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TOWARDS STANDARIZED BUILDING PROPERTIES TEMPLATE FILES FOR EARLY DESIGN ENERGY MODEL GENERATION

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ABSTRACT

Recent advances in the field of building performance simulation (BPS) have not only expanded the quantity of available tools but also widened their audience from the engineering professions to architects and planners. As the user pool expands and team efforts become more common, issues of standardization and exchange of simulation data have become critical for modelers.

Although significant efforts have been made in the development of formats for the exchange of geometry and weather data inputs for simulation, or full building energy models (gbXML, IFC), limited attention has been paid to the documentation and exchange of model inputs for building properties, such as material definitions or load profiles. The lack of a widely accepted file format for their comprehensive management becomes especially problematic in the case of rapid energy model generation during early schematic or urban design explorations, because it reduces the time available for design iterations and increases the risk of errors.

Supported by a survey of 150 BPS professionals about their current energy modeling workflows, this paper outlines a vision for a new energy modeling data framework based on the use of building properties (BP) templates as a standard input format through the design stages of a project. A proof of concept implementation of a BP template file format and a BP template editor tool are presented along with an example design simulation exercise.

INTRODUCTION

In the last decade, the field of building performance simulation (BPS) has significantly diversified both in terms of the variety and capabilities of tools developed, and the professional background of BPS users and developers. As architects and urban designers are starting to embrace and even develop new BPS tools, questions arise about how to ensure the quality of energy models built by this group as well as the positive impact of results in their design decisions.

To advance these questions, it is first necessary to understand and better define the specific purpose of the use of BPS tools in early design. At that stage, usually before mechanical systems are considered or expert consultants get involved in the project, BPS tools should ideally be used to inform architecture-related decisions regarding building orientation, form, envelope, glazing, and passive strategies,. The American Institute of Architects (AIA) has indeed highlighted and encouraged the use of BPS in design with the publication "An architect's guide to energy simulation" (AIA, 2012) where the term Design Performance Modeling (DPM) is used to define early design simulations as "*typically prepared during the early stages of design, before engineering systems are incorporated. Their analysis of energy use is less complex and time consuming, in order to allow for more rapid exploration of a greater number of parameters.*"

In order for DPM to become common design practice, an effective early energy modeling workflow is needed, that acknowledges the skills and weaknesses of the members of a design team. Given this constraints, it seems useful to organize BPS inputs into three separate groups: Weather data, building geometry and building properties (Figure 1). The term "building properties" (BP), representative of the third group, is used in this work to refer to all non-geometric data inputs that are assigned to a thermal zone within a building energy model. BP inputs can be classified into three main types: Constructions, thermal load profiles and conditioning systems. The reduction in the complexity of documentation and setup of the three types of model inputs in Figure 1 is a critical issue to be addressed in order to achieve the AIA's goals stated above. While significant progress has already been made regarding the first two, this paper is specifically concerned with the management of BP data inputs.

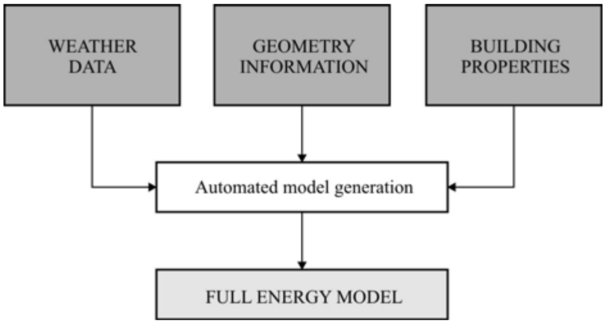

Figure 1 Components of a simulation model setup

Automated thermal model generation directly out of design environments such as Rhinoceros, SketchUp and Revit has been possible for a number of years. Prominent early examples of this genre are tools such as Autodesk Ecotect (Autodesk, 2014), OpenStudio (NREL, 2014), or Diva-for-Rhino (Jakubiec and Reinhart, 2011). While supported building geometries used to be quite limited, increasingly robust algorithms are becoming available that can automatically convert architectural models into multi-zone thermal models (Jones et al., 2013; Dogan and Reinhart, 2013).

In the case of weather data inputs, extensive work by Dru Crawley at the US Department of Energy (US DOE) during the early 2000s has led to the widespread use of standardized annual climate files, so called typical meteorological years (TMY) worldwide. This successful dissemination is the result of several activities, from the definition of a method to assemble hourly climate data (Hall et al., 1978), to the definition of the "epw" climate file format (Crawley et al., 1999) and finally, to the provision of epw files free of charge by the US DOE (DOE, 2014). This example shows that the successful adoption of a file standard requires both, an adequate format and a critical amount of useful content available in that format.

The previous paragraphs have shown that automated model generation and standard weather file formats have already helped to simplify and accelerate the process of setting up the geometric and climate aspects of a building energy model. Surprisingly, relatively limited attention has been given to improving the provision, exchange and documentation of the BP data inputs also required. The purpose of this paper is therefore to identify and address existing limitations regarding the effective management of such inputs for early design model generation. The driving hypothesis of this work is that the establishment of comprehensive standard "BP templates" as a BP data format will address those limitations and contribute to the widespread of BPS in architectural and urban design modeling.

The following section provides a review of previous efforts to standardize data formats and provision strategies for BP model inputs. Based on this review as well as a survey of simulation professionals about their current energy modeling workflows a number of limitations of current BP data provision formats are identified. The authors then outline a vision for a new data framework and a XML BP template standard file applicable from the early design stages onwards. Finally, an simulation exercise conducted in a class on energy modeling at MIT demonstrates the use of the format through different stages of design.

REVIEW OF CURRENT DATA FORMATS

The relevance of data inputs for building properties

The task of gathering information for all required BP inputs and entering it in a given BPS software constitutes the first step in any energy modeling workflow. The process can be time consuming and requires adequate knowledge of building physics and simulation tools as has been pointed out by others in the past: The uncertainty in load profile assumptions was identified as a main source for error in models and part of the four "big uglies" (known unknowns) of energy simulation (IBPSA Boston, 2010). Similarly, during the 2011 BEM Innovation Summit hosted by Rocky Mountain Institute (RMI, 2011), the lack of quality in model data inputs was identified as one of the main issues preventing the effective adoption of BPS in industry.

In the case of early design explorations, the issue of BP data quality becomes crucial because inadequate inputs may not only result in significant errors in the results, but actually misinform the design process altogether. For example, if the assumed value for internal loads is too low, the selected window to wall ratio determined by DPM might be too large. In this context and without further support from modeling experts, the lack of knowledge among designers of what reasonable input values are increases the risk of error. To mitigate this risk, two steps have to be taken.

First, it is necessary that simulation tools are taught in conjunction with their underlying basic physical fundamentals and limitations. How to accomplish this lies out of the scope of this paper. Second, meaningful BP data inputs have to be effectively available so that designers can use simulations to improve a proposal without requiring an excessive amount of time for model setup. Indeed, classroom experiments developed by Diego Ibarra showed that only in cases in which simulation trainees were provided with predefined sets of BP inputs, they were able to iterate through several models and improve their initial design within a 1.5 to 2 hour time window given in the exercise (Ibarra, 2014).

Previous work on building properties data sources

In addition to the stated risks of using wrong BP inputs in early design, the gathering of BP input data itself is a tedious and time consuming process that requires a consensus between client, consulting experts and designers. Which standard is the project trying to comply with? What energy efficiency measures are considered? Collecting and agreeing on these assumptions is a necessary step before any meaningful project-specific design exploration can be conducted.

When setting up a model, typical sources of data include reference guides published by professional organizations such as the ASHRAE Handbook of Fundamentals (ASHRAE, 2009), ISO international building codes, or publications from research institutions such as the US National Laboratories (NREL, 2011). These sources are available in the form of physical and digital reports which require time and knowledge for their implementation into building energy models. While some BPS tool developers provide basic data sets in a file format specific to their tool there is yet no standard open format which - as in the case of weather files - bundles all data required for a thermal zone setup into a single file.

The library structures typically present in BPS tools help in the management in BP data in early design. In addition, a few tools such as DesignBuilder include large pre-populated libraries of materials, schedules and systems, making them very useful for early design modeling. However, neither of these tools supports an open file format for BP data exchange. Although understandable from a commercial point of view, their protection of in-tool data sets hinders the potential for exploring different performance aspects, such as daylight or life cycle cost in other simulation programs.

While a general open BP data structure is still missing, there have been succcessful contributions focusing on specific building components. For example, the data format used in the Complex Glazing Database commonly retrieved through the WINDOW software (LBNL, 2014) can be imported by several building simulation programs. More recently, ASHRAE has been involved in the definition of standards for specification and exchange of HVAC&R data through the published Guideline 20 (ASHRAE, 2010) and the still under revision Standard 205p. While laudable, these very specialized successes are unlikely to have a sizeable impact on the use of early design simulations. In the field of data standards, two main BIM open file formats, Industry Foundation Classes (IFC) and gbXML, have been proposed in order to facilitate the exchange of complete building models (IFC, 2014) (gbXML, 2014). However, while they offer data structures applicable to many BP data inputs, they have not been designed for storing and distributing BP definitions not yet assigned to a particular geometry. The generation of an exchange file format such as gbXML requires a designer to previously setup detailed BP inputs in the model, and does not help to provide references of adequate input combinations in the generation and setup of the model itself.

Another project aimed to improve BP data sharing and distribution is the Building Component Library (BCL) developed by NREL (Fleming, Long and Swindler, 2012) which addresses many of the previously stated limitations by offering an online library infrastructure for sharing simulation data. The BCL currently includes single components, such as materials, schedules, or systems, in EnergyPlus, OpenStudio and xml formats, addressing issues of data quality, provision and exhange. While representing an important contribution to the improvement of BP input management in early design, it lacks the extensive content of software libraries and does not provide BP data for full models.

Summing up, while the reviewed initiatives have contributed to facilitate BP inputs management in early design simulations, current workflows, especially in the case of non-expert design modelers, leave space for improvement. Since these conclusions are solely based on an analysis of available data sources for energy modeling, and a better understanding of BP data workflows in professional practice is necessary to further support them. A survey of energy modeling practitioners was therefore developed as part of this research which is presented in the next section.

PROFESSIONAL PRACTICE SURVEY

Survey purpose and methodology

In March 2014 the authors developed an online questionnaire on current building simulation workflows in professional practice. Its specific goals were to:

1. Identify the most usual sources and workflows for model setup and exchange of BP data.
2. Characterize the amount of time spent in a project on setting up BP model inputs.
3. Assess the acceptance of a BP templates open format for data provision and documentation.

The survey included a total of 15 questions and was organized around three main sections: (1) Participant characterization, (2) usual model setup workflows, and (3) assessment of limitations. A link to the electronic survey was sent to participants of “onebuilding.org” and “IBPSA” mailing lists and professional contacts of the authors. Between March 7th and April 30th, one hundred and fifty valid responses were gathered.

Survey results analysis

The participant pool included a variety of consultants and designers of which 50% reported to use simulation during early architectural design. The main source of participants was the US (47%) followed by Europe and Asia. Within the context of this manuscript, three key finding were made based on the survey responses.

First, there is little exchange of BP data inputs between practitioners when setting up a model in a new project. When asked about their typical model setup procedure 7% reported they start by adapting inputs or models from a colleague. The majority reported to either set up BP inputs from scratch (62%) or reuse a previous personal model (31%). In the former case typical data sources included software libraries or reference guides, but almost never discussions with colleagues or clients.

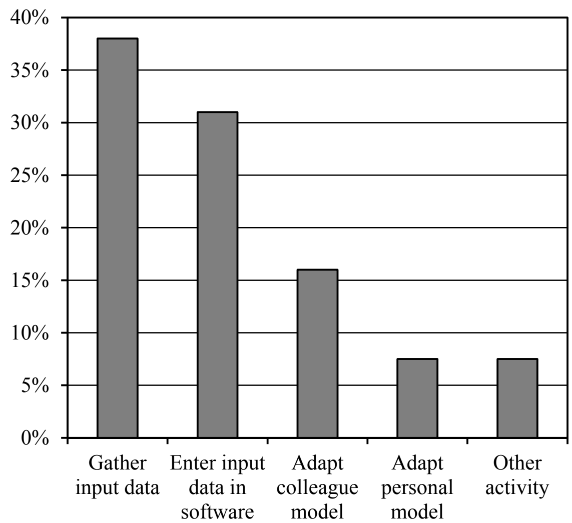

Figure 2 Main time loss in the setup of model inputs

Second, 90% of all participants responded they typically dedicate 20%-50% of the time spent in a project on setting the BP inputs for the energy model. In addition when asked about the specific use of that time, data gathering (38%) and data entering in software (31%) scored much higher than any other activity (Figure 2).

Third, a majority of the participants (87%) indicated a willingness to use BP data provided in a standard format from professional or academic institutions. The number fell to 48% in the case data comes form other professionals due to concerns regarding liability and data quality.

Based on the previous section review and the results of this survey, the authors identified three remaining barriers to the use of simulation in early design related to the management of BP data inputs and the lack of a standard file format for their distribution:

1. Time consuming data input: The tedious gathering and validation of BP data – up to 50% of the time spent in a simulation project – inhibits the possibility of rapid energy modeling during early design.
2. Risk of modeling errors: The low expertise of designers in energy modeling, especially in the absence of collaboration with consultants, can mislead the design process. The survey results suggest that data exchange with experts is rather infrequent.
3. Barrier for data provision: The lack of a common specification format represents an obstacle for institutions and professionals to distribute data, leading to many modelers largely working in isolation. However, 87% of the surveyed were willing to use a public standard BP dataset format if properly referenced and validated.

In response to these three barriers, the following sections propose a data management framework for simulation in early design and a prototype for a XML file format to store “BP templates”.

DATA FRAMEWORK PROPOSAL

In the following proposal, a “BP template” refers to a comprehensive set of energy simulation BP inputs that characterize all attributes of one or multiple thermal zones and which can be combined with geometry data in order to generate a full energy model. While BP templates might be too limited to describe certain advanced energy models with complex spatial configurations or mechanical systems, they are useful for managing and assigning BP inputs in most schematic and urban design models. In the following, an early design simulation framework based on BP templates is developed through the following components: (1) A BP template file format prototype, (2) a data management workflow for design, and (3) a BP template editor software tool.

BP template library file prototype

Within a BP template data structure, information can be grouped into four main categories: General data, constructions, thermal loads and conditioning systems. Within these categories each BP input is assigned to abstract building attributes such as “exterior wall” in the case of constructions or “occupant density” in the case of thermal loads (Table 1). In the proposed file the categories mentioned in Table 1 can be organized into a data tree structure with three levels of information: The zone template itself, the category level and the attribute level. In addition, certain dependencies such as constructions, materials and schedules require their own definition outside of the building template structure.

Table 1 BP template data structure contents

Category	Attributes
General data	Use, code, description
Constructions	Exterior wall, roof, ground floor, internal floor, external floor, basement wall, glazing and window to wall ratio, partition, thermal mass type and ratio.
Thermal loads	Occupation density and schedule, equipment density and schedule, lighting density and schedule, infiltration rate.
Conditioning systems	Heating and cooling set points and schedules, mechanical ventilation rates and schedules, natural ventilation rates and schedules, CoP for systems.

As a proof of concept, the proposed BP template file has been implemented as an Extensible Markup Language (XML) file which offers flexible and accessible classification of data, and is highly compatible with potential online applications. The application of XML structures in BPS definition of building components is not new, with gbXML being the most accepted example of a format used for the definition of complete BIM models. Within a gbXML file, context, building shell and interior space geometry form the first section of the data structure and are followed by a list of materials and schedules that are used in that particular model. Another existing XML format for BPS is the earlier mentioned BCL online library for individual building properties inputs. It should be stressed that the BP template proposed in this manuscript could be adapted to any of the existing file models. In fact, it already follows the structure of a gbXML file in which the geometry definition has been substituted by a set of BP template data structures.

The proposed BP template file is organized into two main sections (Figure 3): Section A includes one or more BP template definitions, each one representative of a different space type, building archetype or design scenario stored in the file. Section B contains definitions for all data dependencies of the templates. These include opaque and glazing constructions, materials, and yearly, weekly and daily availability schedules. The file capability of storing multiple thermal zones or building definitions, not available on existing XML file types, makes the BP template adoptable in different uses ranging from early architectural design to urban design and planning. More importantly it offers the possibility for designers to work with predefined standard templates greatly reducing input time and errors.

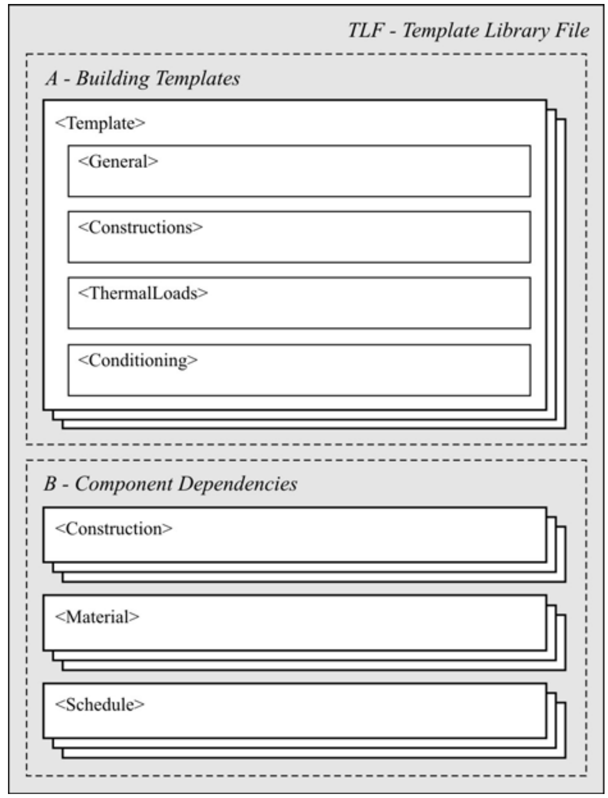

Figure 3 Proposed XML format file structure

Workflow for BP template management in design

A main innovative attribute of the BP template library file is that it allows separating the production of the BP templates from the energy modeling itself. During design a simulation expert could hence be responsible for providing the BP template, while geometric manipulations and simulations are run by a designer. Such a shared workflow would streamline the model setup and likely improve overall model quality. Figure 4 summarizes the proposed workflow in three phases: Provision, design modeling, and documentation.

In the provision phase the data for BP templates would be gathered and validated by a separate entity from the designer, such as a professional institution (e.g. ASHRAE, USGBC), a municipal building department, an expert consultant, or a combination of these. Afterwards templates would be organized and given to the designer in the form of the proposed BP template library file. The structure of these files could represent:

1. Archetypes of an existing built stock as a base for retrofit projects provided by a city government,
2. Multiple code compliant building settings provided by professional institutions or,
3. Different EEM combinations for a project custom-tailored by a consultant for design.

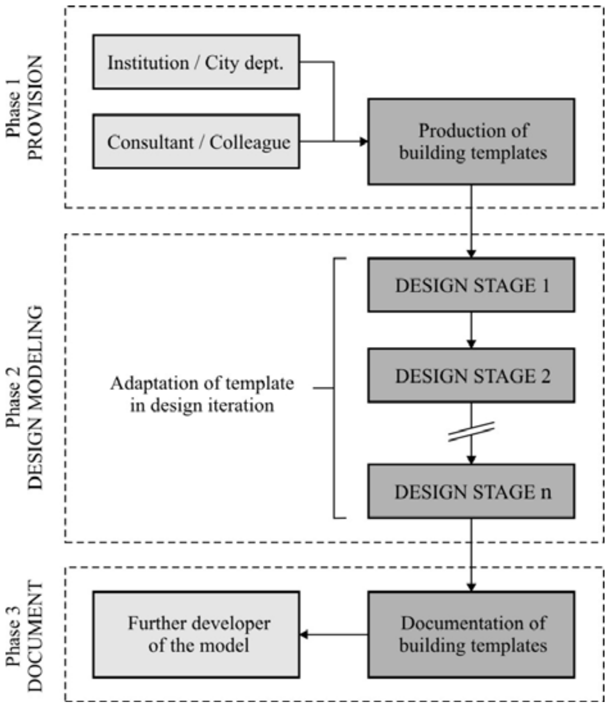

Figure 4 BP template files use and provision workflow

During the design modeling phase, the open template library format could be used at different scales and for different types of simulation analysis. The proposed workflow envisions the simulation work of designers to start with the development of "shoebox" type models to understand the characteristics of the template, to then move to the scale of complete building massing explorations, and potentially to urban massing with the inclusion of multiple building types. Versions of the same BP template definitions could be progressively added to the BP library file throughout these stages.

Finally, during the documentation phase, the template files used or modified during design could be stored and shared with clients or institutions. Given the similarity of a BP template library file with complex BIM data structures such as gbXML, the former could also be used to generate a full BEM using the later.

BP template file editor

Since in the envisioned workflow the task of the management of BP template files is separated from the modeling itself and is assigned to specific agents which are not those typically in charge of the design, it is necessary to provide a digital infrastructure for their manipulation. The authors propose that the typical library functionality present in BPS software could be isolated as an individual tool that is engine independent. As part of this work a simple BP template editor was developed as a stand-alone application programmed in .NET framework.

The BP template editor consists of a simple explorer interface divided in two panels (Figure 5). On the left panel a data tree representing the opened BP template provides access and control of all template components. On the right panel selected component attributes can be reviewed and edited. Initial versions of the BP editor have been successfully implemented as a plug-in application for two simulation tools currently being developed by the authors for Rhinoceros/Grasshopper: Archsim, a multizone modeling tool (Archsim, 2014) and Umi, an urban modeling tool (Reinhart et al. 2013).

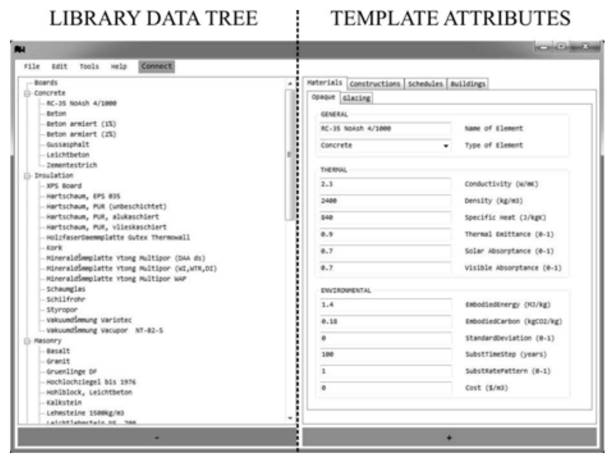

Figure 5 BP template editor screenshot

In addition to file production and editing, the BP editor supports the import of the BP data from two existing open text file formats (IDF and gbXML). It further incorporates tools for merging and dividing existing library files and intelligent auto-completion of empty entries with similar components within a BP library set. Finally, in order to share simulation input libraries with a wider audience the BP editor could be synchronized with a web server database such as the BCL (Figure 6).

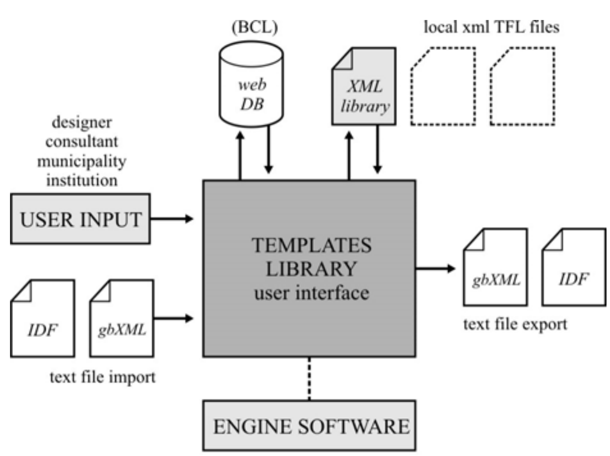

Figure 6 Exchange functionality of the template editor

In class simulation exercise: Modeling MIT campus

In order to demonstrate the benefits and mechanics of the introduced data framework, this section briefly describes a case study project that was conducted in the context of the class "*4.433 Modeling Urban Energy Flows*" at MIT during Spring 2014. The class teaches the fundamentals of energy modeling in individual buildings and at the neighborhood scale. The goal of this class project was to build an energy model of the entire MIT campus in order to develop a long term energy retorfitting strategy for the institute's built stock. While the general findings are not relevant for this work, this following description focuses on the continous use of BP template files through the analysis, calibration and design phases of the project.

As a preparation for the class, information about buildings on campus was gathered including drawings, space use breakdowns, metered energy use, and construction data. Where applicable, the data was converted into a BP template files and provided to the students. Throughout the class, as shown in figure 7, the students applied the templates at three scales: Individual space (1), building (2), and the campus (3).

In a first step the students applied the BP template of a selected building space type to a shoebox model to familiarize themselves with the BP data (1). Later, they built detailed multi-zone energy models of a particular building, and applied the respective BP templates to each zone within (2). The template inputs were then modified to better approximate the metered energy use. During step 3, all campus buildings were clustered into five space types: academic, laboratory, dormitory, classroom and services. Secondary spaces such as hallways, restrooms and kitchenettes were averaged into these fundamental space types using the BP template editor. The resulting five BP template files were assigned to all campus buildings resulting in an overall simulation model.

Based on that campus scale model, retrofit scenarios could be created by furtther modifying the BP templates. In order to test the response of the buildings to certain upgrade measures, the students brought back the BP templates to shoebox simulations. Whenever a measure was effective, the students saved the model configuration as a new BP template file and then moved on to test the next measure. The result of this iterative search was a BP template library file that included a collection of plausible retrofitting scenarios for the campus, which were then reapplied to the whole campus model. The multiscale design exploration of the project through simulation, developed as the work of a group in collaboration with campus facilities, was made possible by the application of the BP template file.

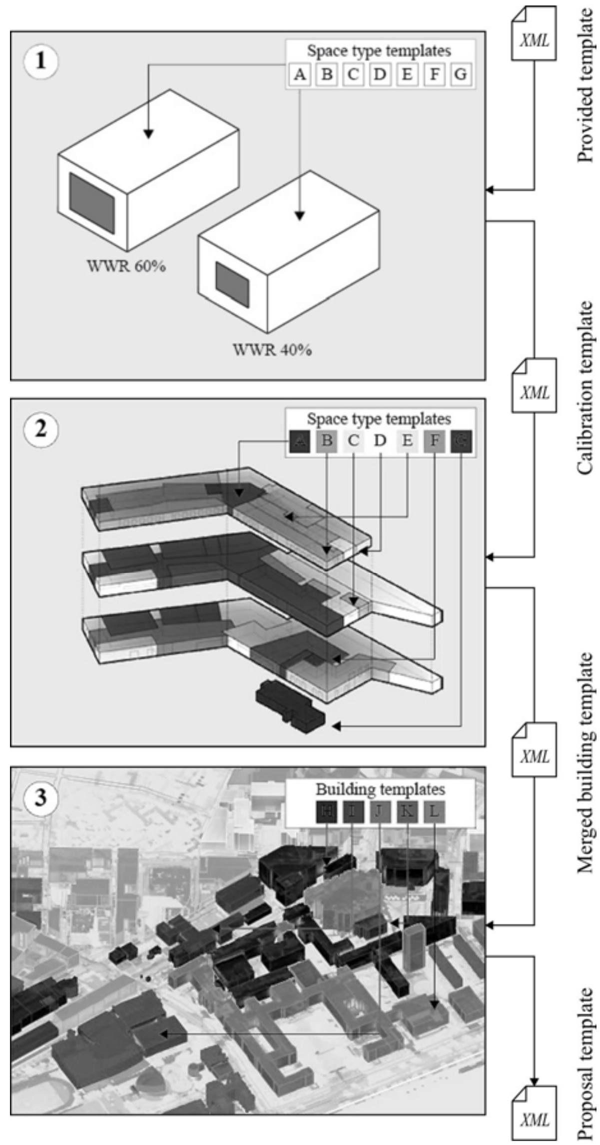

Figure 7 Use of template files in MIT model scales

DISCUSSION

Streamlining BPS data in collaborative design

Previous sections have shown that separating BP inputs from geometry inputs in a model allows designers to effectively apply in their work templates provided by experts within or outside the team. A critical reader might consider whether this approach goes against the idea of integrated design simulation by reducing the agency of both architects and consultants. However the authors foresee a more fruitful form of collaboration, as the ownership of a full energy model can now be shared by all parties through the separate manipulation of BP template files and model geometry. That way the task of each party is better aligned with their skillset.

The template file thus becomes an attractive design tool for the architect, because it encapsulates complex BPS inputs in an architectural object which can directly be used to generate an energy model. It should be stressed that this framework does not seek to replace the functionality of current exchange formats such as gbXML, but rather increase their effectiveness in design by strategically isolating their components.

Standard data provision for BPS

Despite of the previously described benefits the authors believe that an effective format is not sufficient to achieve a wide acceptance of BPS in architectural design. As the epw example has shown, the success of a file format is highly dependent on the amount and quality of available data publicly offered in such format. Who should be responsible for the task of generating and maintaining this infrastructure?

The role of data providers should be assumed by trusted institutions such as ASHRAE, USGBC, AIA or IBPSA capable of assuring the quality of data and that way guaranteeing its acceptance by professionals. This BP data, which in many cases has already been published by the referred institutions, could easily be distributed in the BP template file format improving its usability.

CONCLUSION

Based on a literature review of existing BP data formats and sources, and a survey of 150 energy modeling professionals this paper argues that despite existing efforts in the field of data standardization for BPS, there is a need for a BP template format that encapsulates all non-geometric model inputs for a thermal zone. A proof of concept BP template file format and editor tool were proposed, and their usability was proven in a class project for the energy modeling of a university campus.

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