Abstract

Simulations enable detailed studies about the behavior of the building for optimizing the energy-efficiency. While this is an absolute advantage there are also problems regarding the daily work of experts because the simulations costs much time and before simulations can be done the configuration can be very huge and the pre-processing erroneous.

To overcome these problems an eeBIM-ontology-based (Energy Enhanced BIM) framework is proposed applying inference rules to pre-check the input data and to pre-analyse the energy performance on a lower detail level, before the simulation phase will start. The ontology specification provides the concepts and relations to describe the building, the external data like the climate data as well as the linking between the BIM-concepts and the external data. Furthermore, constraints and calculation methods are transferred as far as possible into logical rules. The surrounding ontology platform enables the integrating of the input data and manages the process of the calculation methods. It also defines certain external connection points for calculating methods, which cannot appropriate represented in rules.

The ontology framework helps to identify building designs which have problems to fulfil energy performance requirements even at a very early stage of the design phase. So, the ontology follows the idea of typical engineering regulations including simplified methods for easy and practical use.

Keywords: BIM, eeBIM, Energy, Knowledge Management, Ontology

1. Problems and Challenges

Building energy performance analyses require a certain quality of the given domain models serving as input for the envisaged analyzing tools. According to the three layers of semiotics syntactic layer, semantic layer and pragmatic layer the domain model quality can be divided into three quality levels:

- **Syntactic Quality**: The domain models fulfill syntactic quality, if the analysis can be executed and analysis results can be delivered.
- **Semantic Quality**: The domain models fulfill syntactic quality and the analysis shows meaningful results (e.g. the energy consumption of a building is realistic and follows energy regulations).
- **Target Quality**: The domain models fulfill semantic quality and the analysis shows results following a task specific target function (e.g. the energy consumption of a building variant has to be lower than the energy consumption of the existing building variants).

The inspection of the model quality needs next to the domain models the descriptions of the requirements of the analyzing tools and the certain context description the domain models and the analyzing tools are used. The type of inspection proposed in this paper aims at pre-checking the domain model syntactic quality by describing the domain models, the analysis requirements and the context information in a holistic model called system analysis model. In most cases these three kinds of information are separately considered and the combination of these information is be carried out manually. This has the consequence that pre-checking of domain models is done for each process step separately avoiding the overall inspection of the whole analysis process. So, the International Alliance for Interoperability (IAI) defined the IFC Model View Definition Format to specify which data should be in the building information model (BIM) (Hietanen, 2006) for a following completeness check. Here, capabilities for inspecting process steps in an overall context are missing. For achieving such a holistic model approach the analysis and the analysis context has to be specified. This will be done in a process model, which supports the different levels of building design by providing different levels of detail for the process modeling. Next to this, the input and output of the processes has to be described. Therefore, the BIM-model has to be semantically enriched to an energy enhanced BIM-model (eeBIM) integrating the additional energy relevant information like climate data, occupancy data, etc. This integration comprises the specification of new
BIM-elements extending the existing elements to serve as connection points for the additional non-BIM information. The development of such an extended BIM-model (eBIM) deriving the extending elements mostly automatically and supporting the linking with the non-BIM data is the first step towards eeBIM.

Several modeling technologies were published to overcome the interlinking or integrating of different heterogeneous data formats in a sufficient model quality. (Fuchs, et al., 2010) showed how the linking of different raw data models, called elementary models, can be interlinked with a light-weight XML format. The elements of elementary models are connected and the raw data is left unchanged. (Curry, et al., 2012) presented a similar approach by using RDF (Resource Description Format) which allows the usage of semantic web features like querying with SPARQL. They used IFC as representation of BIM and mapped elements to RDF. (Beetz, et al., 2008) presented an approach how to map EXPRESS to OWL (Web Ontology Language) which can be used to transform IFC to the ontology representation (IfcOWL). In this paper an ontology is proposed as modeling technology forming the framework for the rule-based eeBIM pre-inspection. Thereby, this system analysis ontology uses IfcOWL for describing the BIM domain.

2. Analysis Context

The inspection of the correctness of the domain models and their combinations (eeBIM) starts with the question in which analysis context they will be used. The analysis describes a process consisting of different sub-processes and process steps. So, the analysis context is formed by the process description and the required input and output. The domain models and their linking as well as the analysis tool description and the related analysis models summarized in an environment model represent the input and the output of the analysis process (Figure 1, left).

Along the process flow the necessary input and output depends on the process or process step, which will be executed. This implies that a model checking is always process bound. Thereby, the description of a certain domain represented by its corresponding elements can be more detailed, but also more abstract at the end of the process. So, according the process flow and the level of detail (LoD) between the IO-models a general qualitative interdependence and a generic specification of process rules cannot be formulated, because also the LoD of the IO-models is process bounded.

The ontology supports the process inspection on different level of process. Here, in contrast to the process flow the detailing of a process requires more detailed information of the input and the output for describing the sub-processes. So, a higher process detailing implies a higher LoD of the IO-models and an inspection fails, if the IO-models of the sub-process are not presented in a higher LoD.

Following the formulated dependencies the ontology process model provides the definition of different process levels starting with process areas, guidelines, etc. and ending with certain process steps specifying a certain view of the domain models. Thereby, the ontology description lays the focus on the static properties of a process. This means, the ontology checks the correctness of the IO-models, but not the correctness of possible alternative IO-models, which will be generated during the process execution. For the model checking each process is related to a set of logical rules specifying restrictions, cardinalities, etc. for the domain model and environment model schemas (Figure 1, right). These logical rules represent the requirements the given models and their instances have to fulfill for the related process. The environment and domain models with their certain instances represent the resources, which have to follow the given model schema and the related rules. Thereby, two processes can be related to the same model-schemas, but to different logical rules. This would mean that the processes are operating on the same domains and the same environment, but they need a different view for the process execution. So, the process model comprises both the “To-be” description represented by the model schemas and logical rules and the “As-is” description represented by the model instances.

The simultaneous use of model description and rule definitions shows the advantage of ontologies as modeling technique, which allow specifying domains and interpreting these specifications by applying common semantic tools.
3. eeBIM

For the certain engineering analyses the use of one domain model is mostly not enough. Often, additional information coming from other domains are required and have to be combined creating an overall information basis and providing the input information for the envisaged external simulation tools and their related simulation models. In particular, the focused energy performance analysis of buildings needs next to the BIM information describing the architecture of the building, information about the climate, the user behavior, etc. To combine these different domain information two core strategies can be distinguished: Centralized information integration and decentralized information integration. By using the centralized approach only one domain model representing the center model is related to the other domain models. The decentralized approach is characterized by domain models, which can be combined arbitrarily with each other. Caused by the fact, that for building design issues the building and the corresponding BIM model is focused, the ontology approach follows the centralized integration with the BIM model as center model. BIM model implementations like the IFC aim to provide general concepts to cover common building design scenarios, but for specific engineer tasks additional BIM information are required to extend the architecture model. This extended BIM (eBIM) has to offer the connection points needed to link the information of the non-BIM domain models and to complete the overall energy enhanced BIM model (eeBIM).

In the ontology approach the BIM model is represented by the BIM ontology, the extension of the BIM model is represented by the Interface ontology and for realizing the eeBIM model the non-BIM ontologies have to be linked (Figure 3, left). To transform the raw data into ontology information they have to be mapped and linked:

1. 1 to 1 mapping just transforms the data format into ontology format. In the most cases it is a XML to OWL or IFC to OWL transformation.
2. The reduced mapping does not map the complete data into the ontology. To achieve a lean ontology model not all data are integrated (e.g. geometry data are not considered). Instead of the whole geometry model only derived abstract data are included (e.g. the width or height of a room instead of the whole room geometry).
3. N to 1 mapping combines several data to get one ontology element. Vice versa 1 to N mapping splits one data element into several ontology elements.
4. Direct linking is done in the course of the element mapping operations or manually, if corresponding elements cannot be identified by algorithms.
5. Implicit linking is based on ontology rules used to interpret implicit information for generating explicit links. This is mainly done for linking the BIM- with the Interface-ontology.
6. External linking describes the linking between an ontology and a data element (mapping ops/manually).

4. eBIM

In order to come to an energy interpretable BIM we defined a step-wise data extension so that energy-related entities are explicitly given and forming the connection points to non-BIM data (see section 3, point 5). For doing so, we check the LoD the information is structured first. As an absolute requirement we suppose that space boundaries are given where associated building elements can be considered geometrically as external or internal (Bazjanac, 2010). With such information we can consider if e.g. a wall is an outdoor or indoor wall etc. Figure
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presents an excerpt of our rule set for bringing the BIM entities to an extended BIM representation which is more type-safe and tool interpretable. Rule number one checks if at least one space boundary is described as “EXTERNAL” and if this is the case the whole window is inferred as outdoor window. Rule number two checks if a building element is a façade element by analyzing the space boundaries in the same manner as in the orange rule. Rule number three expresses that all façade elements are part of the building façade.

In another rule set we make a similar analysis where IfcSpace entities are evaluated. For example, based on the name of the room and the definition given by a room book an IfcSpace is assigned to be an office room (defined as OWL class “WorkRoom”) or a technical room (“TechnicalRoom”) which both extends IfcSpace. With such an association heated rooms (e.g. office, living area etc.) can be isolated from unheated rooms (e.g. cable funnel, elevator etc.) in a next step.

After the extended elements were generated and linked, a check is performed if all individuals were inferred correctly. When rule sets which bring the BIM to an eBIM cannot be applied (and validated), it indicates that there is a problem regarding the possibility to perform an energy analysis. The checking against constraints and reasoning with rules are big advantages when working with BIM. While there are many existing specifications how a well-modelled building should be provided (e.g. through LoD), it is not explicitly defined in the model schema and therefore not mandatory. The way of expressing model requirements through rules leads to a consistent workflow later and saves time in the case, that an energy simulation fails or produces wrong results.

Figure 2. Rule set for finding outdoor walls, outdoor slabs, outdoor windows, indoor windows, façade elements and the façade

5. SemeeLab

To integrate the overall system analysis ontology and its functionalities a specific platform called SemeeLab (Semantical energy efficiency Laboratory; Figure 3, right) was developed. SemeeLab is a web platform for building energy performance analyses based on BIM. It allows assignments to BIM entities, performs thermal energy simulations and simple cost calculations based on energy resources like materials, climate and occupancy. SemeeLab brings together architects, energy planners and facility managers while integrating their specific software tools for design and result validation ((Baumgärtel, et al., 2011), (Baumgärtel, et al., 2012)) and store needed resources in a BIM server.

The web platform consists of a middleware, called SemeeCore, which controls the data management, tool management and workflows. SemeeCore is connected via web service with a BIM server where all the resources are stored and versioned and is connected to a cloud environment where the energy analysis computation will be executed. End user applications like design tools, e.g. CAD tools, and validation tools, e.g. room requirements or cost calculation tools, are connected to SemeeCore via web clients and have access to prepared ready-for-simulation data and energy results of previous simulations.

For integrating the heterogeneous data models into the system analysis ontology according to the needed level of detail a multi-layer approach is used (Baumgärtel, 2013). This multi-layer approach comprises seven layers: Data Models, Model Services, Unified Information Model, Business Services, Process Definitions, Access Layer and Apps. Thereby, the integration process begins at the bottom in the data model layer and ends in the application layer.
Data models are models represent domain related information like the building model for the architectural domain, climate data and occupancy data for the energy domain or the product data catalogues of manufacturers. They are provided in different data formats like IFC2x3, XML, STEP or CSV. The purpose of the platform is to keep each data model as it is and only change it by the user who is responsible for that model.

For doing so, Model Services comprise in first place parsers (e.g. IFC parser like BIMfit (Windisch, et al., 2012), XML parser) which read the models and bring them in computational state. For other data like eeData there exist XML parsers or other text parsers to allow the data exchange. To fill the ontology triple store (subject-predicate-object) an ontology model service (Multi-Model Combiner) based on Apache Jena (Jena, 2010-2013) is implemented and can be used by all other model services. When parsing the models the multi-model combiner checks the LoD of the model and integrates the needed model elements.

From this point of time all information will be retrieved from business services. Business services are top-level services which mainly use the system analysis ontology to retrieve needed information, e.g. to process user requests and to bring BIM to eBIM and finally to an eeBIM representation. These workflows are aligned in the process definition layer and can be started through the access layer which provides web interfaces (with REST) to external applications where users can configure simulations and can take a view on the energy building performance.

The Application Layer contains all programs, tools web and desktop applications which are using SemeeLab for data visualization, information management, simulation management or report management. The clients have to implement the functionality to call the REST interface provided by the access layer. The other layers are hidden behind the access layer so that the applications only have to fulfil the contract of the web interface.

![Figure 3. Multi model integration](image)

6. Conclusion

In this paper an ontology approach was presented forming the base for a semantic integration of different domain models for supporting the design of an energy efficient building. Here, the advantage of ontology-based description was used to consolidate the heterogeneous resources and to inspect the given model quality with regard to the envisaged energy performance analysis. So, on the one side the ontology provides the description of the domain models by specifying certain concepts and on the other side the underlying mathematical basis enables the definition of logical rules and in this way the interpretation of the made specifications and their interoperable use. Cause of the reason, that simulations costs much time and before simulations can be done the configuration can be very huge and the pre-processing erroneous, the ontology approach aims to pre-check the given input data by defining and applying appropriate logical rules. This kind of inspection allows the identification of modeling mistakes in a very early stage of the design process by using only common semantic tools. For achieving such a holistic model approach the analysis context was specified formulating a process model and the BIM-model was semantically enriched to an energy enhanced BIM-model (eeBIM) integrating the additional energy relevant information like climate data, occupancy data, etc.
The ontology and the corresponding ontology platform were developed and will be further developed in the European ISES project. It could be shown, that the application of the ontology approach helps to identify modeling mistakes as it was planned. At the moment there exists only a small set of inspection rules checking the syntactic quality of the eeBIM model. This set of rules will be extended in further work. Furthermore, rule implementations are planned checking the semantic and target quality of the eeBIM model and reducing the time simulation software will use for quality control.

Acknowledgments

We kindly acknowledge the support of the European Commission to the project ISES, Grant Agreement No. 288819, http://ises.eu-project.info.

References