DATA ENVIRONMENTS AND PROCESSING IN SEMI-AUTOMATED SIMULATION WITH ENERGYPLUS

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ABSTRACT

Building energy performance (BEP) simulation is increasingly used worldwide to quantitatively justify building design decisions and building operations strategies. It is becoming increasingly obvious that the results of such simulation are often questionable, cannot be trusted, and may lead to wrong decisions. Poor simulation model definition and the use of inappropriately acquired and transformed data are two of the most common causes of this. The use of LBNL methodology for semi-automated BEP simulation data input automates data acquisition and transformation, which removes human decision making from the simulation input data definition process. The first of the three major software components (the Geometry Simplification Tool or GST) is already in use. Work on the second component (an interoperable HVAC graphic user interface for EnergyPlus) is under development. The third component (an internal loads generation tool) will be developed in the near future. The original HVAC GUI for EnergyPlus component has evolved into a BEP simulation platform code-named Mojito. A new internal data model which defines all object/attribute/relationship sets used in BEP simulation, called SimModel, is the central feature of Mojito.

Modeling imprecision is very characteristic of geometry representation in building models submitted by the Architecture-Engineering-Construction-Owners-Operator (AECOO) industry. This, and the lagging and very slow development of CAD utilities that can generate higher-level space boundaries needed in BEP simulation, has forced the development of a new tool (SBT) that calculates higher-level space boundaries from IFC-compliant definition of basic building geometry from any model-based CAD tool. It has also forced the addition of new data transformation rules in GST.

This paper describes the principles and high-level views of SimModel, SBT and GST internal architectures, and discusses some of the model and tool functionalities. It also provides a brief summary of quality assessment characteristic of building models generated in the AECOO industry.

Keywords: Building data, semi-automated simulation, simulation software, energy simulation data model, data transformation.

1. INTRODUCTION

The increase of awareness about the critical role of buildings in the overall consumption of energy in all industrialized economies is resulting in an increase in the use of building energy performance (BEP) simulation to quantitatively justify building design and operations decisions. Yet, it is becoming increasingly obvious that the results of such simulation are often questionable, cannot be trusted, and may lead to wrong decisions. Poor simulation model definition and the use of inappropriately acquired and transformed data are two of the most common causes of this. The use of the methodology for semi-automated BEP simulation data input (Bazjanac 2008) automates data acquisition and transformation, and thus removes human decision making from the simulation data definition process. The first of the three major software components (import of building geometry, mechanical systems definition, and schedules of use and operation) necessary to deploy this methodology (Figure 1) – the Geometry Simplification Tool (GST) – is already in use (Bazjanac

2009). Work on the second component – an interoperable HVAC graphic user interface (GUI) for EnergyPlus – is well under way. Given the necessary funding, the third component – an Internal Loads generation Tool (ILT) – will be developed in the near future.

The methodology for semi-automated BEP simulation data input was originally (and still is partially) based on the use of data defined in IFC format according to the rules and protocols standardized by the IFC data model of buildings (buildingSMART International 2011). IFC-compatibility was also originally (and still is in some cases) required for software that generates original building data needed in BEP simulation.

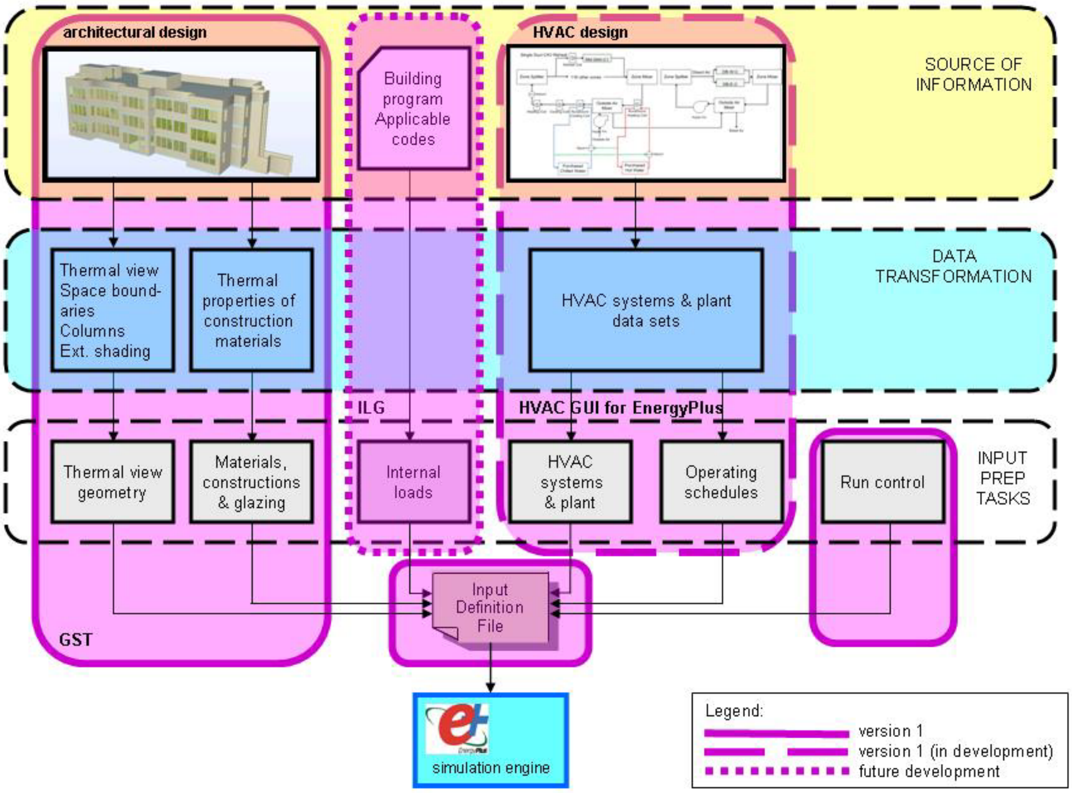


Figure 1: Implementation of the methodology for semi-automated building energy performance simulation (Bazjanac 2009)

The HVAC GUI was originally conceived to serve as a component that provides semi-automatic data acquisition and transformation for HVAC equipment, systems and plant information resident in instances of IFC-based Building Information Models (BIM), per data transformation rules embedded in the GUI (similar to the function of GST related to building geometry data). This concept has since grown into a much more comprehensive (and complex) utility with a code name Mojito: a platform that facilitates data flow to and from BEP simulation from/to potentially *any* tool, IFC-compatible or not, that is capable of seamless communication with Mojito.

This platform concept facilitates import, transformation and bi-directional flow of data originating in diverse sources, such as IFC-based BIM, DOE-2 and tools that use DOE-2 as their simulation engine, EnergyPlus, and tools with gbXML export. Tools that perform data transformation (like GST) are part of the platform and are invoked in Mojito as necessary. Conceptually, all tools that implement the methodology for semi-automated BEP simulation data input are folded into a more comprehensive and flexible tool environment – Mojito.

Since internal data models of EnergyPlus (defined in EnergyPlus IDD file) or any other BEP simulation engine are limited, inconsistent, "flat" (i.e. not object-oriented) and do not individually contain all data definitions used in BEP simulation in general, the central feature of Mojito is a new object-oriented internal data model which defines *all* object/attribute/relationship sets used in BEP simulation. Since this data model defines specifically data and data definition protocols used in BEP simulation, it is called *SimModel* (O'Donnell et al. 2011). Data from IFC-based BIM, from tools with

DOE-2 engine, from EnergyPlus and from tools that export data in gbXML format are automatically imported and mapped to this SimModel. Data are also automatically mappable the other way – from SimModel to the original data base that contains the data from which the transformed data were derived.

Interoperability with other pertinent software packages relevant to the simulation and/or analysis of BEP will be added in the future. Beta release of the first version of Mojito with somewhat limited functionality is expected late in the fall 2011.

2. SIMMODEL – DATA MODEL FOR ENERGY SIMULATION

The primary objective of SimModel is to accommodate the existing input data requirements of EnergyPlus, while allowing mapping from/to other domain data models and easy incorporation of new definitions. New definitions will include those that define new features of EnergyPlus, new features in the BEP simulation domain and future new building elements and features. Concepts and internal architecture of SimModel are in general derived from principles of the IFC data model of buildings. Since SimModel contains data definitions not present in the IFC data model, definitions corresponding to the missing object/attribute/relationship sets will be added to the IFC data model as an addendum to IFC 4.

SimModel features an object class hierarchy that includes "hard" and "soft" class types. The "hard" types represent the overall modeling concept of a building, its systems and its use, while the "soft" types and subtypes add content to the "hard" types. This data driven flexible approach ensures that a large amount of data is loadable at runtime and that SimModel is compatible with all versions of existing and future data models that are mapped to/from SimModel. Such approach also provides greater consistency in schema-driven code generation for tools that leverage SimModel.

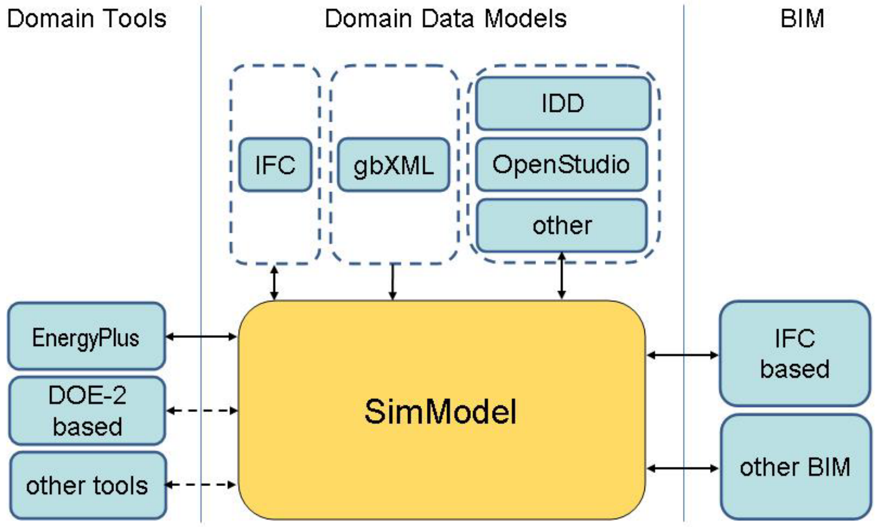


Figure 2: SimModel service environment

The complete SimModel (Figure 2) will be able to import data from a variety of sources: domain tools (EnergyPlus, tools that deploy DOE-2 as engine and, in the future, other tools that may or may not be IFC-compatible), as well as from BIM (IFC-based BIM or BIM based on BEP simulation domain data models other than IFC). BEP simulation domain data models (Energy Simulation Model View of IFC, data models which support exchange of data in gbXML format, the internal models of EnergyPlus and OpenStudio, and potentially other domain data models) are or will be mapped to SimModel. In this way SimModel will provide data definitions for the entire BEP simulation domain.

Figure 3 shows the SimModel data hierarchy and path. Both are similar to those in the IFC data model. Elements that represent "location," "simulation" and "simulation reports" in the diagram define data specific to the instance of the simulation and are not transformed. "Other systems" represent energy systems that are not HVAC (such as electrical systems) and systems yet to be defined in SimModel (such as hybrid systems). This model architecture allows easy identification, locating and access to any datum in the SimModel (LBNL 2011).

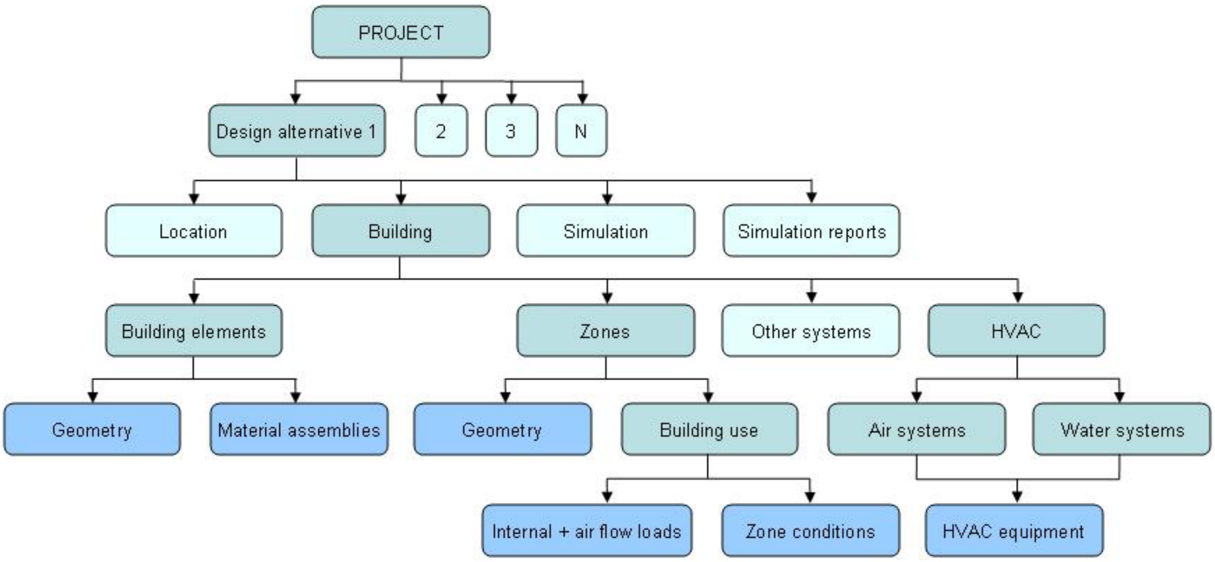
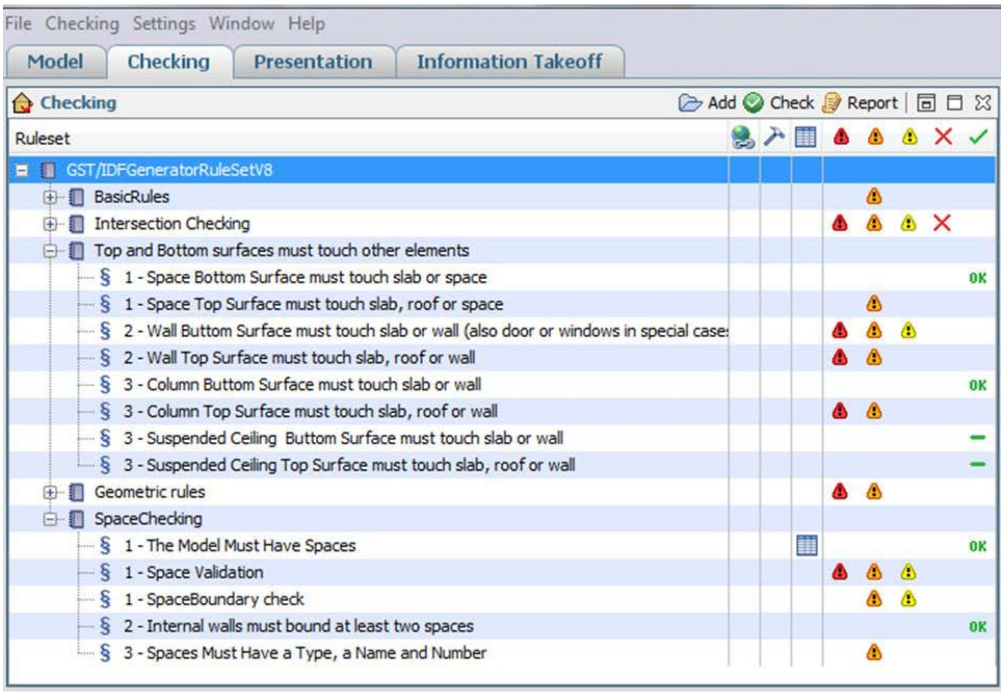


Figure 3: High-level SimModel data hierarchy; by courtesy of Richard See (See and Keep 2009), adapted.

3. BUILDING MODELS FROM INDUSTRY: CURRENT REALITY

Semi-automatic import of building geometry into EnergyPlus (and into other tools that have a geometry model similar to that of EnergyPlus) requires a “clean” original geometry model. A “clean” building model is one that is immediately readable by data transformation tools and can subsequently be processed without any difficulty. LBNL checks of building models created by the AECOO industry with Solibri Model Checker (Solibri 2010) typically reveal modeling problems – submitted models are anything but “clean.” Almost as a norm, most of the problems result from lack of precision in modeling, omissions, and/or duplications of modeled objects.

Solibri Model Checker (SMC) checks instances of building models for inaccuracies: meeting and intersection of objects, consistency of space geometry definitions, inadvertent object duplication and more. SMC incorporates a number of different “constraint sets” (rule sets) which check models for issues characteristic of a particular industry discipline, domain, IFC model view and/or software type.



Ruleset			▦	⚠	⚠	⚠	✗	✓
⊟ GST/IDFGeneratorRuleSetV8								
⊞ BasicRules					⚠			
⊞ Intersection Checking				⚠	⚠	⚠	✗	
⊟ Top and Bottom surfaces must touch other elements								
§ 1 - Space Bottom Surface must touch slab or space								OK
§ 1 - Space Top Surface must touch slab, roof or space					⚠			
§ 2 - Wall Buttom Surface must touch slab or wall (also door or windows in special case				⚠	⚠	⚠		
§ 2 - Wall Top Surface must touch slab, roof or wall				⚠	⚠			
§ 3 - Column Buttom Surface must touch slab or wall								OK
§ 3 - Column Top Surface must touch slab, roof or wall				⚠	⚠			
§ 3 - Suspended Ceiling Buttom Surface must touch slab or wall								–
§ 3 - Suspended Ceiling Top Surface must touch slab, roof or wall								–
⊞ Geometric rules				⚠	⚠			
⊟ SpaceChecking								
§ 1 - The Model Must Have Spaces			▦					OK
§ 1 - Space Validation				⚠	⚠	⚠		
§ 1 - SpaceBoundary check					⚠	⚠		
§ 2 - Internal walls must bound at least two spaces								OK
§ 3 - Spaces Must Have a Type, a Name and Number					⚠			

Figure 4: Example of a summary of results from model checking with SMC

Figure 4 shows an example of SMC model checking results when invoking the GST/IDFgenerator constraint set (all models intended to be the source of information for simulation of building energy performance should be checked using that constraint set). SMC checked the particular building model for correct (i.e. *sufficiently precise*) definition of object intersections (e.g. that walls, slabs and/or columns meet but do not penetrate other walls), object connections (e.g. that walls and columns "touch" the floor slab underneath and the ceiling slab above), geometry rules (e.g. space boundaries which define walls, slabs and/or columns are correctly calculated), and defined spaces (e.g. proper tagging of defined spaces). When the model fails a particular check, a red triangle appears in the report – the modeler then must be corrected the model before it can be further used. Currently, the correction is manual and typically tedious, *very* time consuming, costly and frustrating. Sadly, virtually all initial checking of building models results in errors similar to those reported in Figure 4.

Given the typically insufficient level of support for modelling work and the often insufficient modelling experience of the modeler, it is not likely that the quality of building models submitted by industry for building energy performance simulation and analysis will substantially improve in the foreseeable future. The only immediate solution to the problem is to define and use "variable tolerances" in model checking – checks which distinguish between model imperfections that can be corrected automatically in software from those that cannot and thus must be returned for correction by the modeler.

4. NECESSARY ADJUSTMENTS TO SEMI-AUTOMATIC GEOMETRY IMPORT

The lack of software that is able to correctly calculate all necessary 2nd, 3rd, 4th and 5th level space boundaries (Rose et al. 2011, Bazjanac 2010) presents another problem. Only the IFC2*x*3 Utility for ArchiCAD 13 is currently capable of the task; unfortunately, Graphisoft has no plans to port it to ArchiCAD 14 or 15. Some of other major CAD vendors are reportedly working on similar utilities that will generate higher-level space boundaries for users of their own CAD tools.

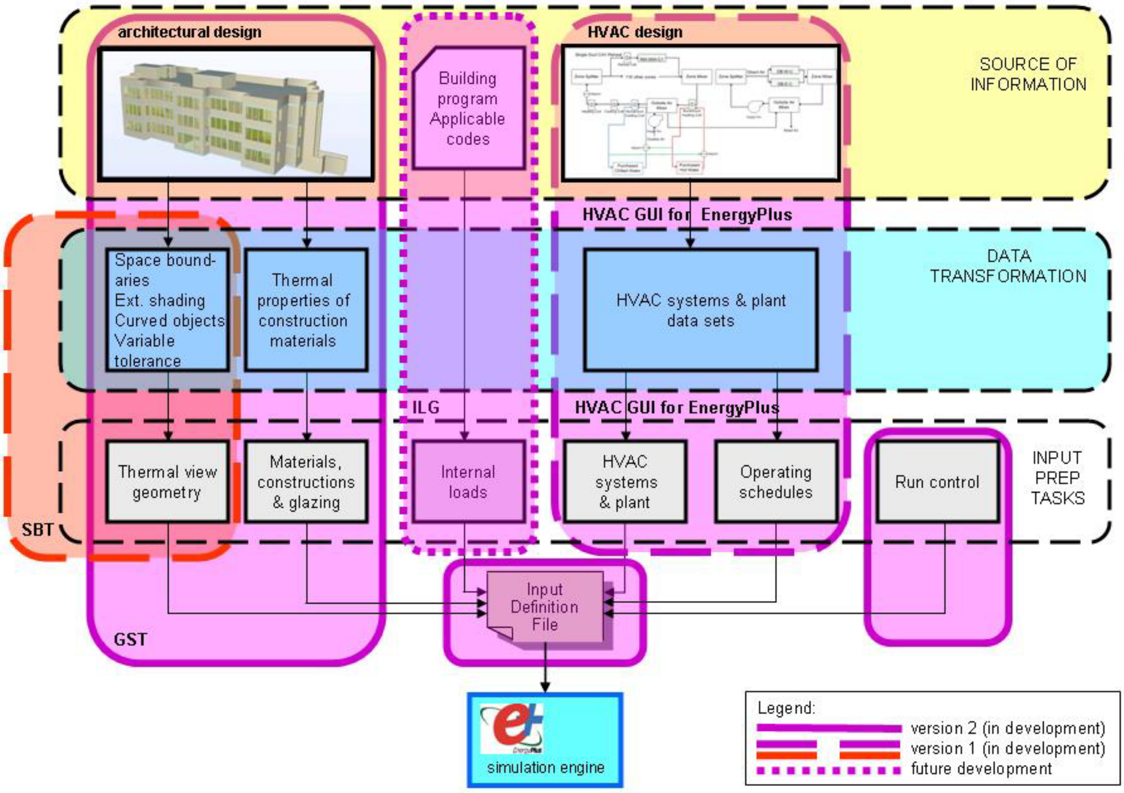


Figure 5: The role of the Space Boundary Tool (SBT) in the implementation of the methodology for semi-automated building energy performance simulation

Since the industry does not currently have an up-to-date, widely usable and reliable tool that can generate higher-level space boundaries needed to import building geometry representations generated by CAD tools into EnergyPlus, The U.S. Department of Energy (DOE) has funded LBNL to develop such a tool – Space Boundary generation Tool (SBT). The new tool will import IFC files that contain the original building geometry (defined by the architect) and calculate all 2nd through 5th level space boundaries for the buildings defined in the IFC files.

Deployment of SBT will require an addition to the diagram that shows the current implementation of the methodology for semi-automated BEP simulation (Figure 1): Its execution will be the first step in the semi-automatic import of building geometry data into EnergyPlus, followed by the execution of GST (Figure 5). With the addition of SBT, the implementation of the methodology for semi-automated BEP simulation will no longer depend on the availability of proprietary software utilities that calculate space boundaries.

5. SPACE BOUNDARY GENERATION TOOL (SBT)

The new tool (SBT) will import building geometry from an IFC file that is compliant with the Coordination View of the IFC data model (buildingSMART International 2010, buildingSMART 2011). In the context of the methodology for semi-automated BEP simulation it is assumed that the imported building geometry is "original" (i.e. authored by the party legally or contractually responsible for its development), but it can be any file that is compliant with the Coordination View. Prior to loading the file into SBT, IFC files are checked with SMC using the new SBT constraint set. Files that contain errors SBT cannot automatically correct are returned to their authors for correction. LBNL will submit the SBT constraint set to Solibri for inclusion in SMC prior to the release of the beta version of SBT ver. 1.

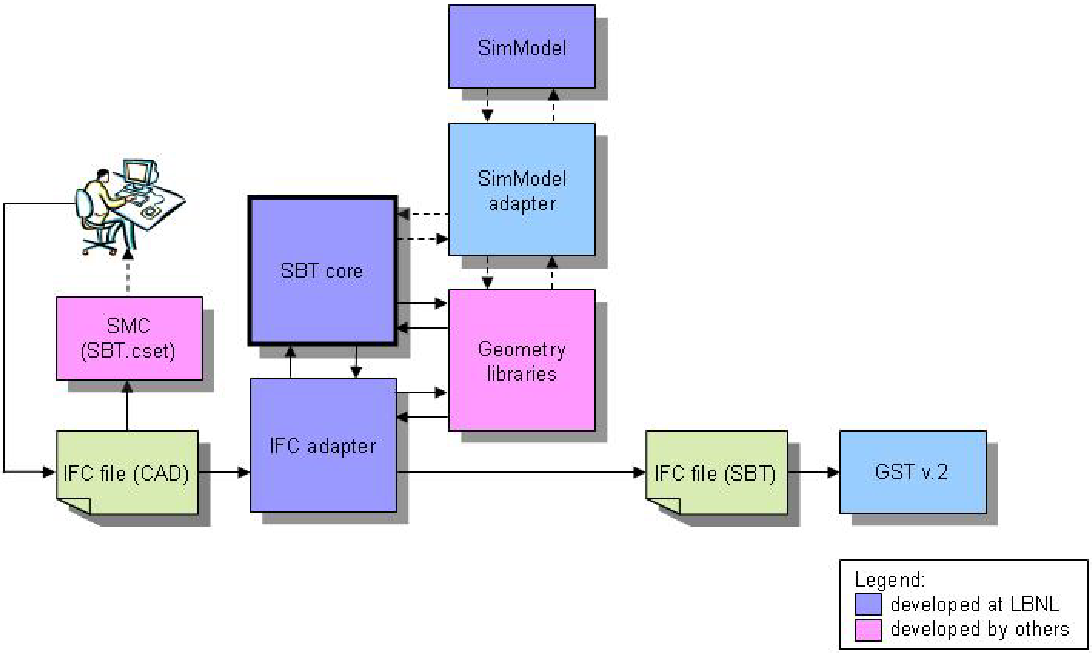


Figure 6: High-level diagram of software architecture – data flow in Space Boundary Tool (SBT)

SBT has two conceptual layers: an algorithmic "core" and an "adapter" (Figure 6). The core is a DLL with C bindings, and the only adapter currently under development (IFC adapter) is another DLL with an executable frontend. The core is an engine that performs the necessary calculations to identify proper higher-level space boundaries and their relationships to each other. It accepts as input a collection of building elements, each of which is represented as a b-rep with some additional information (such as whether it is embeddable in other elements). These are only *nominally* "building elements" within the core algorithm; they are more appropriately thought of as annotated polyhedra. The core API is very simple (a single callable function); the data structures it accepts and returns are primitive. The design intent behind the core is to make it as widely usable and conceptually simple as possible. Higher-level representations are used through an adapter.

The IFC adapter contains the library that allows SBT to be used with IFC files. It performs the following functions:

- Extracts relevant information from an IFC file and converts it into a format usable by the core engine.
- Invokes the core space boundary calculation.
- Reconciles the building spaces calculated with the building spaces found in the IFC file.
- Creates IFC space boundary objects and correctly relates them to their associated spaces and building elements.
- Writes the completed IFC model, including the created space boundary objects, to a new file.
- Performs all necessary geometry calculations to relate representations in local coordinate space (as defined in IFC files) to representations in global coordinate space (as used by the core).

LBNL plans to develop soon a similar adapter for SimModel representations. The SimModel adapter will import building geometry directly from the SimModel. Instead of creating a new IFC file, this adapter will export the created space boundaries back to SimModel.

Some data transformation rules currently embedded in GST (such as the splitting of slabs with voids) will be moved into SBT. SBT will also include some new rules, including rules for correction of model inaccuracies (such as rules that correct unintentionally non-parallel object sides into parallel). Data transformation per rules embedded in SBT will take place in one of the adapters. The resulting IFC file written by the IFC adapter will contain all definitions found in the original IFC file that is compliant with the Coordination view, with the addition of the calculated higher-level space boundaries. Thus it will preserve the original building geometry while adding "corrected" and/or transformed space boundaries needed for BEP and other simulation tolls which use internal geometry similar to that of EnergyPlus.

SBT will execute both as a stand-alone application or embedded in Mojito. It is developed as an open source tool, and will be publicly available with source code reuse licensing options yet to be determined. The SBT ver. 1 beta is currently scheduled for release in the middle of October 2011.

6. GEOMETRY SIMPLIFICATION TOOL (GST), VERSION 2

The current version of GST (GST/IDFgenerator ver. 1, now called GST ver.1) actually contains two software components: GST and IDFgenerator. GST is implemented as an executable, and uses C++ Boost libraries (boost 2011). It uses the EDM server (EPM 2010) to access IFC files. IDFgenerator consists of a DLL and a Graphic User Interface (GUI). While GST performs about half of the data transformation, IDFgenerator performs the other half and wraps generated data with EnergyPlus input syntax (IDF). The GUI provides the necessary user input to manage the data transformation process, file handling and export of the generated IDF file that contains building geometry, construction materials' thermal property definitions, and simulation run control parameters. The architecture of GST ver. 1 is linear, as illustrated in Figure 7.

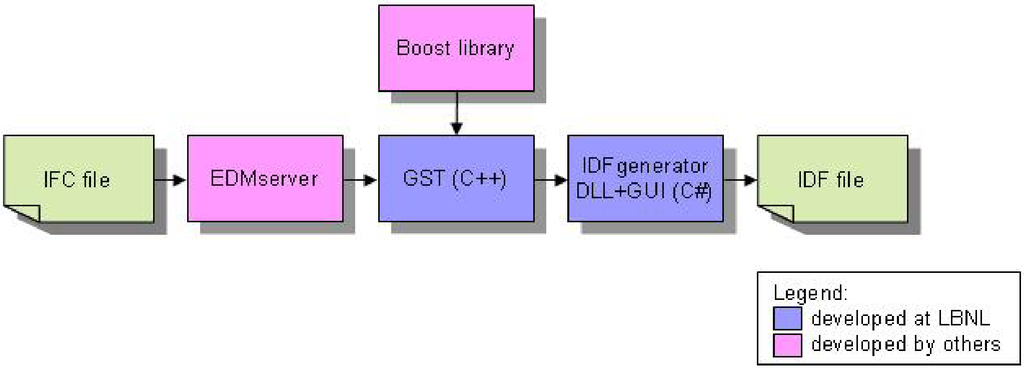


Figure 7: High-level diagram of software architecture – data flow in Geometry Simplification Tool (GST), ver. 1

The two most significant architecture changes in version 2 of GST are multiple APIs and the addition of an IDF toolbox (Figure 8). Multiple APIs facilitate flexible use of GST in different environments and the use of building geometry data from different sources, and allow the integration of IDFgenerator into GST. The different APIs connect SimModel and OpenStudio (NREL 2010) to GST. (Building geometry in OpenStudio is technically equivalent to the geometry of 2nd level space boundaries.) IDF toolbox loads the IDD schema (the internal data model of EnergyPlus) to streamline the writing of IDF data. It parses IDD, creates EnergyPlus objects and wraps them in IDF (i.e. IDD) syntax.

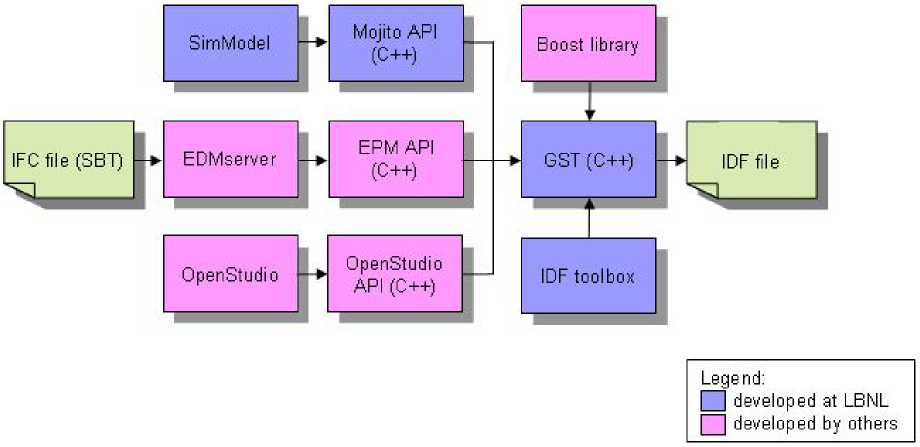


Figure 8: High-level diagram of software architecture – data flow in Geometry Simplification Tool (GST), ver. 2

GST ver. 2 will include new features and data transformation rules that will further streamline the semi-automatic import of data into EnergyPlus. Among the new features are the automatic library entry name mapping from common CAD libraries of constructions and materials to the ASHRAE tables of thermal properties of materials (ASHRAE 2009). Some of the new rules will make window data transformation more robust.

LBNL will continue to update the GST constraint set for SMC as new features and data transformation rules are added to GST. Like SBT, GST ver. 2 will execute both as a stand-alone application or embedded in Mojito. It is also intended to be an open source tool, and will also be publicly available with source code reuse licensing options yet to be determined. The beta release is expected by the end of December 2011.

7. CONCLUSION – A LOOK TOWARD THE FUTURE

While new tools take time to develop and mature, implementation of LBNL methodology for semi-automated BEP simulation data input is gradually progressing. The new Mojito platform is designed to effectively integrate the working of all tools in the BEP simulation domain, even if some tools are IFC-incompatible. SimModel will provide data definitions for the entire BEP simulation domain.

Poor quality of building models developed by the AECOO industry is persistently hampering the effective use of interoperable tools as well as the swift and seamless data exchange that is needed in semi-automated simulation. Model checking will become an integral part of LBNL methodology implementation, which will improve model quality before model data are transmitted for use in simulation. Automated corrections of model inaccuracies performed (when possible) by SBT will partially eliminate problems with the quality of building models.

Effective use of BEP simulation and analysis in the AECOO industry is likely to increase measurably, and simulation and analysis results are likely to become more reliable. Successful implementation of LBNL methodology will free modelers from spending most of their effort on input data definition. Input data for BEP simulation and analysis will become much less error-ridden, modeling and simulation will be much cheaper and much faster, and the process will require less skill than is currently the case. Finally, results of BEP simulation may become reproducible.

ACKNOWLEDGMENTS

The authors wish to acknowledge the contribution to this work of Mr. Richard See of Digital Alchemy (Seattle, WA) and numerous other individuals (too many to list here individually) who are working on the Mojito project. Mr. See is managing the project for LBNL.

This work was supported by the LBNL internal research grant LDRD-36601C and by the Assistant Secretary for Energy Efficiency and Renewable Energy, Office of Building Technology, Building Technologies Program of the U.S. Department of Energy under Contract No. DE-AC02-05CH11231.

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