill Construction 2010; Becerik-Gerber and Rice 2010; Gilligan and Kunz 2007), the over-all measurement of BIM-related benefits for planning networks and practice is still difficult to justify, due to the high level of complexity of employed tools and of the process, but also due to the lack of a standardized measuring methodology (Jung and Joo 2011; Barlish and Sullivan 2012). The issue of how to measure BIM benefits is especially important in the emerging markets, such as Austrian is, in order to enhance the adoption of the technology and more over the process in the industry. For the adoption in the AEC market the closer research of interrelations within the triangle: technology (operability) – people - process is necessary, in order to create a guideline for BIM adoption, assessment, usability, risks, and evaluation (Gu and Kerry London 2010).

In order to evaluate BIM-performance within an integrated planning process in relation to the technology-people-process triangle, we conducted an experiment with students, simulating a multi-disciplinary planning process for sustainable building within a design-studio class in the winter semester of 2012/13. The experiment is a part of an on-going research project "BIM-Sustain: Process Optimisation for BIM-supported Sustainable Design" involving co-operation of university research and BIM-software vendors and developers. This interdisciplinary collaboration of academy and industry enables development of customised strategic concepts for the individual BIM-settings within multi-disciplinary planning context. The final aim of the project is compilation of guidelines for BIM-supported design and planning. The guidelines will include the conventions for efficient data-exchange and a road-map for the standardization process at Austrian Standardisation Institute (standardization body), recommendations for the planners for the inter- and intra-firm organization of BIM-supported design process, and finally proposals for improvement of interoperability for the software-vendors; based on experiment-findings. Similar guidelines were

	Architect	Structural Engineer		Building Science (Simulation in TAS)	
	CAD	CAD	FEM	CAD	Calculation
1	Allplan 2009	Allplan 2009	Scia Engineer	Allplan 2009	Allplan 2009
2	Autodesk Revit Architecture	Autodesk Revit Structure	SOFiSTiK	Autodesk Revit MEP 2012	PLANCAL Software für Gebäudetechnik
3	GRAPHISOFT ARCHICAD 16	TEKLA	Dlubal	PLANCAL Software für Gebäudetechnik	PLANCAL Software für Gebäudetechnik
4	GRAPHISOFT ARCHICAD 16	Allplan 2009	Dlubal	PLANCAL Software für Gebäudetechnik	PLANCAL Software für Gebäudetechnik
5	Autodesk Revit Architecture	Allplan 2009	Scia Engineer	PLANCAL Software für Gebäudetechnik	PLANCAL Software für Gebäudetechnik
6	GRAPHISOFT ARCHICAD 16	Allplan 2009	Dlubal	Autodesk Revit MEP 2012	PLANCAL Software für Gebäudetechnik
7	Allplan 2009	TEKLA	SOFiSTiK	Autodesk Revit MEP 2012	PLANCAL Software für Gebäudetechnik
8	Autodesk Revit Architecture	TEKLA	Scia Engineer	Allplan 2009	Allplan 2009
9	GRAPHISOFT ARCHICAD 16	Autodesk Revit Structure	Dlubal	PLANCAL Software für Gebäudetechnik	PLANCAL Software für Gebäudetechnik
12	GRAPHISOFT ARCHICAD 16	Allplan 2009, TEKLA	Dlubal	Autodesk Revit MEP 2012	PLANCAL Software für Gebäudetechnik
13	GRAPHISOFT ARCHICAD 16	TEKLA	SOFiSTiK	Autodesk Revit MEP 2012	PLANCAL Software für Gebäudetechnik

Figure 1 Software-combinations used by the teams.

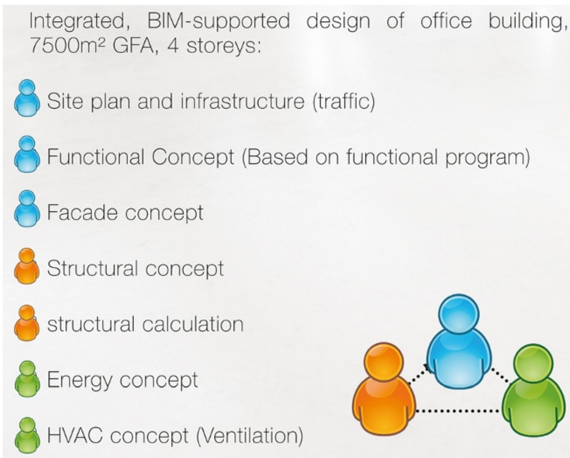

Figure 2 Assignments for each discipline of the team.

compiled by the Penn State within the Computer Integrated Construction Research Program (2012); or the Integrated Project Delivery For Public and Private Owners (2010).

The empirical research by experiment has often been employed to test of BIM-performance and capabilities. Plume and Mitchell (2007) conducted in 2004 an experiment with 23 students in a design studio setting, 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 adaptation for the use of other disciplines or their tools. Further issue needing closer attention is model management – tracing of the changes and updates carried out on the common model. Sacks et al. (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 can be assigned to object-semantic, a similar problem addressed by the Plume and Mitchell (2007).

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).

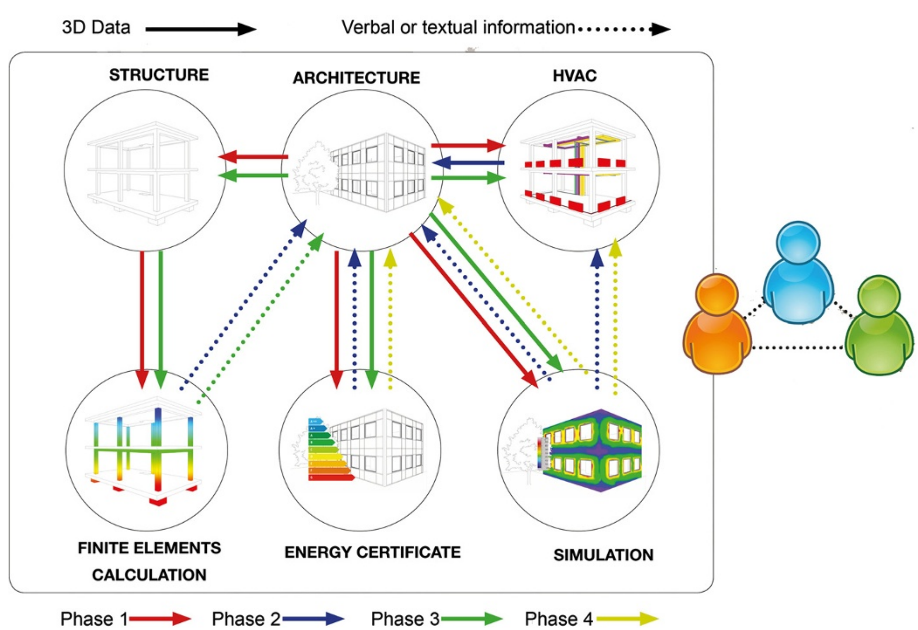

Figure 3 Modelling and data-transfer in multi-disciplinary team.

Peterson et al. (2011) conducted a simulation of integrated project management within two classes at Stanford and TU Twente, using pre-made BIM models in Revit, Tekla and AutoCAD 2006 and 2007 (which in our understanding cannot be considered as BIM models due to the lacking of parametric characteristics), the models were imported in the various cost and scheduling software such as Primavera or Vico.

The formerly mentioned experiments and research of BIM-supported planning practice focus on evaluation of singular issues - some primarily focus on the technology performance (interoperability, building model semantics), such as Plume and Mitchell (2007) experiment and Sacks et al. (2010). Sturts Dossick and Neff (2011) on the other hand focus mainly on the process issues. The student classes carried out at Stanford and TU Twente apply the holistic evaluation, however examine the BIM-supported project management, which in terms of data exchange displays lower complexity than multi-disciplinary design, involving structural and thermal simulation, which both are based on exact transfer of geometry.

In our research, we have addressed the triangulation of the technology, people and process parameters, in order to identify how they are correlated. Therefore, through the experiment the data on a) BIM-performance in terms of data-transferability in different software-constellations will be collected through protocols and revision of delivered models and b) the team performance using different BIM-tools will be assessed through protocols and recorded feedback workshop. The executed experiment is the first one to have a holistic approach on the evaluation of people-process-technology triangle, testing a large number of software tools (all together thirteen) and software combinations on the transfer of complex geometrical data, but also on usability.

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 multi-disciplinary teams 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 the questionnaire a matrix of software-combinations used by each team was compiled (Figure 1).

In the course of the experiment (design class) basically two work-flow models can be identified: One-Platform BIM (proprietary) and Open-Platform BIM (using IFC exchange format). The experiment began in September 2012, the latest available software versions were used. The Open-Platform BIM teams (Figure 1, Teams 3–13) use different, for each discipline typical (custom)

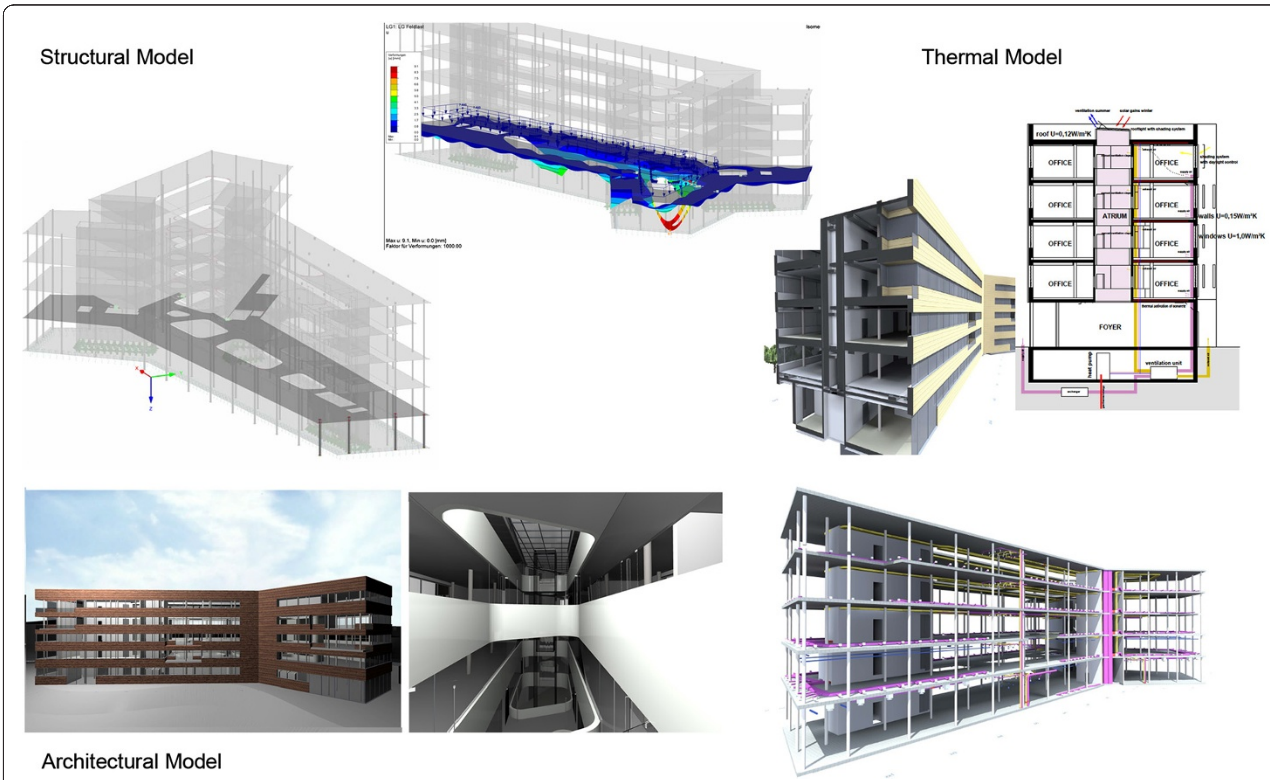

Figure 4 Project example including architectural, structural and ventilation model, Team 3.

software, and work with central architectural model, exchanging the data using the IFC. By central architectural model we mean the physical, architectural model as the point of origin for the further transfer into a) structural, analytical software or b) into the thermal analysis software. The One-Platform BIM teams (Figure 1, Teams 1 und 2) work with one software family Nemetschek Allplan (2012) or Autodesk Revit (2012) using proprietary standards, again starting with architectural model.

The teams are assigned with compilation of the architectural (in Allplan 2012, Revit Architecture 2012 or ArchiCAD16 2012), structural (Simulation in Dlubal REFM 2012; Sofistik 2012 or Scia 2012, drawings in Tekla Structures 2012; Revit Structure 2012 or Allplan 2012), and ventilation (in Plancal 2102 or Revit MEP 2012) models, as well as the light simulation and energy certificate (Figure 2). For the thermal simulation TAS 9.2 (2012) is used, for light simulation Dialux 4.9 and for energy certificate Archiphysik 10. Planning documentation was handed out, 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 in the period of 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 (Figure 3). Between the presentations the reviews with teachers as well as tutorials provided by software vendors are taking place.

Figure 4 presents the final model as delivered by one of the student-teams (Team 3) at the final presentation, including architectural model with visualization, model of loadbearing structure and maximal slab deformation under load, model of ventilation and energy and HVAC concept (Figure 5).

On the level of technology, the experiment is examining the fitness of various software constellations for data transfer, import and export, documenting the data loss and needed rework if data-loss has occurred. In terms of process, the efficiency and efficacy of multi-disciplinary teams working with BIM: efficiency of the employed BIM methods for data-exchange, communication effort, and work-allocation (work-flows); and on people-level

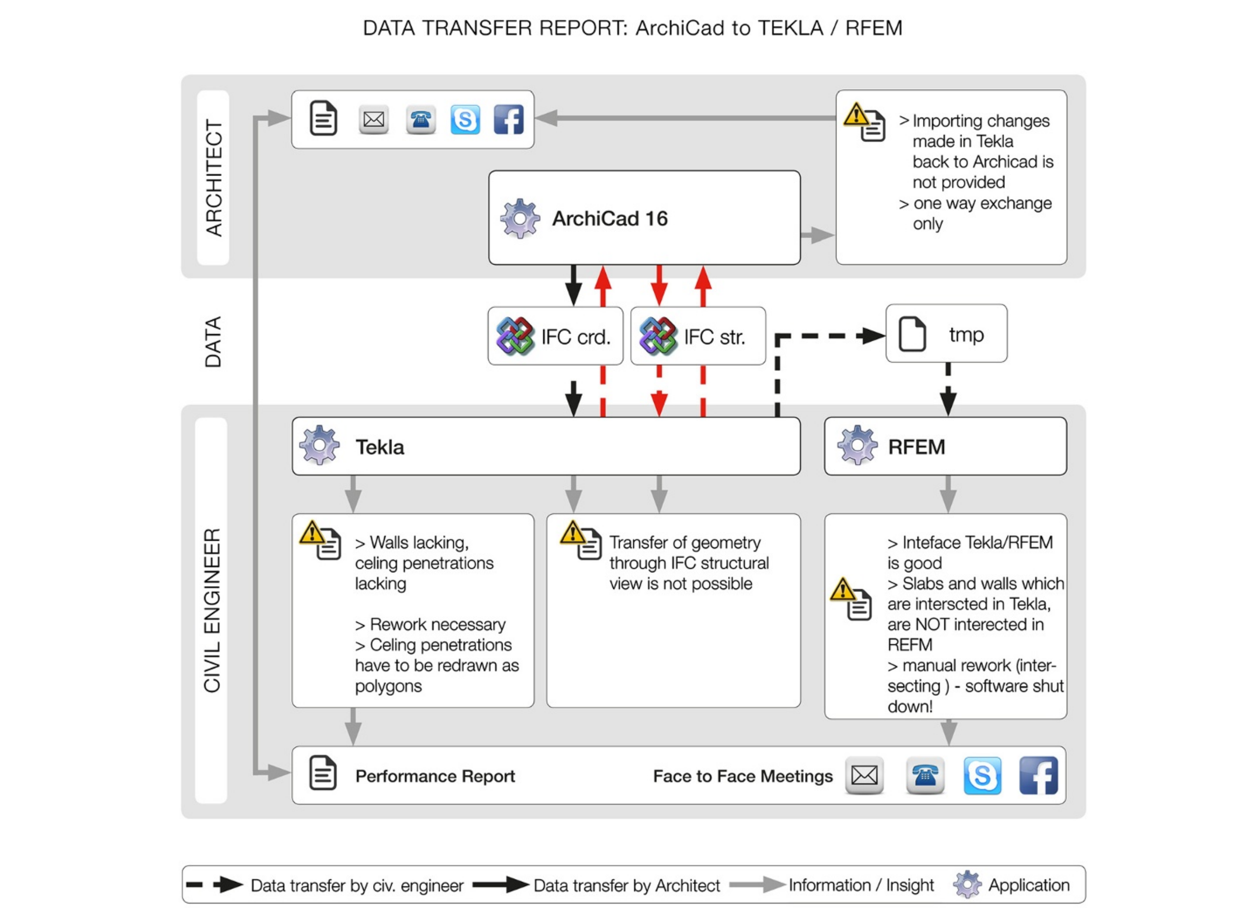

Figure 5 **Mistake tree for data exchange from architectural into structural model, based on protocols, Team 3.**

satisfaction and conflict levels are assessed. 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 (Figure 4). 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.

Results and discussion

People-related problems

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 FEM (Finite Element Method) Software 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 (workflows), d) conflict-level and e) stress-levels were questioned on the scale ranging from 0 (low) to 6 (high) (Table 1).

The general BIM-technology dissatisfaction resulted from data transfer problems, as 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 adaptation of the imported model was equal to the time effort for creation of the new model (two days).

Technology-related problems

When passing architectural geometry into structural analysis software two types of IFC-Files are used: Coordination View and Structural Analysis View (Building Smart 2013). Software for Finite Element Method (FEM) calculation requires the Structural Analysis View of an IFC-File. But only a few CAD-Programs support the export of this type (Table 2). Additionally, not every FEM-Software supports the import of the physical model (Coordination View –Table 3). 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 6). Figure 5 displays a few typical problems when importing from physical (architectural) model into analytic model (structural engineering) – the construction line of intersecting walls is not intersected in the analytic view, which requires remodelling after the import of physical model. This problem originates in the semantics of modelling, namely that architectural models are a set of spaces which require closed elements, whereas structural engineers model a building as a set of loadbearing elements, slabs, columns and plates. Due to this incompatibility it was i.e. not possible to import an Allplan-Model as an IFC-File into the FEM-Software Sofistik, because both programs support the type which cannot be read by the other one.

The IFC 2×3 (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.

For example, problems were the identified with Tekla Structures: stairs become boxes, openings disappear, and round elements become rectangles. Findings from data transfer from Allplan to Scia: 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 7 illustrates the architectural model; Figures 8 and 9 the interpretations by different FEM software - a completely different result when importing the exact same IFC file.

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

Table 2 Compatibility with IFC – Structural Analysis View

CAD		FEM	
ArchiCAD		Dlubal RFM	⇆
Allplan		Scia Engineering	⇆
Revit	⇆	Sofistik	⇆
Tekla	⇆		

Table 3 Compatibility with IFC – Coordination View

CAD		FEM	
ArchiCAD	⇆	Dlubal RFM	←
Allplan	⇆	Scia Engineering	⇆
Revit	⇆	Sofistik	
Tekla	⇆		

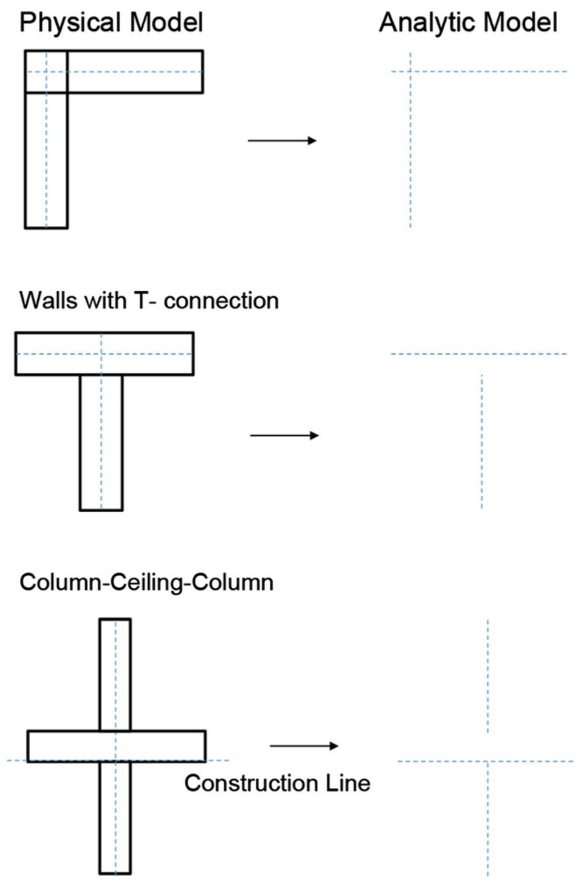

Figure 6 Results from export from architectural model, import in RFM simulation.

Considering the data transfer from architectural model to thermal simulation as the main problem appeared the incompatibility of TAS software with the IFC standard. TAS can only import the proprietary gbxml interface, which again can only be produced by Revit. When working with ArchiCad, Encina plug in for creation of gbxml can be used. In any case – using direct transfer via gbxml or via Encina, numerous problems related to the geometry were identified: walls are not transferred correctly, and were reworked in TAS instead of Revit; missing windows, etc.

Conclusion

This paper presented the first results of an experiment: simulation of BIM-supported multi-disciplinary design for energy-efficient office building, using various BIM-tools for architectural, structural, energy and ventilation modelling, and thermal simulation. 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 to Sofistik, or ArchiCAD to Sofistik (see Tables 2 and 3). For building physics this applies to the Allplan to TAS, since TAS does not support IFC standard, and Allplan does not have plug in or possibility of producing a gbxml file. 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

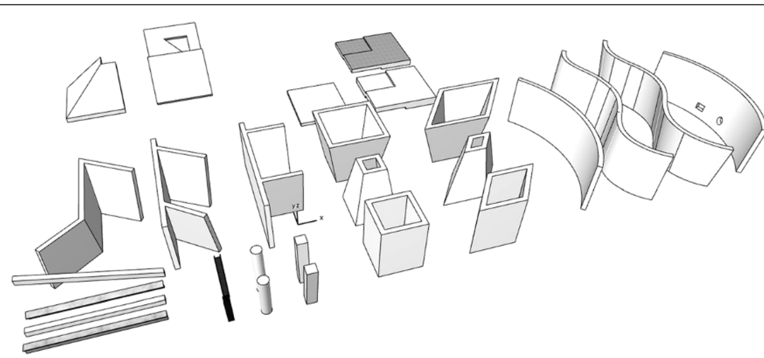

Figure 7 Architectural model from ArchiCAD16a.

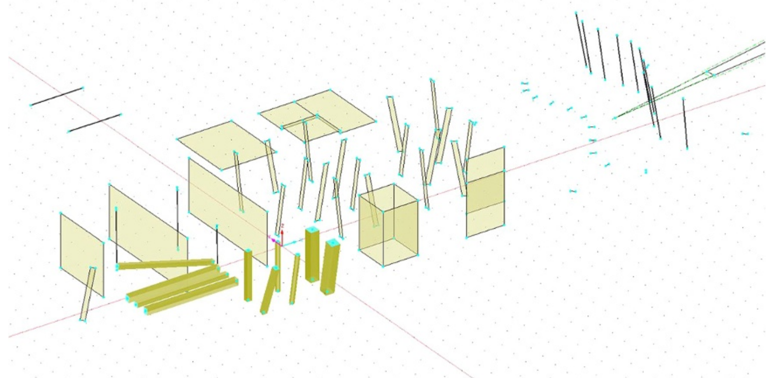

Figure 8 Import in Dlubal REFM.

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 the structural model and under condition that simple geometry is involved.

Our findings in comparison to the student experiment executed in 2004/05 by Plume and Mitchell (2007) show that ArchiCAD has made significant progress (at that time it was very limited in exporting an IFC file, today it is the software with the best functioning IFC translator); 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 and import of IFC; Rosewood experiment works with the same version of IFC. Further development of IFC is urgently necessary, since software-side interfaces are still underdeveloped, as well standards IFC 2×3 and 2×4 are still lacking many information (e.g. surface materials (announced for 2×4), real window frame geometry, 3D wall/slab layers.)

The satisfaction with the BIM-technology at intermediate stage of the design class 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: workflows 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 adaptions 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

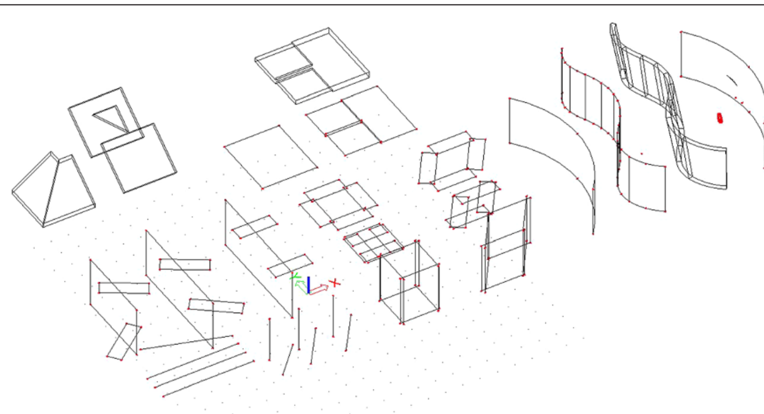

Figure 9 Import in Scia.

with most of the teams, often a bonding between 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 general to the lack of experience and knowledge in 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 the rights (who may change what and when?) related to the change management.

As possible solution of the bi-directional model management the model server architecture is proposed (Kiviniemi et al. 2005). Jørgensen et al. (2008) develop different scenarios for the use of separate models, separate models with aggregate model and one shared model, where rights, accessibility and ownership is exactly defined, however with the limitation of the model server using ArchiCad, as the only software properly handling the IFC import and export.

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. The recorded feed back workshop (interviews) will be coded and analysed, to gain qualitative information on process efficacy, not only efficiency.

In September of 2013 the second experiment will be conducted, in the framework of second multi-disciplinary design class, where we will be able to use the first findings and propose a framework for data-exchange procedures as well as for careful design of communication, including a kick-off workshop for team building. Finally we will compare the results of the two experiments, evaluate the benefits and compile the guidelines for the planning practice and standardization bodies.

Competing interests
The authors declare that they have no competing interests.

Authors' contributions
IK organized the experiment, carried out the survey, evaluated the results and drafted the manuscript. LO and CM carried out the experiment, compilled and evaluated the data. CA supported the experiment-design. All authors read and approved the final manuscript.

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, Construsoft Tekla, Dlubal REFM, Nemetschek Allplan and Plancal. We gratefully acknowledge the work of the academic partners: Institute for Management Sciences, Prof. S. Köszegi and Dr. M. Filzmoser and Institute for Building Physics and Ecology, Prof. A Mahdavi, L. Skoruppa and K. Kiesel, and to the students taking part in this project of Vienna University of Technology.

Received: 20 August 2013 Accepted: 3 December 2013
Published: 13 December 2013

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doi:10.1186/2213-7459-1-13
Cite this article as: Kovacic *et al.*: The “BIM-sustain” experiment – simulation of BIM-supported multi-disciplinary design. *Visualization in Engineering* 2013 **1**:13.