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BIM-SUPPORTED LIFECYCLE-ORIENTED DESIGN FOR ENERGY EFFICIENT INDUSTRIAL FACILITY - A CASE STUDY

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Abstract
The rising requirements on building performance in terms of energy- and resources efficiency result with increasing complexity of design and planning process. The consequence is a large number of planning process stakeholders working with different models and tools, numerous simulations and increasing data-flows. New methodological approach and tools for design and construction process is necessary, in order to provide for more efficient communication and information management. BIM (building information modeling) as tool as well as method promises enables high level of integration and therefore management of complex data and information loads. Research shows that for successful realization of complex projects such as sustainable buildings are, is not only implementation of innovative technology, but also design of planning network necessary.
This paper will present a case study of BIM-use for design and life-cycle optimization of energy efficient industrial facility within research project INFO (Interdisciplinary Research for Energy Efficiency in Production). The research project introduces a holistic approach to the design and planning of energy efficient production facility; developing an integral simulation for analysis and optimization of energy flows form micro (machine) to macro (production layout, building) level. Within the project scope, different Building-Information-Modeling-tools have been tested for design of a parametric, digital building-model. The information embedded in this model was transferred in the first step to thermal simulation- and life-cycle costing models. Based of qualitative analysis of potentials and deficits of the practicability, usability and interoperability of BIM-tools within complex collaborative environments, recommendations for producing and processing building information models serving a multitude of purposes will be presented.
Keywords: BIM, interdisciplinary collaboration, energy efficiency, industrial building, LCC

1. INTRODUCTION

The complexity of the planning and construction process has been evidently rising (Doyle and Hughes, 2000; Magnet et al, 2009); and even more so through introduction of numerous regulations and planning targets for achievement of sustainability. The factors such as ever larger project-size (mega-projects), complex building geometry, and numerous requirements on the building performance with respect to energy and resources efficiency, upcoming number of building certificates lead to a growing number of the planning process participants and disciplines. The spectrum of the implemented specialised tools used by each discipline is consequently rapidly increasing.
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 numerous planning process participants; and eventually to leading to maximization of efficiency- and quality and reducing time effort. (Sebastian and van Berlo, 2011)
BIM (Building Information Modeling) is largely understood as object-oriented digital representation of a building or built environment, which enables interoperability and data-exchange in digital form. However, BIM addresses primarily the process of model-building and information exchange (Succar, 2007). BIM is much more about how (design of design process), that about what (building model and its properties).
The continuous growth of technical possibilities of current BIM-tools positively influences the market presence within planning and building industry sector for such tools. (McHill Graw, 2010) However, despite the large and in the meanwhile unquestionable rising demand for BIM-supported tools by the planning practitioners, the knowledge on the actual design of optimal BIM-supported design and planning process is still lacking in the Mid-European region.
In the practical BIM operation and use the 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 Kviniemi, 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. Much more a guideline for efficient design of design process for optimisation of communication, administration and time-effort is necessary.

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. Closer research of both aspects: technology and design of BIM-supported planning process is necessary.

2. SCOPE OF RESEARCH

The introduction of sharpened regulations and standards on built environment in terms of sustainability (energy- and resources efficiency, increasing of use of renewable energy, reduction of emissions) result in increasing project complexity. Projects participants, numerous specialists for different areas of expertise, are getting more diversified using numerous modeling and simulation tools (Dossick and Neff, 2008). The efficient planning process requires carefully designed communication and collaboration; for which BIM-tools prove to be suitable, enabling interoperability and integration.

A BIM model and BIM-supported optimization process of energy efficient industrial facility, carried out as case study within project INFO (Interdisciplinary Research for Energy Efficiency in Production) at the Vienna University of Technology (VUT) will be presented. The project is supported by the Climate and Energy Fund and aims to realize a systemically integrated model of an energy efficient production facility; simulation and analyzing energy flows from micro level (comprising the production process and the machine tool) to the macro level (involving the production layout and the facility). Thereby, the project consists of five main phases (analysis, modeling, coupled modeling, optimization, and implementation) in which processes, machines and the building will be addressed. As the final outcome of INFO-project, an integrated simulation will be developed, to serve as managerial tool for optimization of energy-, emissions and costs of industrial facility.

The project involves seven institutes of the VUT and ten industrial partners. The institutes cover wide range of specializations, involving faculties of architecture, civil and mechanical engineering and computer sciences. Due to the large diversity of the specialized experts and high level of sophistication of simulation-tools to be employed, it was crucial that the building model, as starting model delivering number of input parameters for integrated simulation fully supports interoperability and offers interfaces for further models, to be carried out in e.g. Modelica (2012), Trnsys (2012) and Energyplus (2012).

Different BIM-tools have been tested for design of a parametric, digital building-model. Using the information implemented in this model, further simulations for thermal simulation and life-cycle costing through scenario based design were carried out; after which the initial model was optimized.

The case study-evaluation of the implemented BIM-model will be based on evaluation-model developed by Rekola, Kojima and Mäkeleinene (2011); developed on BIM and IPD implementation case-study of university building project. There an evaluation–framework of technology-, process- and people-bound problems and benefits was developed; where as process is described by workflows, timing, procurement, contracts; people are related to competences, skills, knowledge, communication; and technology to software (tools).

In our case study following evaluation-model will be proposed:

- Technology-related issues of tested BIM-tools: practicability, usability and interoperability for data exchange formats IFC (Industry Foundation Classes) (BuildingSmart, 2012) and gbXML (2012) interfaces
- Process- and people- related issues: communication, coordination, network-organization, workload distribution

Finally, after identification and qualitative evaluation of problems and potentials of BIM-implementation within research project a way of producing and processing building information models serving a multitude of purposes for life cycle optimization of facility will be present.

3. METHODOLOGY AND MODELING PROCESS

The systemic integrated simulation for energy efficient industrial facility; as final outcome of INFO project will be using holistic, life-cycle oriented approach in optimization of energy consumption and performance of an industrial facility. In order to compile a holistic model for the integrated simulation, main optimisation-fields were defined: machines and production system, energy systems and building. On a case study of existing production facility, these fields were analysed in terms of energy flows, occupancy rates and functionality; based on the gathered data a conceptual model for optimised facility was carried out.

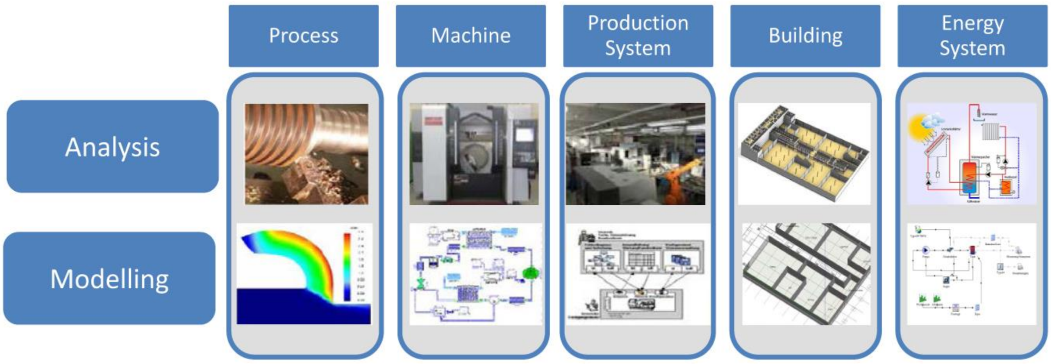

Figure 1: Optimization fields as subcomponents of integrated simulation (Kovacic, Leobner et al, 2012)

As first step in modelling process of optimised facility the conceptualisation of new building was chosen, in order to provide input parameters for the integrated simulation, such as:

- building geometry (orientation)
- information on building hull (percentage of transparent vs. translucent areas, U-values) , function (occupational rates, number of people/m²)
- energy performance (loads of machines, lightning and HVAC facilities).

In order to provide a large amount of “intelligent” data, easy to handle and to transfer, we decided for BIM method for design and representation of the building and HVAC (heating, ventilation, air-conditioning).

The conceptual design of new building model started with analysis of the existing industrial facility in terms of work-flows (delivery, storage and production), energy-flows, emissions (oil, dust, humidity, noise and heat losses), occupancy parameters (working hours and shifts for offices and production). A pre-design of the facility was compiled upon briefing process with client, involving workshops and interviews, after which functional and spatial program was compiled. Finally, a real layout, considering the location and infrastructure (public and private transport, delivery and logistics) together with building orientation and micro-climatic conditions has been developed as BIM, parametric 3D model allowing the representation of interactive, data-rich elements.

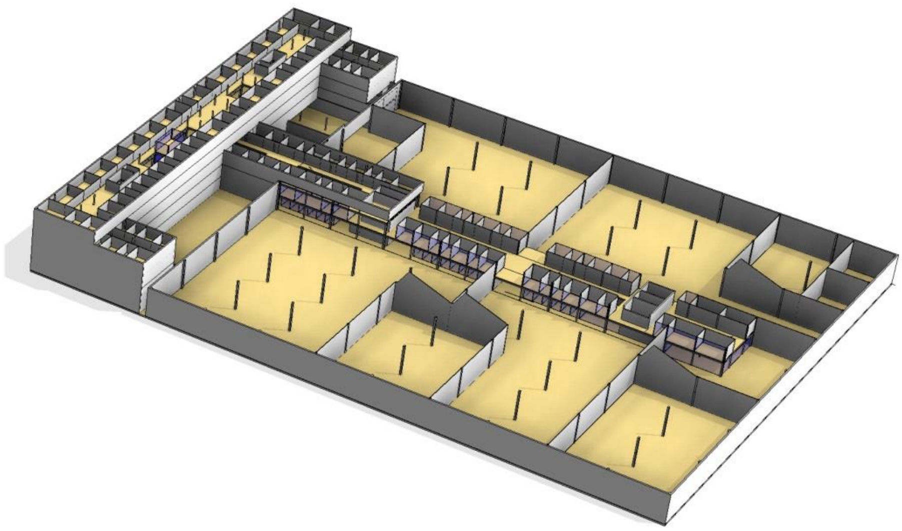

Figure 2: BIM-model of industrial facility

For the BIM-modelling of the facility Autodesk Revit (2012) and ArchiCAD (2012) were employed, for comparative evaluation on technology-aspects: usability/practicability and interoperability.

Special focus in the modelling was put on the design of façade as of determining element for corporate image but at the same time energy efficiency through quality (U-Value), percentage of glazing (solar gains), shading, free ventilation and -cooling through operable window-elements. Tree variants were developed based on web-based investor-inquiry, determining the key design and performance indicators for industrial facades for investors. The facades were built up as parametric building element-sets; replaceable per one click-access.

Façade type	Exterior panel	Insulation	U-value [W.m-2.K-1]
A	Metal	Mineral wool	0.26
B	Metal (zinc coated)	Polyurethane foam	0.1
C	Metal (zinc coated)	Wood fiber insulation panel	0.27

Table 1: Overview of facade typologies

The finished 3D parametric model was handed over to building physics department, for thermal simulation of internal loads, to be carried out in Energyplus. To enable data transfer to thermal simulation, the gbXML interface based model was crated from both BIM-models.

Due to the numerous problems of the gbXML model mostly resulting from the too complex geometry (Figure 2), the model was redrawn in simplified rectangular geometry directly in Energyplus by the building physics partner.

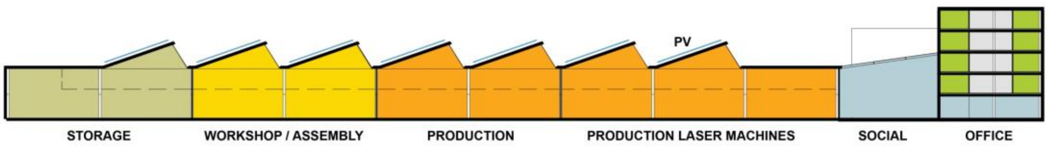

Figure 3: Shed-roofs in longitudinal section of facility

The results of simulation were handed over to architectural team in form of xls-based lists; upon which the facades were optimised. (U-Values neglected, external shading and operable windows provided); and life-cycle cost were calculated in specially customised xls-based IEEFA tool (Waltenberger, 2011).

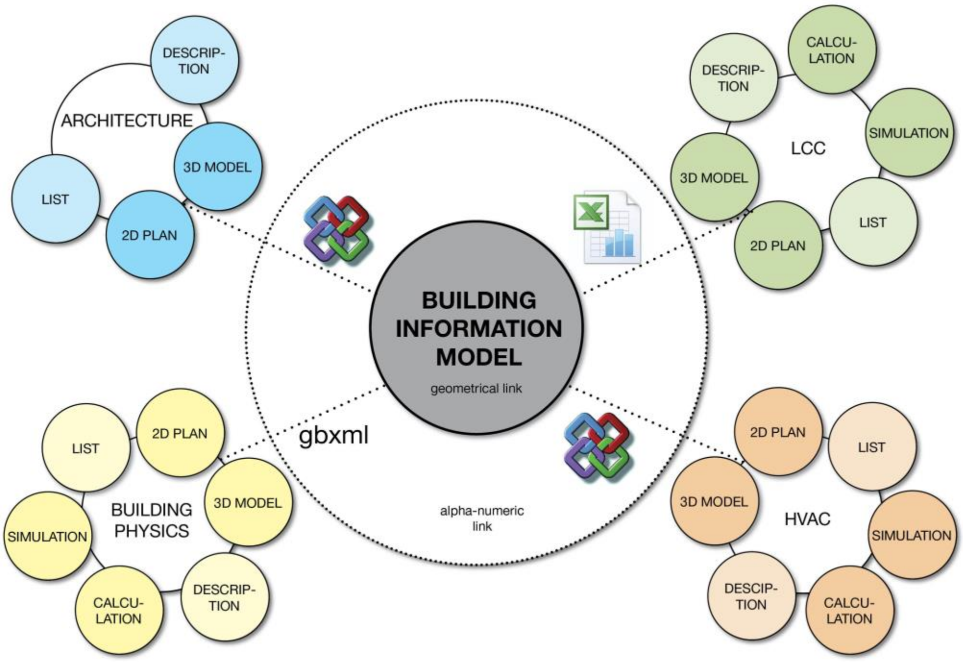

Figure 4: BIM-process as implemented in the case-study

4. FINDINGS AND RESULTS QUALITATIVE EVALUATION

4.1 Technology related issues:

- Usability/Practicability

Usability and practicability were tested in terms of user friendliness, intuitive operation, support and service.

- Interdisciplinarity

The issue of interdisciplinary work was evaluated through aspects of BIM-tool related capabilities for architectural, structural and HVAC design.

It was not possible for MEP engineer to work with provided BIM models, so 2D Autocad drawings were provided; resulting with additional drawing effort for architectural team, consequent changes will not be possible in parametric manner, but will have to be executed manually (increasing the effort and time spent on change management).

- Interoperability

For the aspect of interoperability IFC interface as the most relevant interface was tested.
It was possible to generate IFC models from both Revit and ArchiCAD; however Revit was incapable of importing IFC model.
The tested gbXML interface could be evaluated as still not mature enough. The complexity of geometry, such as round pillars and shed-roofs caused problems, reflected in exorbitant file

sizes and open geometries in energy plus, which again disabled the simulation. gbMXL was equally inefficient from both models (Revit and ArchiCAD).

This was reflected in increase of drawing effort, since the building had to be redrawn in simplified geometry by the physicist.

BIM-models, as primarily architectural models tend to be too detailed in the representation and of too small granulation for the simulation. Architectural models use room stamps per room, where as the simulation needs the partition into (thermal) zones – again simplification is necessary.

Criteria:	Revit	ArchiCAD
Usability	+	++
Data exchange between different BIM-Software (IFC)	-	++
Capabilities Architectural Design	+	++
Capabilities Structural Design	+	-
Capabilities HVAC Design	-	-

Table 2: Qualitative BIM-evaluation of technical benefits and problems

4.2 People- and Process

The technological problems have immediate impact on people- and process related issues:

In order to provide functional process and data transfer, significant communication and coordination effort was necessary. The disciplines needed to find conventions on data- and model- representation, to provide for more efficient planning process. Simulation is especially effected by the need for conventions, due to the high level of simplification of architectural model.

The proceeding tested in this case study was “one-way” BIM, since only architectural team was using BIM, all others 2Dcad, xls-lists or customised xls-based tools. Automated optimization was not possible, since BIM was used as “one-way ”, but only manual for which again feedback was necessary, occurring in workshops, meetings etc. Result was significant increase of communication and loss of productive time. Through several feedback loops (repeated cycles of optimization – simulation – adaptation) the errors in input-data for simulation started increasing, resulting with uncertainty and finally in lack of trust in generated data. The danger is that “one-way”-BIM ends as “dead-end” BIM.

5. CONCLUSION

The BIM-implementation tested in this case-study was atypical, since used in research environment, and not in business-as-usual planning practice. Therefore, it was not bound to the strictly predefined boundary conditions concerning efficiency, time- and cost- limitations (budget) which often increase conflict-potential through high stress-levels of planning teams when adapting new technology.

It can be said, that the test was carried out in BIM-optimistic environment, which again should (positively) influence qualitative evaluation. Despite this BIM-approving setting many problems on both technological as well as process related level were identified.

The key factor for efficient implementation and use of BIM within holistic planning- and simulation process is careful design of the actual process; which should precede the actual planning. In number of workshops the exact scope of action and level of detailing for specific representations (disciplines) to be extracted from BIM model should be determined. In this way unnecessary multiple editing can be avoided. Further on, more effort should be put into definition of work-flows and responsibilities of stakeholders within work-flows (who does what?).

Great potential is to be seen in further development and interoperability of BIM-add-on tools for energy-optimization and calculation such as Archiphysik (2012), which extracts geometry, masses and functional units from BIM model for calculation of energy demand and energy certificate.

The increasing requirements on prediction and optimization of life-cycle costs can also beneficially use data richness of BIM model. Through compilation of several options within short period of time; option based planning is enabled, difficult to carry out in the past due to the lack of time-resources for thorough calculation.

The greatest criticism can be addressed to the use of “one-way-BIM” against the “fully-integrated” BIM where all disciplines would work simultaneously in one BIM-model; instead of generating and extracting the necessary information form a BIM-model and feeding it back by alpha-numerical data. Such proceeding requires higher-information-rich transfer mechanisms, such as seminars, workshops, committees, formal and informal meetings and video conferences, because of the information-complexity, which again is time consuming and costly, with increased probability of errors. Therefore, we argue a “fully-integrated BIM” Model is most beneficial for efficient, interdisciplinary planning process; requiring however precise design of design process.

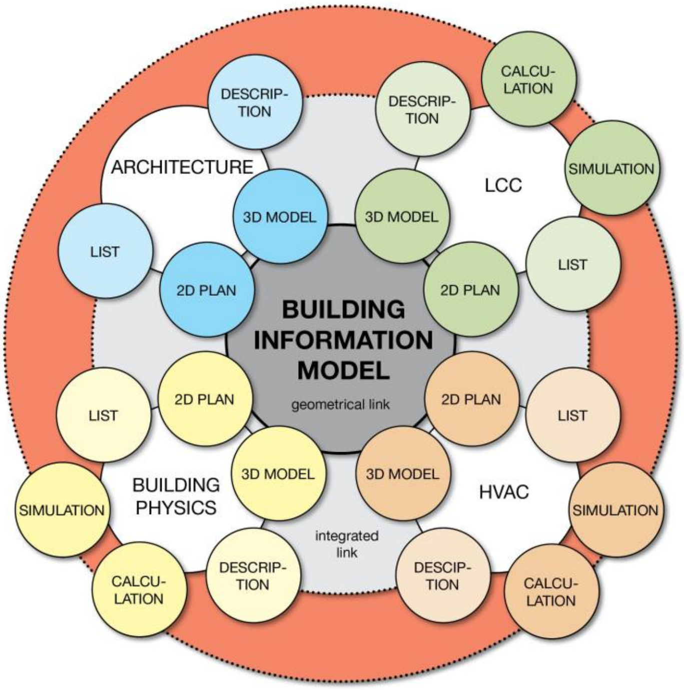

Figure 5: "Fully-integrated" BIM-Model

The full scope of BIM-benefits will be assessed after completion of integrated simulation, which will show additional value of data rich model and potentials to carry out time saving evaluation of large number of options.

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