Extending BIM for Energy Simulation and Design Tasks

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ABSTRACT

The recent advance of Building Information Modelling (BIM) and the related needs for BIM-based interoperability of more and more specialized AEC tools in various construction subdomains showed that (1) a global model for all data in a construction project is neither realistic nor practical target, and that (2) BIM data typically have to be combined with other kinds of construction related data to be efficiently applied in real tasks. This paper addresses the issue of BIM extension for such multi-model domain tasks on the basis of work done in the frames of the EU project HESMOS for the development of an energy-enhanced BIM framework (eeBIM) enabling the integration of multiple needed resources (climate, occupancy, material data etc.) and the interoperability of various energy analysis and monitoring tools in an Integrated Virtual Energy Lab Platform (IVEL). It explores the pros and cons of three principal approaches (1) Extending the BIM Schema, (2) Extending the BIM data, and (3) Using a Link Model, before focusing in particular on the latter approach which provides for greatest generality, modularity and application scope as it does not require changes in the BIM schema and guarantees maintenance of each model within its own domain. The generation of the eeBIM model from initial architectural CAD-BIM data and future research plans complete the presentation.

INTRODUCTION

The advance of Building Information Modelling (BIM) in recent years expedited its use in a growing number of AEC projects and practical tasks. Along with that, various problems that had been addressed earlier in narrower scope had to be reconsidered in search for adequate industry relevant solutions. Such problems include collaborative work support, change and version management, life cycle sustainability and so on (Eastman et al. 2011). Continuously extending the use of BIM-based working and the related needs for BIM-based interoperability of more and more specialized AEC tools in various building construction subdomains showed also that (1) a global all-encompassing model for all data in a construction project is neither realistic nor practical target, and that (2) BIM data typically have to be combined with other kinds of construction related data in order to be efficiently applied in real AEC tasks (Scherer &

Schapke, 2011; Arayici et al. 2011). Thus, while the current BIM standard IFC (ISO 16739) has been successfully extended to support various domain-specific processes (http://www.buildingsmart-tech.org) and several international research and development projects such as STAND-INN and InPro (http://www.aec3.com/en/5/index5.htm) have shown how domain application interoperability can be achieved by suitably extending BIM-CAD data, the problem how non-BIM data or BIM-related non-AEC data from external resources can be best integrated is still relevant in many practical situations. A specific such situation is provided by the areas of energy aware design and facility management and the related energy performance simulation.

To tackle that challenge, the European FP7 project HESMOS (2010-2013, http://www.hesmos.eu) has been set up with the following major objectives:

- Providing advanced simulation capabilities during the whole lifecycle of a building
- Closing the gap between BIM and Building Automation Systems (BAS)
- Integrating CAD and energy analysis and simulation tools into a BIM-based virtual lab platform enabling execution of a number of energy related tasks already in the early design phase and later on, up to operation management and refurbishing.

Within the building lifecycle, simulation of building energy system performance in HESMOS is done on 3 levels of detail: (1) whole building, (2) space/zone, and (3) building element. This requires not only design data that is in the focus of current BIM developments (Bort et al. 2011). In fact, the challenge how to access and integrate the required external data resources is highly important not only with regard to energy performance but also for many other AEC domains.

BIM EXTENSION APPROACHES

In many cases, available BIM models like the current IFC2x3 or the new IFC4 model (IFC4, 2013) do not provide sufficient data to fully support data exchange requirements and tool interoperability for a particular domain. Therefore, while the re-use of already available BIM data is of undisputable benefit with regard to teamwork, coordination and life cycle information management, the integration of BIM with external information resources is an essential issue to solve for the achievement of an efficient BIM-based work process. However, before actual modelling and/or implementation work starts, the appropriate approach for the targeted BIM extension framework has to be decided.

Figure 1 below exemplifies the problem statement for the energy domain. It illustrates the idea of a common BIM repository providing the link and the gateway between design and operation data and energy simulation / energy cost estimation tools but shows also the issue regarding external data that is not available in BIM which needs to be adequately solved. This data includes climate / weather conditions and characteristics, occupancy / activity schedules and related set points, specific material properties related to the needs of various energy analysis and simulation tasks, sensor data from the building automation systems and so on.

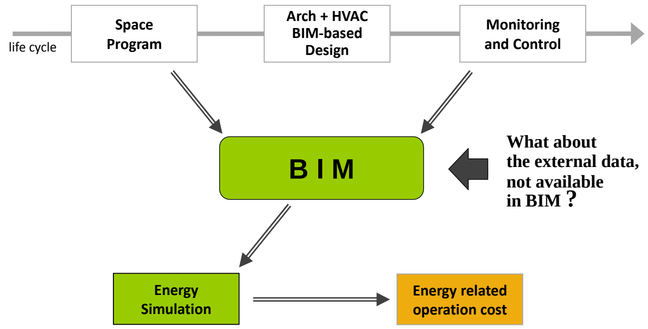

Figure 1. The challenge of BIM-based interoperability in the energy domain

To achieve the needed BIM extension framework, three principal approaches are to be considered: (1) Extending the BIM schema, (2) Extending the BIM data, and (3) Using a Link Model. These approaches are not mutually exclusive. They can be usefully combined as necessary to support interoperability in a specific area.

Extending the BIM Schema. Extending the BIM schema(s) with new concepts, attributes and relations to accommodate the needed external information resources relates to standardisation work done e.g. in the frames of the BuildingSMART alliance. Such model extensions are already available for various domains like building services, structural analysis and design, facility management etc. (cf. http://www.buildingsmart-tech.org) This requires achievement of consensus among the involved parties and leads to a new version of the standard. Technically, it is the most efficient way to extend BIM functionality but it also has some significant drawbacks: development work typically takes very long time, the model becomes increasingly complex and consequently more difficult to use in software, domain applications are overburdened with data of other domains they do not actually need, and – last but not least – external data originating from other sources or even other industry branches (e.g. meteorological data, geo data, various supplier data etc.) are difficult to maintain up-to-date and to keep under control. Therefore, this approach is preferable mainly when large, re-usable domain tasks are targeted, the required data is within the competence and control of the AEC industry, and schema changes remain compatible with earlier model versions to ensure fluent implementation. It is less advisable for tasks involving extensive use of external modelling data and ad-hoc situations.

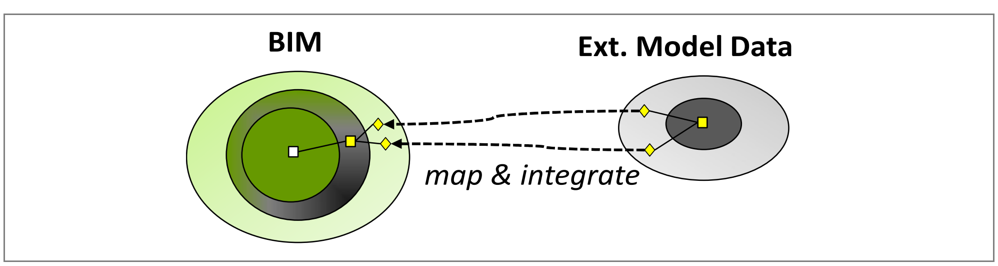

Figure 2. Schematic presentation of the BIM Schema Extension approach
(Inner circles show the schema definitions (object classes), the outer circles the instantiation; the middle circle on the left illustrates the schema extension layer)

Extending the BIM Data. Extending the BIM data by using existing interface facilities in the model without changing the model schema provides a different, undisruptive approach. In IFC various such extensions are possible via the *IfcRelationship* subclasses, the *IfcProxy* concept and especially the IFC property set mechanism allowing simple add-on attribution to various standard BIM entities. The benefit of this approach is the easy to agree upon and implement specification of the needed external information resources and the avoided change of the model itself. However, the latter is also one of its main drawbacks because the use of proxies and property sets has relatively low semantic depth and requires agreement between applications that are not part of the model, an issue of arguable sustainability. Another drawback is that the expressiveness of the available interface extensions can only cover scenarios where the needed external data are of manageable complexity. Thus, this approach is only applicable when the use of external modelling data is minimal.

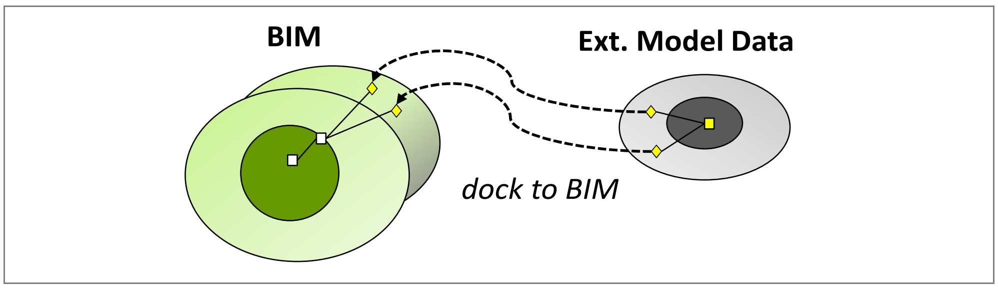

Figure 3. Schematic presentation of the BIM Data Extension approach
(The second circle on the left shows the extension layer as foreseen in the BIM-IFC schema definition)

Using a Link Model. Using a separate Link Model as a bridge between BIM and non-BIM data can provide for greatest generality, modularity and implementation scope. It does not require changes in the BIM schema and the external models used and it guarantees maintenance of each model within its own domain (e.g. climate data maintained by meteorologists). Furthermore, it provides for greater semantic depth, helps to handle almost arbitrary data structures and enables a clear interoperability strategy. Its essence is in capturing the relationships of BIM data to external information sources within a separate data structure, the Link Model, and resolving these relationships by means of model management tools at run-time. Drawbacks are the difficulty regarding the maintenance of the Link Model, the need of additional link model management services, some run-time performance deficits due to the increased data complexity, and possible consistency problems in the rare case of overlapping multi-model data. Thus, whilst possible for any multi-model problem, the Link Model approach is most useful where (1) a large amount of external information resources is needed and these resources have non-AEC origin, and (2) where a flexible platform for a set of (exchangeable) software tools is sought. A typical case here is the HESMOS development of a Virtual Lab for energy-efficient building design and life cycle management.

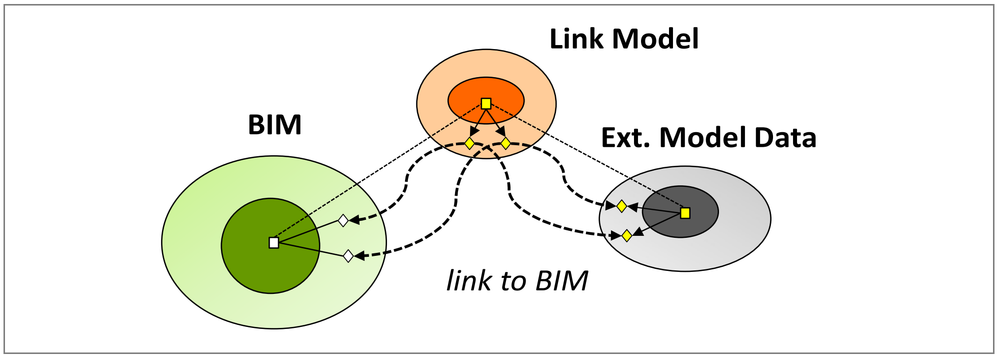

Figure 4. Schematic presentation of the Link Model approach

THE HESMOS ENERGY ENHANCED BIM FRAMEWORK

Development of an energy enhanced BIM framework (eeBIM) has been undertaken by the authors in the frames of the EU project HESMOS on the basis of the Link Model approach outlined above. As already mentioned, the objective was to close current gaps between existing data and tools from building operation and design so that to enable efficient lifecycle energy performance estimation and decision-making. One thing which became clear already at the outset was that realization of the envisaged eeBIM framework requires:

- *Filtering* the BIM data to a model subset tailored to the needs of the domain,
- *Inter-linking* the filtered BIM data with the external model data required for the various necessary computations, and
- *Mapping* specifications and tools for the transformation of the BIM-based data from/to computational application models (energy simulation model, energy monitoring model, cost model).

Here we discuss primarily the use of the suggested Link Model approach in the HESMOS project. Details on the developed overall approach are provided in (Liebich et al. 2011) and (HESMOS 2014).

Basically, five types of non-BIM data are considered in the eeBIM framework. These are: (1) Climate and weather data, (2) Extended, detailed organized material data providing the needed material properties for sophisticated energy analyses, (3) Energy Templates providing ready-made configurations useful for early design decisions, such as space use, occupancy profiles, default element construction etc., (4) Pre-fabricated components with their specific energy-related properties from digital supplier catalogues, and (5) Sensor data from Building Automation Systems. Each of these types of data requires specific binding to the BIM data as shown in Table 1 below. However, the table also shows some of the difficulties that have to be overcome in the practical implementation of the Link Model. Thus, along with the trivial case of 1:1 correspondence between the BIM and the external data (as e.g. between climate data and *IfcBuilding*) more complex cases need to be resolved, too, such as the association of one external data item to a group of BIM entities known or not known in advance (e.g. material data associated to typed building elements, but also occupancy profile associated to a grouping of rooms that is not available as such in the IFC model) or the inter-linking of nested BIM objects to external entities (e.g. material properties to material layers in *IfcWallStandardCase*). In addition, there are various situations where geometric algorithms must be considered, such as the estimation of spaces which are bounded by outer (facade) elements, the estimation of the facade elements as such etc. For such cases, a set of open model management services called BIMfit have been developed to facilitate the multi-model integration.

Table 1. Overview of the multi-model links in the eeBIM framework

Multi-model issue	Related BIM concepts	Link type	Multiplicity
Climate data	Building; Facade	Explicit; Algorithmic	1:1; 1:N
Material data	Building element (& subclasses)	Explicit (nested assoc.)	M:N
Energy templates	Building; Storey; Zone; Space	Explicit (grouping assoc.)	1:1 to M:N
Pre-fabricated components	Building / Distribution element (& subclasses)	Explicit (grouping or nested associations)	1:1, 1:N, M:1
Sensor data	Space (external, internal); Building element	Explicit (algorithmic for locations)	1:1, N:1

Figure 5 below shows the overall multi-model framework. Starting with a BIM-CAD model, achieving run-time eeBIM integration and subsequent use of the model for energy simulation applications uses the following principal workflow.

At first, the architectural BIM-CAD model is filtered to strip off the data that is not needed in energy computations. In a second step, the obtained partial model is validated against specific domain requirements because not all formally valid models are also sufficient as basis for eeBIM. In a third step, the validated model is enriched with external data that can be incorporated in the model according to the model schema. This includes e.g. first to second level boundary conversion which is done fully on IFC level in HESMOS. In the next step, external non-BIM data (climate, occupancy etc.) is integrated via a pre-processor tool, using the described Link Model approach. Finally, a specific mapping for each integrated energy tool is applied.

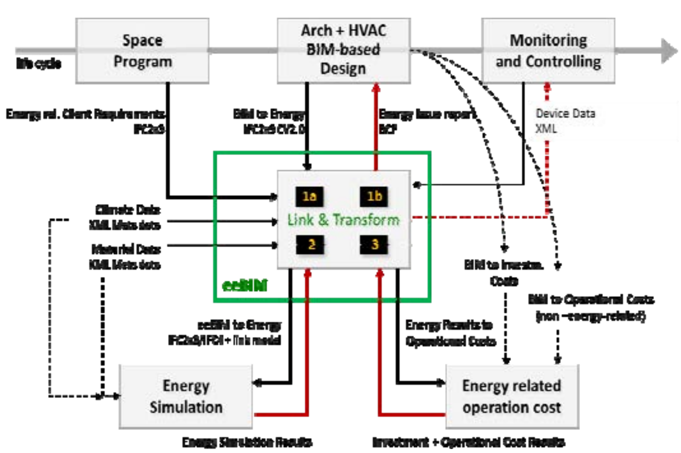

Figure 5. High level schema of the HESMOS eeBIM framework

BIM FOR ENERGY STANDARDISATION

Using the eeBIM framework of the HESMOS project, work on an Energy Model View Definition (MVD) has now begun within buildingSMART. This work is based on the overall MVD concept and the new mvdXML development enabling the formalisation of partial models as well as the definition of certain model consistency rules (Chipman et al. 2012). The scenarios developed in HESMOS are thereby considered as starting point for the definition of exchange requirements, such as client requirements, BIM to energy analysis, BIM to operational costs etc. (Bort et al. 2011). The expected result is an Energy MVD which shall be used for the certification of CAD applications that will support the export of relevant, sufficient and reliably verified BIM data for energy analysis and simulation tools such as DOE-2, EnergyPlus etc. Currently, mvdXML developments have started to define data quality checks to make sure that all required data is properly contained in an IFC file, thereby extending data validation capabilities. This work beneficially augments the HESMOS approach providing valuable, reliable and standardized support to the important first steps in the eeBIM integration process – retrieval, filtering and validation of the BIM-CAD data. Experience from the HESMOS testing phase has shown that there are numerous model validation issues that need to be considered before actual energy simulations can take place. Such issues include proper space boundary generation, space use assignment, consideration of technological spaces, material name assignments in alignment with IFC/IFD etc. Thus, the upcoming Energy MVD can considerably strengthen the HESMOS multi-model approach.

CONCLUSION AND FUTURE WORK

The eeBIM framework of HESMOS is based on an innovative multi-model concept comprising a consistent set of elementary models, with IFC-BIM as central integrating part and a Link Model to bind the distributed model data together. First practical results obtained from two real pilot projects showed already the validity and the benefits of the proposed approach. Further research work regarding eeBIM includes the realisation of the Link Model in the OWL ontology language, including model management and decision support extensions. Such eeOntology is currently under development in the frame of the EU project ISES (http://ises.eu-project.info). This is also an on-going discussion about how to combine static standardized BIM developments with highly flexible, decentralised and quickly evolving semantic web technologies enabling additional reasoning and decision-making capabilities.

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