BAUSIM 2014: A PROTOTYPICAL AUTOMATED BUILDING MODELING TOOL

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ABSTRACT

Building energy modeling is a complex and time consuming process. Automation may reduce the complexity and cost associated to the building modeling process; especially when highly specialized personnel are necessary. This paper presents a prototypical building model generation tool which automatically generates a complex building model for thermal simulation. The generated models allow forecasting of yearly or monthly thermal energy demand of a building, and are able to consider individual conditions for every floor with respect to different load profiles as well as geometry. These two features improve the quality of the energy consumption forecast significantly, especially by increasing the range of possible applications to multi-usage buildings e.g. partially used as residential or office building. A proof of concept has been performed for typical building geometries to outline the following benefits: reduction of modeling effort, improvement of the energy performance evaluation and comparability between buildings with similar geometries.

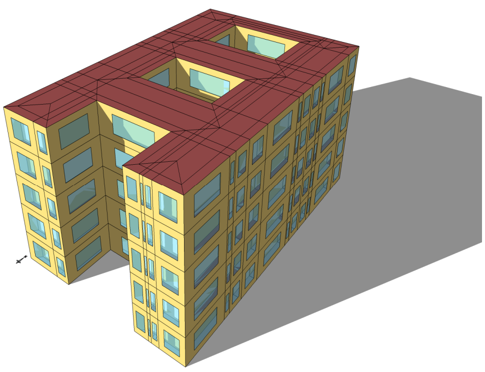
INTRODUCTION

The use of Building Information Modeling (BIM) is becoming regular practice in building design, as many of the commonly used CAD programs, like ArchiCAD and Autodesk Revit, are based on the principles of BIM. It is even possible to store energy relevant data in those systems, such as material properties (Mahdavi et al. 2009). The main issue for the use of BIM for energetic analyses is the capability to exchange integrated information between design tools and analyses tools (e.g. transient-thermal simulation). For this interoperability, in general, two data formats are used: IFC (Industry Foundation Classes, Release 2x, standardized in ISO/PAS 16739) and gbXML (Green Building eXtended Markup Language).

But data exchange between BIM solutions is still work in progress. At the time being, none of the available software solutions allow an easy and successful exchange of information: Either a third party application is necessary to translate data formats (e.g. in EnergyPlus, BIM data has to be translated to IDF format by using a third party software) or compatibility problems arise due to disparate interpretation of the information in each software solution, leading to a loss of information in each conversion between different BIM tools. Furthermore, information loss may also occur if BIM data provides input for numerical flow and heat transfer simulations utilizing other platforms, such as for example the ANSYS Workbench platform. Only the geometry information which has to be exported from the Autodesk or ArchiCAD environment can be re-imported. Boundary condition information like material data may be lost in the process.

On the other hand, commercial software products, especially some CAD programs are very well developed in terms of integration of energy evaluation, including air flow and heat transfer simulation. For instance, ArchiCAD 16 has an integrated simulation based energy evaluation tool and Autodesk offers a cloud based service called Green Building Studio. Autodesk additionally offers a module for project associated flow and heat transfer simulations (Autodesk Simulation CFD). Therefore, it seems uncertain that there will be a further focus on interoperability of products from different companies driven by the software industry. To overcome these challenges a software tool able to support data integration and model generation is desirable. It has to be flexible, scalable and compatible with the existing data formats used by the simulation tools. A desirable result of the software tool is shown in figure 1. A simplified building model for simulation purposes was generated using two templates, namely an O-shape and an H-shape.

Figure 1: Example of a simplified building model generated using two geometrical templates.



RELATED WORK

Building performance simulation is used primarily in building design, in order to support the design decision making process (Hensen and Lamberts 2011). Mainly lighting and thermal performance simulations are used to support design decisions (Mahdavi et al. 2007). These tools rely on building models to have an internal representation of their own geometry and semantics (Hensen and Lamberts 2011). A set of information generated and maintained throughout the life cycle of physical buildings enables building models (BM) (Mahdavi et al. 2007). There, geometry, spatial relationships, geographic information, quantities and properties of building components are represented, accompanied by their relations. In some cases, BM may allow to convey the entire building life cycle from conception through the processes of construction and facility operation to decommissioning (Mahdavi et al. 2009). Mahdavi et al. 2009 affirms that in those cases, quantities and shared properties of materials may be extracted from building models and further used to determine building performance. Real-time simulation-based building control focused on building performance has been extensively discussed in (Mahdavi et al. 2007) and is further extended by validated implementations in lighting and shading domains (Mahdavi et al. 2009).

A framework that allows a real-time comparison of actual and simulation-based building performance has been developed in (Pang et al. 2012). A modular architecture composed of an Energy Management and Control System (EMCS) and a real-time Simulation Environment has been developed within this framework. A BACnet gateway is offered to interface existing sensors and control devices in the EMCS. The Real-time Simulation Environment uses Building Controls Virtual Test Bed (BCVTB) (Haves and Xu 2007), which offers a link between the simulation tool, the control systems and EnergyPlus (Crawley and Lawrie 2000) simulation tool.

Brunner (Brunner 2007) presented a Building Model Service where the current building state is reflected in an object tree that is continuously updated by sensor data. A building model based on a Shared Object Model (SOM) was used in (Mahdavi et al. 1999). SOM is a fairly straight-forward object hierarchy and served well as a simple building model representation. Brunner argues in (Brunner 2007) that this simplification is an advantage over, e. g. Industry Foundation Classes due to the resource saving creation of a simplified model. A building monitoring, control, and interface system architecture and functionality have been introduced in (Fuetterer et al. 2013). Model-based approaches in building management have been applied in different projects: the OptiControl project (Gyalistras et al. 2010) has used model-based control to optimize HVAC and controls in a prototype installation. Use cases for model-assisted building HVAC system control parameters fine-tuning are examined in (Constantin et al. 2013) and the Pebble project (PEBBLE 2014) examines the improvement of control decisions in order to achieve positive energy buildings.

Data requirements for building performance simulation are challenging in terms of automatic modeling and data exchange, because they are depending on the questions the simulation model should answer. Recent research on model simplification has been reducing the modeling effort and easing the development of dependent technologies (for example Zucker and Hettfleisch 2010, Leal et al. 2012). A study of thermal and electrical performance simulation using simplified building models has been performed (Leal et al. 2013). The case study assessed the feasibility and adaptability of simplified models for realistic performance simulation purposes. Results demonstrated a high level of agreement between the simplified model and existing office building. With the previous developed tools it was possible to create building models automatically but the degree of freedom with respect to the building geometry, building loads and usability was limited.

Dynamic energy performance models, which may be used to simulate any building by varying the related shape and orientation, construction materials, climatic zone, position, number and geometry of windows and shadows, have been proposed (Buonomano and Palombo 2014). These models may be used to study suitable design guidelines and in some case to analyse physical response to environmental changes. Furthermore retrofit analyses of the examined buildings can be evaluated.

In most cases trained professionals are necessary to perform building energy analysis, which result in additional costs. Building energy simulators require a certain level of technical expertise to be used (Chuah et al. 2013). There it is discussed that, although trained auditors produce in general more customized and accurate building energy analysis, still the additional costs discourage many building owners from adopting state of the art technologies to assess of the building performance. This results in a sparse adoption of building energy simulation for the continuous assessment of the building performance. Moreover, most building energy simulators are not retrofit-oriented. Nor do these building energy simulators offer a scenario analysis and rank. Consequently building energy simulator users still have to adapt or even create manually building models in order to be able to simulate across multiple retrofit choices (Chuah et al. 2013). Much effort has been made to overcome these limitations. For example, ROBESim is a retrofit-oriented building energy simulator based on the EnergyPlus framework, which provides a database of widely used existing retrofits (Chuah et al. 2013). It has a core simulation framework that uses EnergyPlus as simulation tool, and extends it by allowing built-in definitions and separate computations for retrofits. Combined with an ease-of-use user interfaces and input file generators, it also immediately provides comparable retrofits database for the user. ROBESim aims to achieve two goals. One is to provide quick and easy retrofit development and retrofit-oriented simulation tools. The other is to support retrofits that depend on occupant positioning information. ROBESim main features are an automatic retrofit integration into building model alongside with scenario comparison, support of occupant profiles, an user-friendly web interfaces and an EnergyPlus compatibility provided by its modular and extensible architecture (Chuah et al. 2013).

METHODOGY

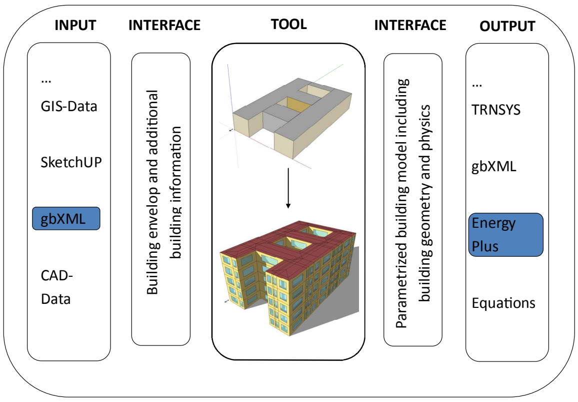
The overall approach was to develop a tool which supports the automatic model creation process, resulting in the advantage of reducing the modeling effort significantly. The generated output of the tool is supposed to be used as baseline information of the performance of a building especially it supports the validation and analysis process of the ISO 50001 regarding forecasting the building performance. In order to perform such studies, following parts are necessary in general:

- Building information regarding building physics and Heating, Ventilation and Air Conditioning (HVAC) components;
- A software tool to generate the simulation file;
- Simulation environment.

Most of the time for the development of a building model will be consumed by collecting the necessary data and generating the input file for the simulation tool. In order to be more effective concerning time savings in the modeling process, the main approach is to link BIM with a suitable simulation environment by which the effort of some traditional modeling steps can be reduced significantly. BIM contains even at an early design phase of a building enough information which can be fed into the new modeling tool by using gbXML as common data interface. The modeling process overall architecture is shown in figure 2. Input data may be available in different formats, such as gbXML or IDF as well as form different sources, e.g. CAD, GIS etc. Relevant data, such as building envelop and building system data (for instance HVAC and electrical components) are made available to the modelling tool though a data interface. The building geometry, building system, set points and internal loads are taken from the data provided as input or estimated based on standard (e.g. ASHRAE Standard 62-2001, Handbooks of Fundamentals) and norms, resulting in a fully parameterized building model. This building model is then sent to the designated simulation tool (for example EnergyPlus, TRNSYS, etc.) for further processing. A simulation interface allows the conversion of the building model into the simulation tool syntax. This process ideally should need no user interaction during its execution, even though in some exceptional cases user supervision may become necessary.

Based on the software architecture of the modeling tool, only a minimum set of necessary input parameters e.g. simplified building geometry, the geographic location of the building and some physical parameters for building envelop and HVAC systems, etc. are needed to generate a building model automatically. On the one hand the description of the building geometry may also be taken from the gbXML description of the building, whereas all other additional information of the building is fed into the tool manually.

Figure 2: Process overview of the software tool



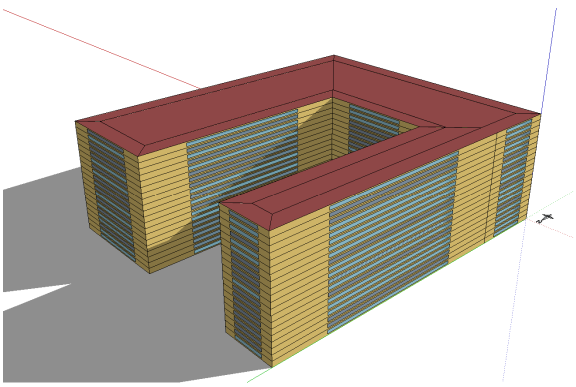
Depending on the availability of the real building data the level of details of the necessary input parameters can vary significantly. As described in Leal et al. 2013 following parameters are mandatory.

- Building geometry including number of floors, fenestration ratio in %
- Building location and construction year
- Building type and usability

All other parameters can be easily estimated based on this set of parameters using the ASHRAE standard (e.g. ASHRAE Standard 62-2001, Handbooks of Fundamentals) or the Norms (e.g. ÖNORM EN 15251:2005, Wegelage 2010) resulting in following model parameters which were stored internally in the modeling tool using an adequate data structure- this gains the possibility to adapt and further improve the tool if needed: the **Building shape** - contains all information about the building geometry (building envelop), number of floors, u-values of the walls, etc. **Window -** contains all information about the window material properties and window area each facade. **Simulation** - contains information about the simulation period, the building location and orientation. **Set-points** - contains information about the heating and cooling set-points of the HVAC system. **HVAC** - contains information about the HVAC system and allows changing some basic specifications. **Internal loads** - contains the internal load profiles of each floor depending on the usage of the building. Improvements within the modeling tool make it now possible to increase the flexibility of the defining multi-usage of buildings floor by floor.

Based on these information the tool generates a building model automatically using an own developed auto-zoning function. Depending on the building dimensions and proportions it generates core zones and outer zones automatically. Using the information of the usability of the building, every zone - on the basis floor-by-floor - can be individually parameterized with an adequate internal load profile. Finally the modeling tool generates an output file which can be used to simulate the building regarding the forecast of the heating, cooling and optional the electricity demand of the building. EnergyPlus was chosen as simulation environment due to its flexibility to generate building models based on simple text-files, and due to it being open source. Figure 3 shows an example of the final output of the modeling tool. This automatically generated building model containing 20 floors took about three minutes and twenty seconds to generate on a laptop equipped with a dual core 2.50GHz CPU.

Figure 3: A large U-shape layout automatically generated in less than four minutes.



PROOF OF CONCEPT

After finishing the development process, unit tests were performed to identify possible software bugs caused by variation of building parameters and the usage of different building geometries. Test scenarios were specified using 4 different geometries and apply 20 different tests. The main focus was to check if all parameters can be changed without producing errors during the generation process and during the simulation. Furthermore the simulation results of each single test were evaluated to proof that the calculation of the heating and cooling demand of the building is reasonable based on the used building parameters. Following points were checked in detail:

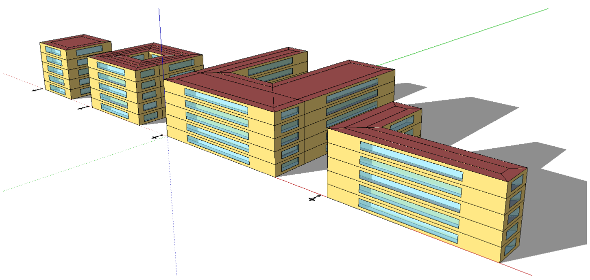
- Check the simulation file for each type of building layout if the parameters were changed correctly;
- Check if the simulation results - created by the EnergyPlus report automatically - differs to the previous ones;
- Check if the overall simulation is done correctly;
- Compare the generated models in SketchUp and check if all changes regarding building orientation, fenestration details, etc. were applied correctly.

The evaluation of the unit tests shows that the developed tool performs well without creating errors during the model generation process and the simulation process. The output - meaning the quality of the simulation results - of the developed tool is of course depending on the quality of the input data, and therefore relies on the user of the software tool.

CASE STUDY

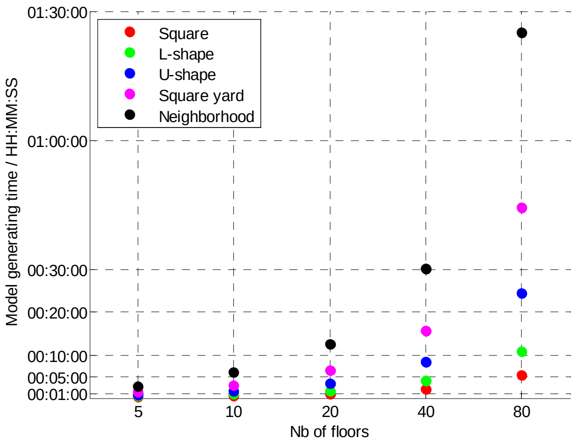
Preliminary results support model generation scalability and performance. The main goal is to evaluate the performance how the developed modeling tool concerning modeling effort and time. Therefore a proof of concept has been performed for 4 typical building geometries: square, L-shape, U-shape and square yard.
As simulation hardware a notebook equipped with a dual core 2.50GHz processor 3.16 GB RAM was used. Tests were extended to a whole ensemble of different building shapes, representing a neighborhood using different size of buildings as shown in figure 4.

Figure 4: Simplified neighborhood model



Depending on the complexity of the different buildings meaning the number of floors and the number of surfaces, the time to generate a complete building model including different usability of the floors varies between ~14 sec and ~44 min. Figure 5 shows a detailed analysis of the generation time of each building and the overall neighborhood (represented as the sum of each single building). The simplest building shape (square) can be generated very fast. It takes between ~14 sec up to ~5 min. Whereas generating a more complex building (U-shape) leads to increasing the computational time up to ~25 min. Compared to a traditional modeling process, meaning parameterize each floor manually, the resulting savings in time and effort are significantly. It should duly be noted that the generation time is linearly with respect to the number of floors.

Figure 5: Process time of building model generation



Furthermore a detailed performance analysis of a single building has been made. Table 1 shows how the model generation and the simulation time increase due to a higher number of floors of each building model. It should be mentioned, the long simulation time of buildings greater than 20 floors results of the fact that every floor is parameterized individually regarding to the usage of each floor. User interaction has not been considered in the calculation of the system performance.

Table 1: Model generation and simulation time for a L-shape building

Nb. of Floors	**Model generation**	**Simulation**
	HH:MM:SS	HH:MM:SS
5	00:00:29	00:06:57
10	00:00:55	00:16:09
20	00:01:44	00:35:20
40	00:04:04	01:18:08
80	00:10:55	03:05:23

EnergyPlus allows reducing the number of simulated similar zones/floors by using the “multiplies” functionality. This results in a significantly shorter simulation time (EnergyPlus 2014). At the moment the architecture of the prototypical tool hereby discussed, does not use this feature, although results of the simulation time show that the implementation of this feature is desirable. As such it should be included in future developments of the prototypical automated building modeling tool.

CONCLUSION

The complexity and cost associated with the building modeling task still prevent a wider adoption of building modeling and simulation in all stages of the building process. To enhance the adoption of such solutions, a prototypical automated building model tool has been developed and tested. Initial results show that depending on the complexity of the building model, correlated to the building geometry and number of floors, the time necessary to automatically generate the building model is linear. Even though, a reduction on the model complexity and modeling cost may be observed. The simplified automatically generated building model may be beneficial for the planning phase of the building process, especially in cases where rapid prototyping of multiple building envelops and building systems may be desirable, such as architectural design contests.

Future work may include the inclusion of the “multiplier” feature of simulation tool EnergyPlus and the possibility to create multifaceted building envelopes beyond the currently supported templates, for example allowing the merger of multiple templates.

ACKNOLEDGEMENT

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