Building Information Modelling for Design and Analysis of Energy Efficient Industrial Buildings

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ABSTRACT

Building Information Modelling (BIM) as emerging technology, bearing promise to reduce the fragmentation of the architecture, engineering and construction (AEC) industry, is thereby enhancing integration and enabling life cycle management of buildings. BIM model serves as a joint knowledge database for the interdisciplinary planning team, involving designers, structural and HVAC engineers, facility managers and other; where data transfer between various models as well as non-CAD tools and simulation software is possible. Thereby BIM bears largely still unexplored potentials to significantly improve over-all energy and resources efficiency of buildings along the life-cycle.

Particularly beneficial is adoption of BIM for design, planning, optimization and management of industrial facilities, where multiple layers of interacting complex systems (building, HVAC and machine floor layout) need careful modelling and management in terms of collisions, change management and multiple adaptions due to the short product-life cycles.

Industrial buildings consume much more energy than other building typologies - the need for powerful modelling, prediction and optimization tools for identification of synergies between the building hull, HVAC systems and production systems is urgent.

This paper explores the potentials and deficits in the current practice of BIM use in the design and analysis and optimization of energy-efficient industrial buildings through case study research of two industrial facilities. So called BIM to BEM approach is thereby applied. As identified problems the varying needs concerning the Level of Detail (detailing of the building model) and semantical differences in the modelling procedures of part-taking disciplines (architecture, structural engineering or simulation) were identified; as well as time pressure as one of the main reasons for defects of building models. In order to improve BIM to BEM not only interoperability issues of the software has to be improved, but moreover, the redefinition of the design process and enhancement of individual capabilities is necessary.

KEYWORDS

BIM, BEM, Industrial Construction, Thermal Simulation

List of Abbreviations

AEC	Architecture Engineering Construction
BIM	Building Information Modelling
BEM	Building Energy Modelling
HVAC	Heating Ventilation Air-Conditioning (Engineering)
TBS	Technical Building Services
MEP	Mechanical Electrical Plumbing (Engineering)
GFA	Gross Floor Area

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INTRODUCTION

BIM (Building Information Modelling) is an emerging software and planning procedure in the AEC (Architecture, Engineering and Construction) industry, bearing large potentials for integration and management of building processes and products along the life cycle. It 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 leading to maximization of efficiency, quality and reducing time effort [1].

The common understanding of BIM terminology in the AEC industry in both practical and academic realm is multifaceted: as the "new CAD"- an advanced version of digital drafting tool or in more advanced viewing as the building modelling tool providing possibility of interaction with non CAD-based tools, such as quantity surveyors or project management tools [2]. The academic community tends to see BIM as the process with focus on model-building and data exchange, or according to [3] "… is a methodology to manage the essential building design and project data in digital format throughout the building's life-cycle." (pp. 403). BIM is often mentioned in relation to building product modelling which is a predecessor terminus to BIM, dating already from the 80ies [3]. The product models address the object-oriented modelling of the data-rich building components, incorporating 3D geometries, spatial information, thermal values, and material properties; upon which the data interoperability builds up [4].

BIM is largely understood as object-oriented digital representation of a building or built environment, which enables interoperability and data-exchange in digital form [5]. In this context BIM addresses primarily the process of model-building and information exchange [6]. Thereby the development of functioning and open interfaces is one of the major tasks in the advancement and successful adoption of BIM technology in the industry. One of the most important, open non-proprietary interfaces is the Industrial Foundation Classes (IFC), developed and supported by buildingSMART (International Alliance for Interoperability) which also certifies the BIM software for IFC-import and export ability. Despite the efforts towards providing maximum interoperability and advancement of the IFC standard, due to the very fragmented AEC market and the lack of process integration software-interoperability remains one of the greatest challenges for successful BIM adoption. A large number of software still offers proprietary, software-specific interfaces, trying to provide in such way one-stop shop solution in form of "One-Platform-BIM".

Particularly beneficial is adoption of BIM for design, planning, optimization and management of industrial facilities, where multiple layers of interacting complex systems (building, HVAC and machine floor layout) need careful modelling and management in terms of collisions, change management and multiple adaptions due to the short product-life cycles.

The most commonly utilized tool for modelling of industrial facilities is the Autodesk REVIT [7] software, which offers architectural, structural and HVAC modules (Revit MEP); in so called One-Platform-BIM, reducing in this way the data transfer via interfaces. Despite the One-Platform solution for the facility side, the tool (equipment) and shop-layout suppliers use wide range of various software tools, most of which are not IFC capable, which poses large problems for BIM utilization in industrial construction.

This paper presents the BIM-potentials for design and energy-optimization industrial construction on a case study of two industrial facilities. The aim was to evaluate the modelling process and interfaces from BIM (Building Information Modelling) to BEM (Building Energy Modelling) and test the suitability of the models as joint knowledge base for life cycle management of architectural, HVAC and floor-shop models.

LITERATURE REVIEW

Use of BIM for design and lifecycle management of industrial facilities is increasing the practice, however due to the confidentiality and data protection there are still a very few published studies identifying the potentials and limits of BIM in industrial construction.

[8] identify the BIM potential for lifecycle management of industrial parks in Taiwan, underlining the advantages of combining the BIM based visualisation, GIS and ICT solutions, for successful management of industrial parks. The multi-modular system architecture offers navigation support, utilities and facilities are modelled with BIM, whereas the uses can retrieve drawing and attribute data in real time of e.g. pipeline and utilities systems. [9] explore the possibilities in the design of industrial facility from the pre-design (workshop design) till construction using Autodesk Revit Software, and interface (DXF) towards workflow-software for optimization of production-workflows. The parametric model delivers statistical and analytical data, maintenance drawings etc.

Especially interesting is the use of BIM for design of semi-conductor production facilities, due to the very short planning and construction time horizons (10 months from pre-design till take over) – where BIM can show advantages in reduction of planning time through reduction of changes (visualization of collisions, automated extraction of cost- and time relevant data) and allowing coupling of the facility supply with the tools. On the concrete case study of semi-conductor facility the information of the tool supplier, facility- and tool-layout designer was exchanged using BIM [10]. Tool Information Model was imported in Revit MEP application (facility supply model) testing the Industrial Foundation Classes (IFC) interface; however it was found that the IFC standard does not match the SEMI Standard (semi-conductor industry standard) thus allowing the data exchange only in one way.

A special focus of this research is the use of BIM for energy-optimization of industrial facilities based on holistic approach, including consideration of waste heat from machines, machining processes, occupancy related interior gains as well as solar gains [11].

The utilization of BIM for semi-automated or even automated building performance modelling and analysis is an increasing research topic in the academic community, due to the BIM potentials for integration of the geometrical, material, technical, structural, and HVAC data on the one hand, and increased requirements, and policies for energy and resources-optimized construction on the other [12, 13,14].

The interoperability and data-transfer as well as ease of use from BIM to BEM systems play a crucial role, in order to reduce the re-modelling efforts and easy creation of building energy models [15]. Lack of interoperable interfaces represents one of the major problems, since thermal simulation tools such as TRNSYS, EnergyPlus, Ecotect and similar expert tools still do not support the open IFC interface [16, 17, 18].

Experiment results on the interconnection of BIM and Building Energy Modelling (BEM) tools showed that there are often problems in data transferability such as error-prone geometry or loss of information (e.g. semantic properties) [19, 20]. BIM models contain a greater degree of information than required and can be translated for a thermal energy analysis [21] – displaying too high Level of Detail.

The numerous semantical modelling problems in data transfer from BIM to BEM are mostly related to the varying boundaries for the room stamps and thermal zones – in architectural model a room stamp identifies an area in m^2 of a specific functional unit (interior boundaries of walls) whereas the building energy model needs a thermal zone definition, which includes the outer wall-boundaries; further on wrong interpretations of geometry and related change management issues [19].

Automated and semi-automated processes for error free data transfer have been developed to assist BIM-BEM software communication without human intervention [15, 22], however these require custom software plug-ins and programming skills or a specific design methodology during the creation of the BIM model [14], an attribute that existing BIM models, designed by planers and architects, do not have. In the practice BEM models based on BIM data export are intensively reworked by simulation experts in order to be used for further analysis, this though bears the risk of arbitrary building definitions based on the person's understanding and expertise and is also time consuming. Several tools have been already introduced for BIM-based and supported simulation and analysis, such as the semi-automated SBT tool supporting IFC interface [14]; or a simplified Revit Plug-In DPV as a for energy optimization in the early-design stages [12]. However non the mentioned tools have found wide application in the practice, due to the formerly mentioned reasons – the knowledge-transfer gap between the partaking disciplines or due to too large challenges for the state-of-the-art design process.

CASE STUDY

In order to evaluate the potentials of BIM for design and energy-optimization of industrial facility, a case study methodology was used. The cases include an existing construction (Case B), where an own BIM model was created based on the provided documentation (AutoCAD and PDF) and a new industrial construction (Case M), with pre-modelled architectural and TBS model.

The Case B (Figure 1) is a partially historic metal-cutting and forming production facility, with numerous additions dating from varying periods, for which own BIM model was created based on the existing documentation (PDF or dwg plans) and transferred to BEM - Energy Plus via Sketchup [17, 23] (Figure 2). The Case M (Figure 3) is a new construction of a food industry consisting of two blocks – bakery and meat factory. For this case an architectural model (Autodesk Revit) was obtained from the architectural office, and had to be re-modelled in Sketchup for the BEM purposes (Figure 4). Table 1 displays the basic data on the cases, such as gross floor area (GFA), volume, building envelope characteristics, and year of construction.

Table 1. Description of the CASES

	CASE B	**CASE M**
	Historical Metal-band Cutting and Forming Factory	New Construction Bakery and Meat Fatory
GFA	20.273 m2	28.526 m2
Volume GV	200.854 m3	173.710 m3
U-Values Facade	Existing Hall outside 600 mm solid brickwork 1400 kg/m3 20 mm cement plaster **U-value: 0,833 W/m2.K**	Bakery Facade outside 30 mm wood sheathing 100 mm air gap 240 mm EPS rigid foam insulation 300 mm reinforced concrete **U-value: 0,438 W/m2.K**
	New Hall outside 35 mm trapezoidal sheet metal 30 mm air gap – fasteners 100 mm stone wool insulation 6 mm cassette profile **U-value: 0,353 W/m2.K**	Bakery Offices Façade outside 140 mm wooden prefabricated element (beech-oak) 180 mm EPS rigid foam insulation **U-value: 0,187 W/m2.K**
	New Polishing Hall (Refurbishment) outside 35 mm trapezoidal sheet metal 30 mm air gap – fasteners 150 mm stone wool insulation 6 mm cassette profile **U-value: 0,233 W/m2.K**	Meat Factory Façade outside 140 mm steel PUR 30/035 foam sandwich façade panel **U-value: 0,240 W/m2.K**
		Meat Factory Offices Façade outside 60 mm middleweight concrete 1800 kg/m3 80 mm reinforced concrete 60 mm middleweight concrete 1800 kg/m3 140 mm steel PUR 30/035 foam sandwich façade panel **U-value: 0,232 W/m2.K**
Year of Construction	In different phases from 1900 until 2015 A: Historical part 1900-1920 B: before 1930 C: 1997 D: 1999 E: New polishing hall 2015	2012-2013

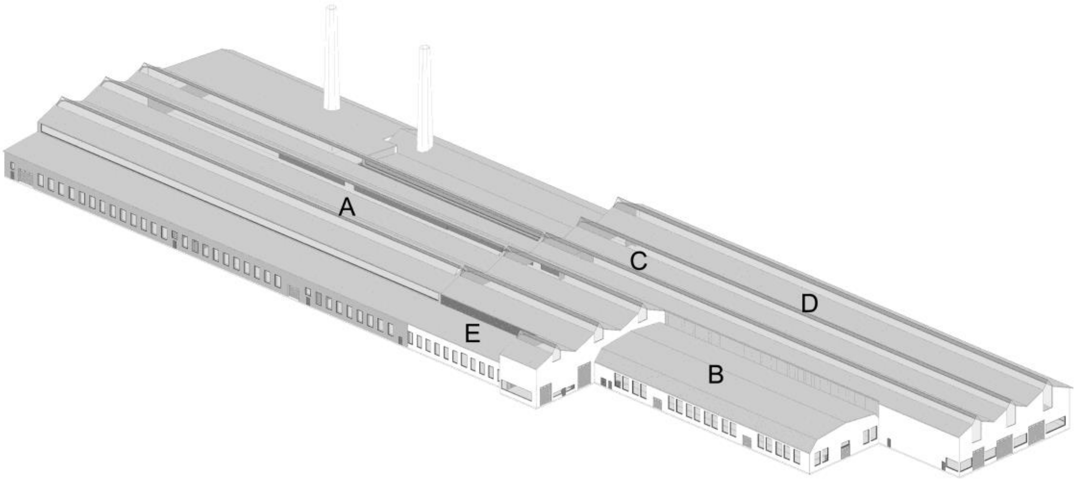

Figure 1. Case B – architectural model in Revit, newly modelled

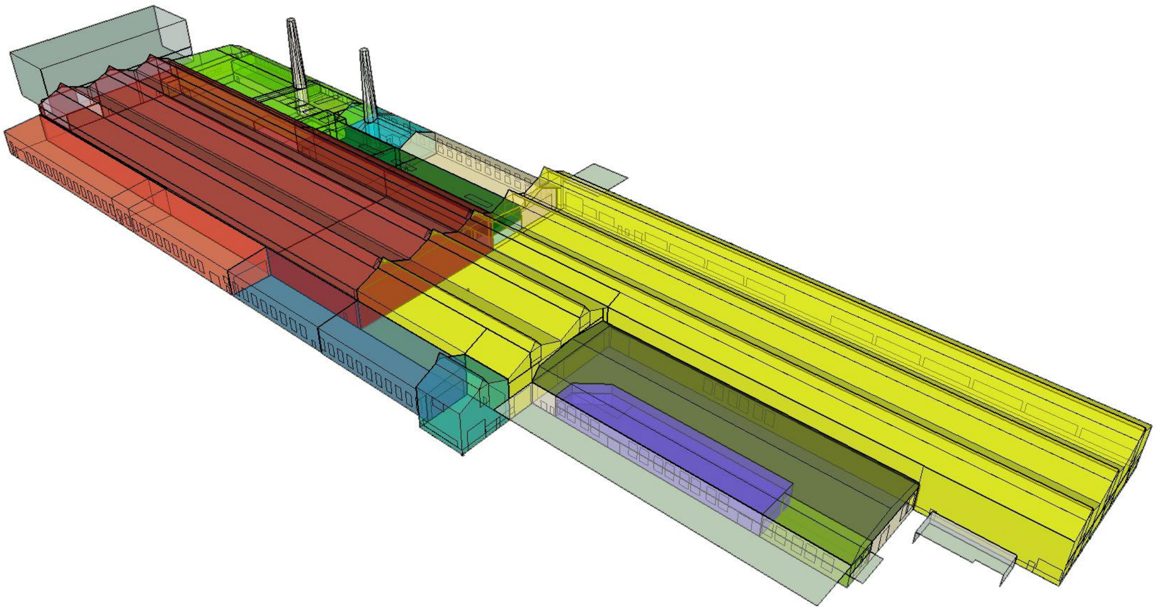

Figure 2. Case B – BEM model of thermal zones

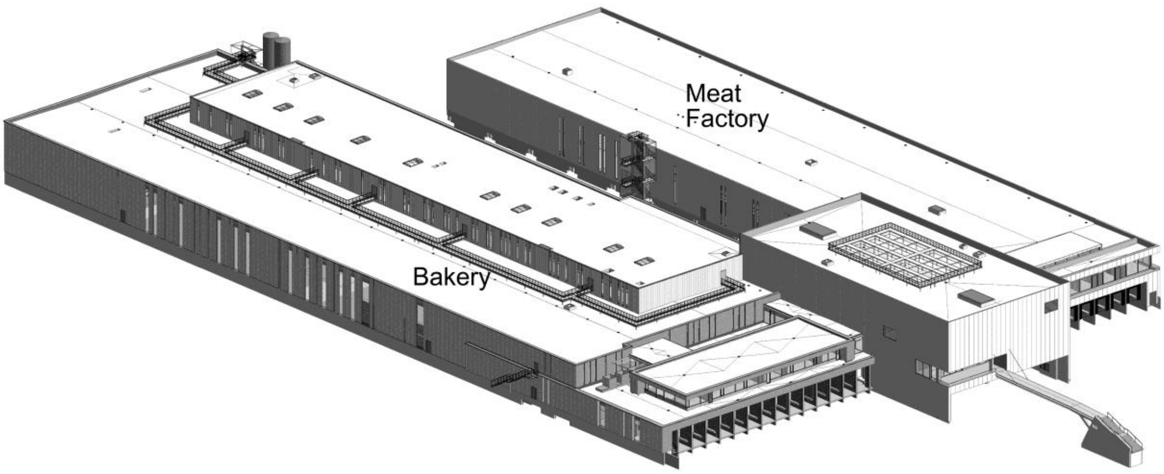

Figure 3. Case M – architectural model in Revit, as obtained

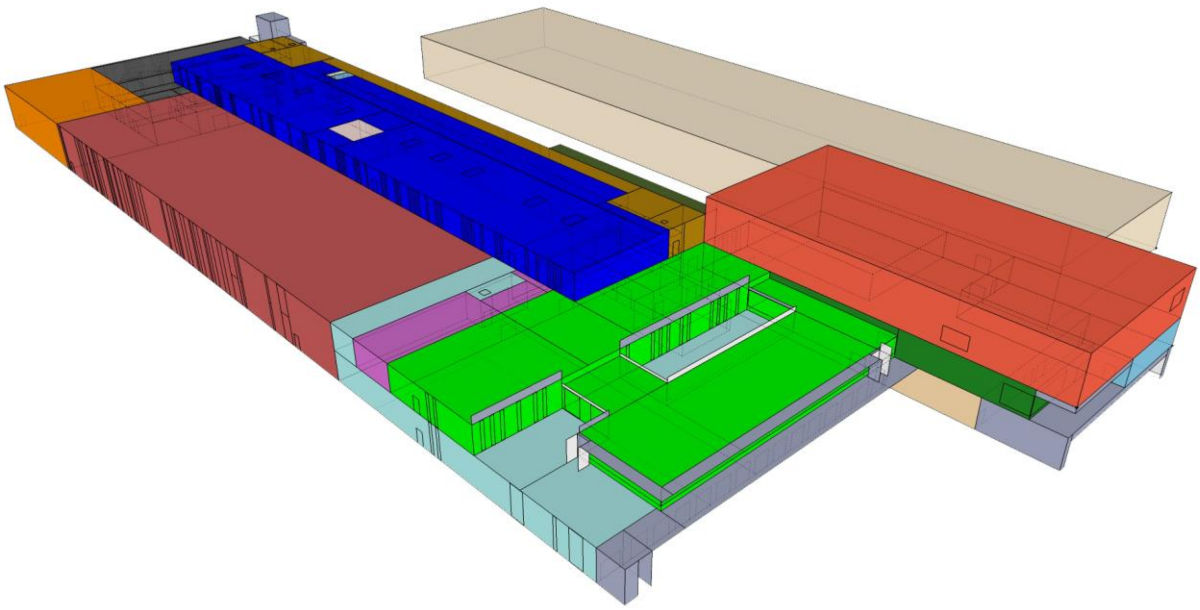

Figure 4. Case M – BEM model of thermal zones

The software used in the modelling process included on the BIM side the Autodesk REVIT for architecture and technical building services (TBS); and the EnergyPlus via Sketchup and OpenStudio Plug-In (Part of EnergyPlus) for BEM (Figure 5). The BIM models were transferred in the thermal simulation software by creating the building energy models (or re-modelling the BIM-models) and finally assessing optimization potentials; observing and recording the process using so called mistake trees.
The greatest challenge thereby is the simplification of the architectural models, and re-definition of the boundaries necessary for the thermal zones-definition as needed by the simulation, as well as the application/transfer of the material and construction bound data.

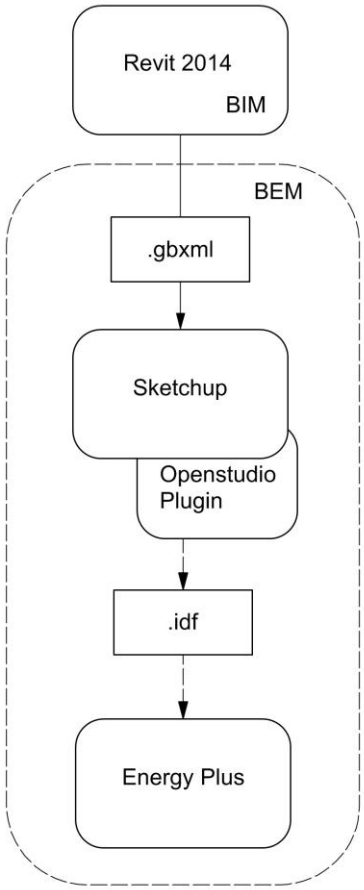

Figure 5. Work-flow with Software constellations applied in the modelling process

The BIM model (geometry) of the cases was exported via Green Building XML (gbXML) format in OpenStudio plugin for SketchUp, a tool that has direct connection with the simulation engine of EnergyPlus (Figure 6). The procedure from BIM to energy analysis software in many cases requires manual corrections at the middle stage of the transition as the geometry and space boundary information can contain errors that affect the simulations input data, as was the case for the Case M. In the Case B, where the BIM model was initially designed in order to be exported in external software; the inconsistencies were kept to a minimum level. Semantic properties of the building elements were applied directly on the EnergyPlus models as it was not possible to export them via gbXML from the BIM model (e.g. thermal conductivity, density and specific heat capacity of constructions' layers).

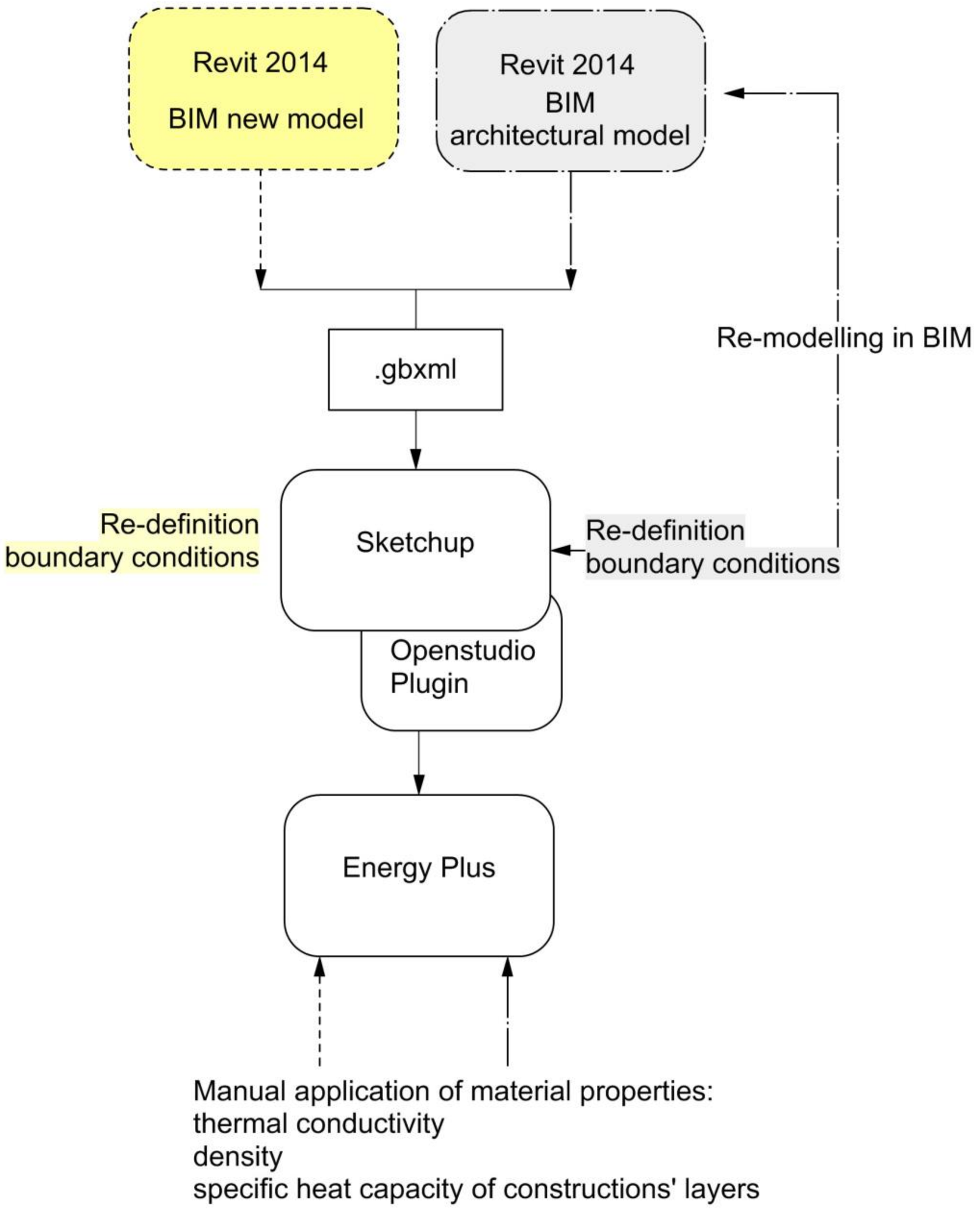

Figure 6. Work-flow, recording the modelling process and transfer from BIM to BEM

The following mistake tree (Figure 7) thoroughly analyses the transfer and re-modelling process or adoption steps necessary to obtain a functioning model for both cases.

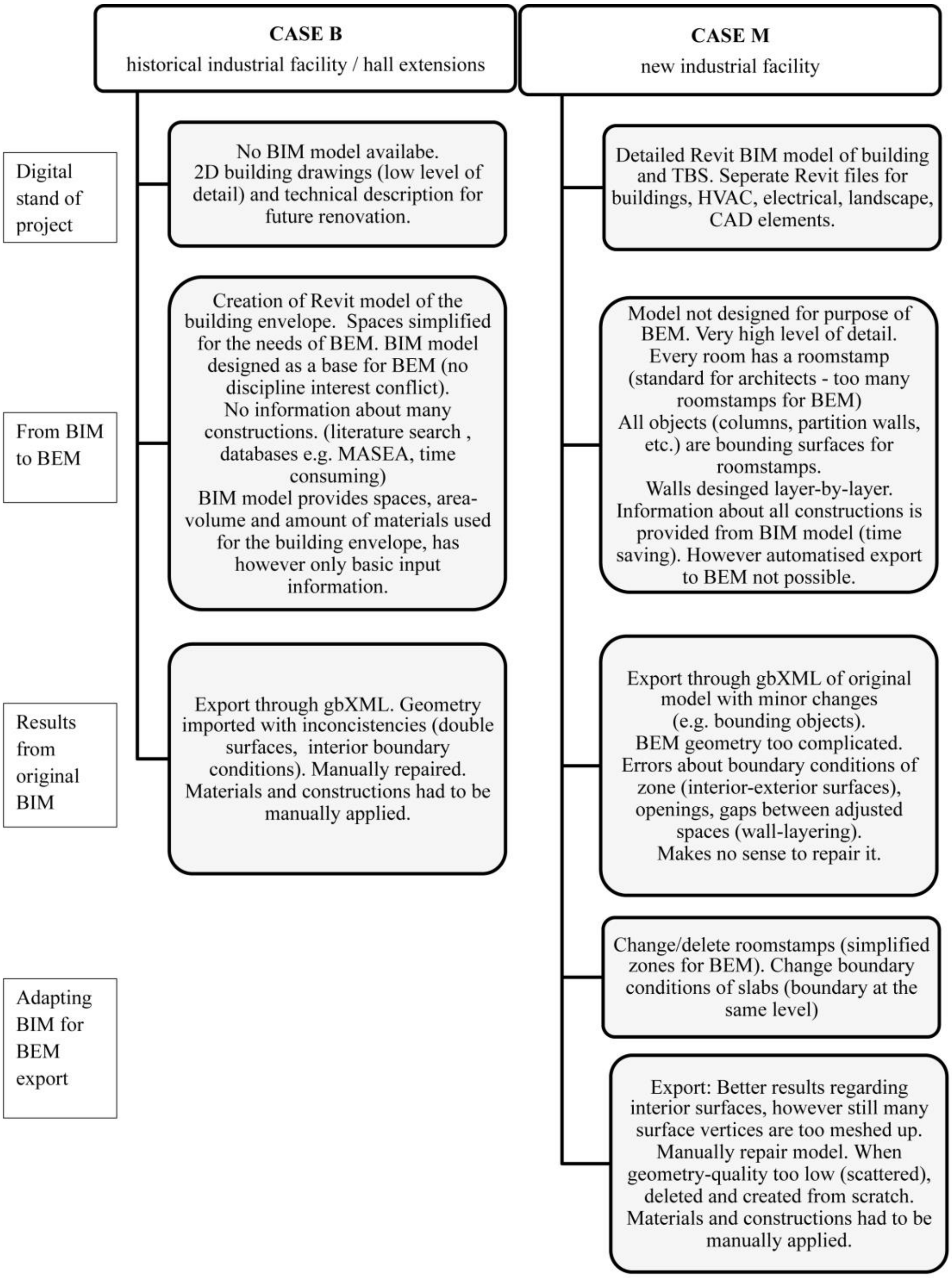

Figure 7. Mistake tree, recording the modelling process and transfer from BIM to BEM

DISCUSSION

On a case study of two industrial facilities, BIM software and modelling process was applied and evaluated for suitability for energy-optimized design of industrial facilities. In the first step the architectural and TBS modelling was carried out, in the second step the building performance analysis and optimization, through so called BIM to BEM approach – architectural digital building model was transferred into building energy model system, for analysis and simulation. Thereby following observations of the modelling process were captured using mistake-tree technique.

The new facility – Case M - was "pre-modelled" by the architectural office, without knowledge that later on a thermal simulation will be undertaken. Thereby the modelling did not consider the specific modelling requirements of thermal simulation software displaying too many room stamps and boundary surfaces. This resulted with many geometrical errors in BEM model; finally requiring significant re-modelling efforts of both original model and BEM models by the building physicist.
The existing facility – Case B - was modelled and analysed out of "one hand", which resulted with immediate creation of customised, simplified model; however this model is not fit for the architectural purposes due to the oversimplification. Despite the simplified modelling in Revit, the boundary conditions of BEM model still had to be repaired after gbXML export.
In both cases the materials and constructions had to be manually applied in EnergyPlus, despite the fact that the Case M architectural model contained very detailed information of materials and constructions.
This test implies that BIM to BEM approach is still not mature enough for everyday application, still requiring large amount of adoption and remodelling. Crucial for the successful collaboration and efficient data transfer the overcoming of the "discipline interest conflict". On the one hand the architectural model is very detailed, including a large number of room stamps and very high granulation and detailed product information; on the other the energy model is simplified requiring basic information on geometry and thermal zone. Thereby a modelling standard has to be established at the beginning of the design process defining the required Level of Detail.
In both cases only one way BIM is currently possible – return of the building performance simulation or optimization information in the original model is not possible – therefore again re-modelling efforts are necessary, together with well documented change management. Currently, in BIM to BEM, BIM-model is not used as adaptive design and management tool, but solemnly as extensive building and TBS database.

CONCLUSION

Despite the increasing importance of BIM in AEC, the potentials of BIM technology remain relatively unexplored in the industrial construction, partly due to the data protection and secrecy in the industry. BIM however bears large potentials for lifecycle management of industrial facilities through possibility of integration of building models and products, HVAC, machines and equipment.
The slow adoption in industrial construction has several causes:

- Duration times of design, planning and construction processes for industrial facilities are very short, due to the short lifecycle of the products and the need to bring the product on the market as soon as possible. From the pre-design till operation there is often less than 12 months. Due to the fragmented AEC in the European region, BOT (built-operate-transfer) commissioning models are still seldom. Thereby a large number of stakeholders is participating in design and construction process of industrial facility (architects, engineers, HVAC engineers, factory designers, logistics) all of which use own software solutions. BIM supported design and construction requires more intensive coordination and communication effort even before the design starts, in order to determine the modelling and data-transfer standards and framework. The fragmentation of the AEC industry together with the enormous time-pressure in industrial construction, represent the major obstacles towards the adoption of fully functioning BIM supported value chain.
- BIM to BEM approach in industrial construction is a completely novel aspect, since energy optimization of industrial buildings is not in focus of an enterprise – building

related energy consumption is relatively low in relation to the process-related consumption. Thereby when keeping the above mentioned time pressure for design and construction in mind, the time as well as financial resources for a thorough thermal building performance simulation and optimization are often lacking. The necessary efforts are not often too large in comparison with possible benefits, the process is too complicated and time intensive, especially if not "designed" from the beginning of the design process, as demonstrated on the Case M.
However, a coupled simulation with holistic approach including building, building systems, machines and processes would allow identification of synergy potentials and thereby much larger energy savings on larger level of an enterprise [24].

- In order to enable full benefits of BIM for design, construction and operation of industrial facilities, further development of open interfaces is necessary. In case of an automated BIM to BEM less time resources and efforts would be necessary and this optimization would become a part of a standardized design process.
  Full BIM potentials for BIM as industrial facility management tool lie however in the integration of several systems - building models, HVAC, equipment and infrastructure, which again calls for a possibility of coupling several software-platforms, such as CAD, ERP, GIS, and equipment-CAD.

In this paper a novel approach using BIM for BEM for design and optimization of industrial facilities was demonstrated. Thereby advantages of a modelling-process where the requirements for BEM were known from the beginning of the design and the modelling was in "one hand" were identified. When this is not the case, but different planning process stakeholders are involved in the creation and subsequently in the analysis of a building model without previous coordination of modelling standards, as currently is the practice, additional re-modelling or even creation of a new BEM model is the result. Such process is time intensive and prone to errors, and is also contributing to the reluctance of both planners and investors to adopt the building performance analysis and thermal simulation as standard design-optimization procedure.
The path towards successful BIM adoption for design-optimization, but more over for life-cycle management in the industrial construction will have to address problems on the process-design level, beside the technology related issues; especially in the industrial context where due to the very large number of process stakeholders there will always be a very heterogeneous software landscape using different data formats, granularity etc. The rethinking of the process can lead towards adoption of an actor network perspective, which is confronted with creation of new routines and relationships initiated through use of BIM [25] as well as establishment of enterprise-aims and abilities (e.g. delivering BIM-FM service) based on individual competencies [26].

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