Framework for Interoperability of Information Resources in the Building Energy Simulation Domain

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ABSTRACT

Designers and facility managers increasingly rely on Building Energy Performance Simulation (BEPS) tools to analyze complex building systems and determine whole building energy performance. A major barrier in the deployment of BEPS tools has been the lack of process interoperability and the magnitude and complexity of the required input data that often results in inaccurate and incomplete simulation models and simulation results. This paper introduces a Simulation Resource Framework that aims to gives end-users access to varied simulation resource libraries and energy-related design decision templates capturing weather data, occupancy activities, construction types and material thermal properties when configuring simulation models. Such templates and resources, bringing in expert know-how from theoretical studies and past experience, are especially valuable in early design where knowledge about the building's performance and components is incomplete but fundamental decisions have to be taken. In the paper we describe the overall concept and development approach of the suggested framework and its integration in a broader Multi-Model environment enabling interoperability of BIM and any needed non BIM resources hosted in the Simulation Resource Framework (SRF).

INTRODUCTION

Following the adoption of the European Parliament and Council Directive 2002/91 on energy performance of buildings (EU EPBD) that regulates nearly Zero Net Energy targets, an increasing demand for more comprehensive and integrated methods for building energy and CO_2 performance assessment in the design process has been recently observed.

Numerous applications and tools have emerged to assist designers in achieving these goals (cf. apps1.eere.energy.gov/buildings/tools_directory). Tools that enable various energy analyses and simulations under various dynamic load conditions and building usage scenarios, which give design teams the opportunity to optimize design solutions, evaluate alternative design options and make informed design decisions with regard to building energy performance and CO_2 emission already in the early design stages. There are however, at least two major barriers to deploy and integrate these tools into the design process.

Firstly, there is the lack of process interoperability. Building energy performance assessment typically relies on multi-disciplinary collaboration. Architects, building and material science experts, engineers and energy simulation experts cooperate to achieve optimal energy efficiency using varied ICT tools. Many of these tools share similarities in their modeling specifications, but this similarity mostly exists on conceptual level rather than on the semantic or schematic level. Consequently, the lack of data model compatibility significantly limits the possibility of automated data exchange without prior time consuming and costly manual or semi-manual reproduction, transformation and mapping of data between the different data models. Secondly, as energy simulation applications have become more and more sophisticated in realistically reproducing the actual building circumstances, so have the complexity of the simulation models and the magnitude of the data required to configure the simulation models. This imposes a considerable effort on the end-users and requires advanced simulation expertise and data modeling skills to achieve reliable and realistic results. Resource libraries are available from many software vendors that provide various reference data to assist users in the endeavor of configuring complex energy simulation models. However, in many cases they are poorly documented with regard to context, sources and scope and these resource libraries also exhibit the same interoperability issue – they target one specific application data model and therefore cannot be readily reused across application.

This paper introduces an approach developed as part of the European project ISES concept (http://ises.eu-project.info) targeting the interoperability in BIM-based building energy performance simulation and energy specific data enrichment by means of a Simulation Resource Framework (SRF) integrated on a virtual energy lab platform built upon a broader multi-model environment including BIM and any needed non BIM resources.

BIM-BASED BUILDING ENERGY PERFORMANCE SIMULATION

The BIM methodology (Eastman et al. 2011) is now widely established as the enabler for BEPS interoperability with design tools and the IFC standard (ISO 16739) provides a good basis for use of BIM information in BEPS applications. Most CAD/BIM and MEP tools offer IFC export of the building model thereby supporting an open standardized method for interoperability between different BIM-based downstream applications. However, despite the capability of the IFC model for capturing building information, energy specific concepts are missing or incompletely defined for downstream data exchanges that are required in BEPS models. Several factor attribute to this limitations in the expressiveness IFC model schema, modeling practices by architects and engineers(Level of Detail), CAD/BIM IFC export capabilities with possible information loss. Consequently, there may be a great deal of energy specific information that is specified in a BEPS model that is not included in the BIM. BEPS engines such as DOE 2.0, EnergyPlus, Nandrad and others (Kavcic et al. 2012) do not support the IFC data model directly. They generally use legacy type flat, text based, rigid data schemas with order and layout-specific mark-up to represent the simulation model

(O'Donnell, 2011). Consequently, for CAD/BIM and energy simulation interoperability the IFC model needs to be extensively pre-processed and appropriate energy specific model views derived that need to be enriched with incomplete or missing domain specific information (e.g. thermal properties, occupancy and operational schedules etc) to comply with the building model used by the BEPS tool. Data enrichment platforms have been demonstrated for example in COBie (East et al. 2012) – an intermediary model for "as built/operated" information in downstream FM exchange, by Simergy (See et al. 2011) together with SimModel (O'Donnell et al. 2011) – a BIM based integration platform for whole building energy performance simulation, and by the more generic Multi-Model Framework for energy enhanced BIM developed in the EU project HESMOS (Liebich et al. 2011).

THE HESMOS MULTI-MODEL FRAMEWORK

As already mentioned above, available BIM models like the current IFC2x3 or the new IFC4 model do not provide sufficient data to fully support information exchange requirements and tool interoperability in the energy domain. Therefore, while the re-use of available BIM data is of undisputable benefit with regard to teamwork and design coordination, the integration of BIM with external information resources is an essential issue to solve for the achievement of an efficient BIM-based work process. In principle, three approaches can be considered for that purpose.

The first approach is to extend the BIM schema(s) with new concepts, attributes and relations to accommodate the needed external information resources. Technically, this is the most efficient way to extend BIM functionality but it also has some major drawbacks: development work typically takes very long time, the model becomes increasingly complex and consequently more difficult to use in software.

The second approach is to extend the BIM data by using existing interface facilities in the model without changing the model schema. Within IFC various such extensions are possible using the flexibility of the IfcRelationship subclasses, the IfcProxy concept and the IFC property set mechanism allowing add-on attribution to various BIM entities. This approach is easiest to implement but it is also the most limited because proxies and property sets have relatively low semantic depth, require agreements that are not part of the model and can only cover scenarios where the needed external data is of low complexity.

The third and final approach uses a Link Model as a bridge between BIM and non-BIM data to provide for greatest generality, modularity and implementation scope. It does not require modification to the BIM schema and the external models used and it warrants that each model is maintained in its own domain. 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 more difficult model maintenance, the need of additional link model management services and some run-time performance deficits due to the higher structural complexity.

In the HESMOS project, the integration of multiple modelling resources has been realized using the Link Model approach (Liebich et al. 2011). Basically, five types of non-BIM data are thereby considered: (1) climate and weather data, (2) extended, detailed material characteristics needed by energy solvers, (3) energy templates providing editable ready-made configurations useful for early design decisions, such as space usage assignment, default element constructions etc., (4) pre-fabricated components with their specific energy-related properties, and (5) sensor data from Building Automation Systems. Each of these data types needs a specific binding to the BIM data. Such bindings range from straightforward 1:1 links to complex M:N relationships requiring additional algorithmic and/or logical processing. For example, the binding of climate data to IfcBuilding is an easy to implement 1:1 link, whereas the link of the same climate data to a specific façade of the building (a concept that does not exist per se in the IFC schema) requires 1:N relationships including sophisticated geometric pre-processing.

Such difficulties have born the idea to extend the HESMOS approach by developing (1) an ontology grounded on description logic; substituting the simpler Link Model based multi-model integration, and (2) a framework for external simulation resources of more general applicability as suggested in the following sections.

SIMULATION RESOURCE LIBRARIES AND TEMPLATES

Many simulation software vendors provide significant amount of reference data, templates and resource libraries that have a significant role in simulation model configuration to reduce the uncertainty and ambiguity in end-user decision making. Furthermore, simulation software engines are supported by different third party resource libraries, most notably, the EnergyPlus e.g. the NREL Building Component Library (bcl.nrel.gov), the window and glazing library (http://windows.lbl.gov/) while others have more limited options. For resource library providers to support a single simulation modeling software they simply need to ensure conformance to the schema specification, whereas supporting more than one or varied number of energy tools remains a intricate and a non-trivial task that involves:

- Data heterogeneity – proprietary data models, non-standardized semantics, lack of standardized methods for property definitions including naming conventions, units, numerical precision
- Technical compatibility – different data formats (text based, xml, binary) and technology platforms (file based, databases, web sites, web APIs)
- Simulation model compatibility – non-harmonized semantics in model schema specifications; the mapping from source model to target model must take into account each model's limitation and capabilities and provide appropriate individual actions

To ensure reliable information transfer of this inhomogeneous data domain in many to many data exchange scenario there is the need to formalize the exchange requirements to facilitate the coherent sharing and re-use of resource data by energy simulation tools in tandem. Based on these prerequisites, a generalized Simulation Resource Framework (SRF) is proposed. It features Common Resource Data Schemas (CRDS) and energy enhancement Templates (eeTemplates) represented as an application independent data model with concepts derived from industry standard semantics e.g. IFC, gbXML and DOE as schematically illustrated in the Figure 1.

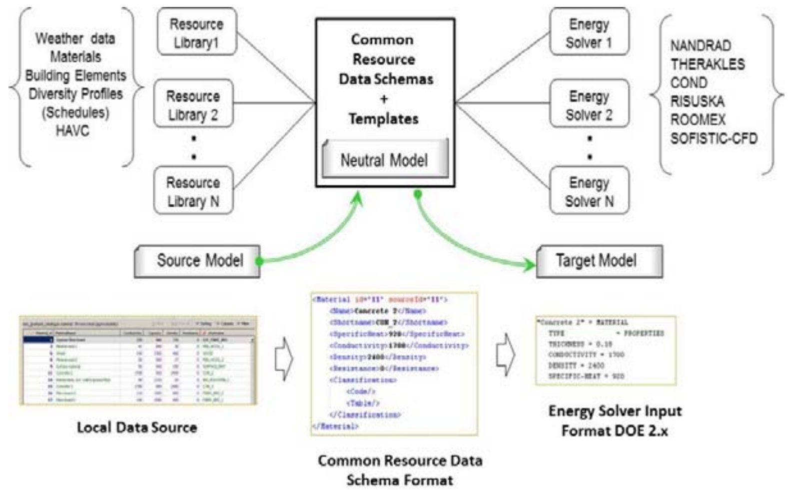

Figure 1. Resource Library Interoperability.

Application independent data models have gained momentum as an enabler in multi-domain information exchange. In the energy domain, relevant work include the Green Building XML (gbXML) an open schema that facilitates interoperability between BIM to BEPS tools (www.gbxml.org), the Simulation Domain Model (SimModel) presented in (O'Donnell et al. 2011), an independent XML schema, built primarily from the unification of the IFC data model, gbXML and the EnergyPlus input data model (IDF) to facilitate interoperability between CAD/BIM applications and simulation tools like EnergyPlus, Radiance, Modelica and TRNSYS. Other such modeling schemas include the HVACie Exchange Requirement Specification and Model View Definition (Hitchcock et al. 2012) and the Standards Data Dictionary developed by the California Energy Commission for energy code compliance checking and analyses (www.energy.ca.gov/title24).

SUGGESTED SIMULATION RESOURCE FRAMEWORK

The suggested SRF provides a service platform supporting the integration of non-BIM energy-related resources with BIM in the IFC based multi-model environment of the ISES platform. Currently the SRF defines its own XML resource schema for interoperability based on IFC, gbXML and DOE concepts and terminology. It therefore shares some resemblance with the SimModel, but its scope is limited compared to the SimModel as it supports only those resource types as discussed in section 3. On the other side, while still limited in scope, the SRF supports flexible integration of varied resource models in distributed networked data sources, thereby offering a broader availability of heterogeneous simulation resource data. The eeTemplate is a principal component in the multi-model integration process. Figure 2 illustrates the linking of eeTemplates in a multi-model eeBIM framework facilitating deriving a simulation model for different BEPS tools from the homogeneous eeBIM multi-Model. The SRF eeTemplates (Template Script) are XML documents whose elements (Template

Element Specification) collectively define a use case or a characteristic context of energy concepts. The template model facilitates dynamic integration of varied resource data models (Resource Services) as an application independent data model (CRDS) in the eeBIM. The SRF template model, further, enable context based adoption of templates by programmatic parametric interfaces and customizable data processing, including any data transformation, mapping and validation and stochastic sampling (Stochastic Processor).

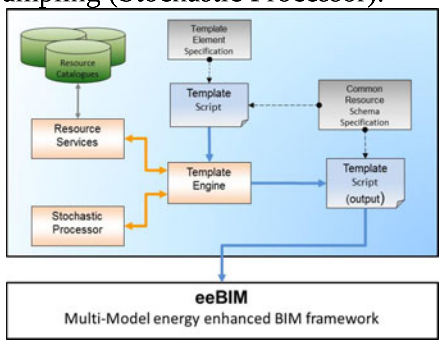

Figure 2. Schematic Overview of Using Templates in the SRF

The SRF uses Apache Jelly (cf. commons.apache.org/jelly) as the template engine, which is a Java and XML based scripting and processing engine that can be extended to support various custom actions as plug-in tag libraries that can work together seamlessly in the same XML document. The SRF defines its own custom tag library to: (1) rapidly retrieve resource data against any networked data source, (2) generate stochastic data sets for simple variables or time series, and (3) allow dynamic integration of data filters and transformers and ad-hoc code to support custom data processing, thereby enabling any data transformation, mapping and validation of the resource data, (4) dynamically adapt templates to a specific use context by a configurable parametric interface making them re-usable and/or adaptable between projects and (5) embed other templates for successive levels of detail. All templates produce output formatted according to the CRDS.

Stochastic sampling is enabled by specialized tags in the template script i.e. stochastic templates. Currently stochastic sampling is enabled for material properties and occupancy profiles. For example a stochastic Uvalue can be calculated for a construction type of compounded material layers, where the material thermal conductivity and thickness are sampled by using Latin Hybercube Sampling (LHS) techniques giving an Rvalue data set for the subsequent Uvalue calculation. Each material is associated with a given material class e.g. concrete, timber, insulation of different densities that contain the probability distributions for each material property. Similar approach is being developed for stochastic occupancy schedules. This however is beyond the scope of this paper.

The SRF development was primarily focused on developing a generic, flexible and extendable framework for energy related data resources. Figure 3 shows the SRF conceptual architecture and its principal components organized in three main layers.

The Adapter Layer facilitates the access and retrieval of heterogeneous energy related networked data. It provides three types of adapters to common resource hosting technologies: (1) file systems supporting protocols HTTP, FTP, WebDav, SMB and cloud-based file repositories, (2) web services SOAP and

REST, and (3) JDBC compliant databases. The framework provides an effective plug-in mechanism to allow custom adapters to be integrated, supporting other types of interfaces or more complex data sources (e.g. Open Linked Data, IFC product libraries). The Resource Manager does the heavy lifting in transforming native data model representations to the CRDS, by inserting a transient data pre-processing pipeline (described in XML) in the input data stream that perform the actual data transformation. This same functionality is also available from templates.

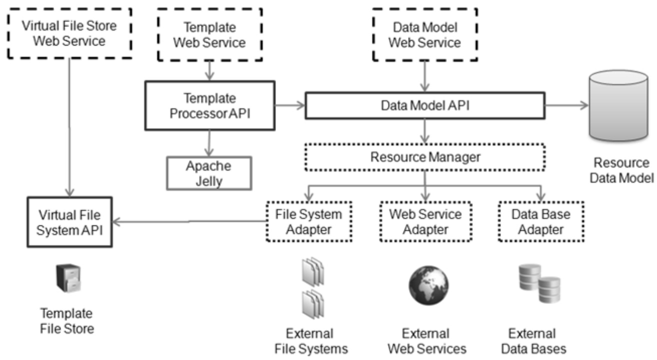

Figure 3. Resource Service Framework Architecture

The API Layer comprises three APIs: (1) Data Model API, which facilitates data management and access to resources through the adapter layer by use of Resource Descriptors (RD) hosted in the Resource Data Model database, (2) Template Processor API for resolving templates, noting that templates are file based resources with their own RDs, and (3) Virtual File Store API, which is an implementation of diverse file system protocols as mentioned above.

The Resource Descriptor is a collection of meta-data for annotation of data sources: (1) the descriptive meta-data e.g. semantic classification, use context, owner information and (2) technical meta-data specifying the resource programmatic interface. It also holds the transient pipeline XML description. To include new resources in the SRF it is only necessary to provide a resource descriptor for the respective data source along with the data model transformation code for which the SRF provides several helper utilities such as database record set to XML mapping and arbitrary XML to XML mapping.

Finally, the Web Services Layer provides the SRF Web API that exposes the three above APIs to the outside world using Representational State Transfer (REST) service architecture and JSON serialized request response representations.

CONCLUSION

This paper described a generic Simulation Resource Framework for integration of heterogeneous simulation resource data and energy-enhancement Templates (energy resources) in a broader Multi-Model environment enabling interoperability of BIM and any needed non BIM resources in downstream data exchange between Design and BEPS tools. These developments have achieved:

- A generic procedure for integrating various simulation resources containing the most essential and common data types
- Standardized and vendor-independent representation of this resource data using the Common Resource Data Schema Format
- Integration of this resource data in a broader Multi-Model environment by means of a flexible, extendible and scalable Simulation Resource Framework.

The scope of the Simulation Resource Framework is to cover some of the most essential and common resources that are associated with the building site, building envelope and building spaces (as outlined in section 3). It is not in any sense complete as not all the needed elements have been identified and defined and thus only part of the simulation domain effectively addressed. Developing a comprehensive vendor independent common data schema is a major undertaking, well beyond the scope to the ISES project.

The framework has so far been validated with various resources types from four independent sources with next steps pending the final ISES platform validation in the pilot projects.

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