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Physical Building Information Modeling for Solar Building Design and Simulation – Annual Report 2012

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Project Activities

What have been your major research and education activities (experiments, observations, simulations, presentations, etc.)?

1 Major research activities

1.1 Research on methods of integrating BIM and physical modeling

We have continued investigation on modeling of passive solar thermal with Modelica, daylighting with Radiance and DAYSIM, and BIPV with Building Information Modeling (BIM) Application Programming Interface (API). We explored the state-of-the-art of BIM-based energy simulation tools. We reviewed research on linking BIM and energy simulation through (1) data exchange formats, such as the Industry Foundation Classes (IFC) and Green Building XML (gbXML), and (2) graphical user interfaces (GUIs), such as eQUEST, Simergy, etc. We conducted comparative studies on architectural modeling in BIM and energy modeling in Modelica, addressing the mismatches between the two disciplines. Our major questions include: how to formulate energy related information from the wide range of information in BIM; how to abstract BIM topology information for energy modeling; how to translate the connectivity of building components in BIM into a network in a thermal model; how to add required information for energy modeling that is missing from BIM; and how to facilitate such mapping processes in our prototyping.

We have developed modeling integration methods and created two corresponding prototypes demonstrating our methods: BIM to Thermal and BIM to Daylighting. We also have continued working on BIM and BiPV integration. The prototypes are created using the BIM authoring tool Autodesk Revit and its API, and simulation tools including Lawrence Berkeley National Laboratory's Modelica Buildings Library and Radiance.

For BIM to thermal modeling, we have researched on how to build an energy model that holds building information of building topologies and energy properties by using the following tools and datasets:

- Modelica as an Object-Oriented Equation-based modeling language
- LBL Modelica Buildings Library (LBNL, 2012) as a simulation engine
- Dymola as a Modelica modeling and simulation environment
- Revit as a BIM authoring tool, and
- Revit Application Programming Interface (API) and C# as a prototype development platform

We identified energy modeling methods for (1) basic building components such as walls, roofs, floors, windows, and doors, and (2) diverse building forms including rectangular, non-rectangular, multi-room single story, and multi-story buildings. Based on these methods, we have developed a prototyping framework, a TAMU-PBIM library, and a series of PBIM prototypes.

For daylighting, we studied BIM and daylighting modeling structures. We extracted building geometry and surfaces in the form of triangles through BIM Revit API, and then converted the geometry to Radiance geometry. We also extracted building element materials from BIM to form the Radiance element materials.

1.2 Prototyping

The main features of our prototypes are (1) generating a thermal model and a daylighting model from BIM, (2) executing thermal and daylighting simulations, and (3) presenting simulation results.

a) BIM to Thermal Modeling

We implemented TAMU PBIM Modelica Package as an intermediate data model between BIM and Modelica for building thermal analysis. The use of the package demonstrates our mapping methods between architectural models in Revit and energy models with the existing LBL Modelica library.

Mismatches of architecture modeling and energy modeling can be explained in two ways: (1) semantic mismatches between an architectural model in BIM and an energy model in Modelica and (2) behavior mismatches between architectural modeling and energy modeling.

These mismatches can impede data exchange and model translations between architectural models and energy models. For example, a building's envelope in an architectural model is commonly recognized as walls, roofs, and floors/slabs, while it can be recognized as exterior or interior surface in energy models. Precise geometry information of building components is embedded in architectural models in BIM, whereas surface area is required in energy models for heat transfer calculations. These semantic mismatches between two domains can hinder data exchange of building objects and their attributes. On the other hand, the behavior of installing an interior wall in BIM can be represented as the behavior of splitting one thermal zone into two zones. Such behavior mismatches between two domains cause complex translations between architectural modeling and energy modeling.

In our prototype and library developments, we addressed (1) semantic mapping of an architectural model in BIM to an energy model in the Modelica library as well as (2) behavior mapping between architectural modeling in BIM and energy modeling in Modelica.

TAMU PBIM library consists of Modelica BIM package and Modelica BIM models. The BIM package holds OOPM-based BIM objects that represent building components, such as rooms, walls, roofs, floors, doors, and windows. In addition, it supports semantic mapping such as translating required energy parameters from building components in BIM to energy model components in Modelica.

The Modelica-BIM models are OOPM-based BIM models that present building topologies and configurations of the building components. Five test case models demonstrate how building design features in BIM can be translated into the energy modeling features in Modelica. Simple building design options through changing room geometry, adding an interior wall, or installing windows and doors on the wall are presented in the test case models as shown in Table 1.

Table 1. Test case models

Name	Description
TestCase1	A single room model
TestCase2	A two room model
TestCase3	A two room model with two windows
TestCase4	A two-room model with two windows and a door
TestCase5	A two room, two story building model with two windows

Figure 1 shows TAMU Modelica BIM Package and BIM Model Samples. The energy model diagram is a graphical representation of the TestCase5_TAMU model. The test case model demonstrates a two-story building with two rooms and two windows.

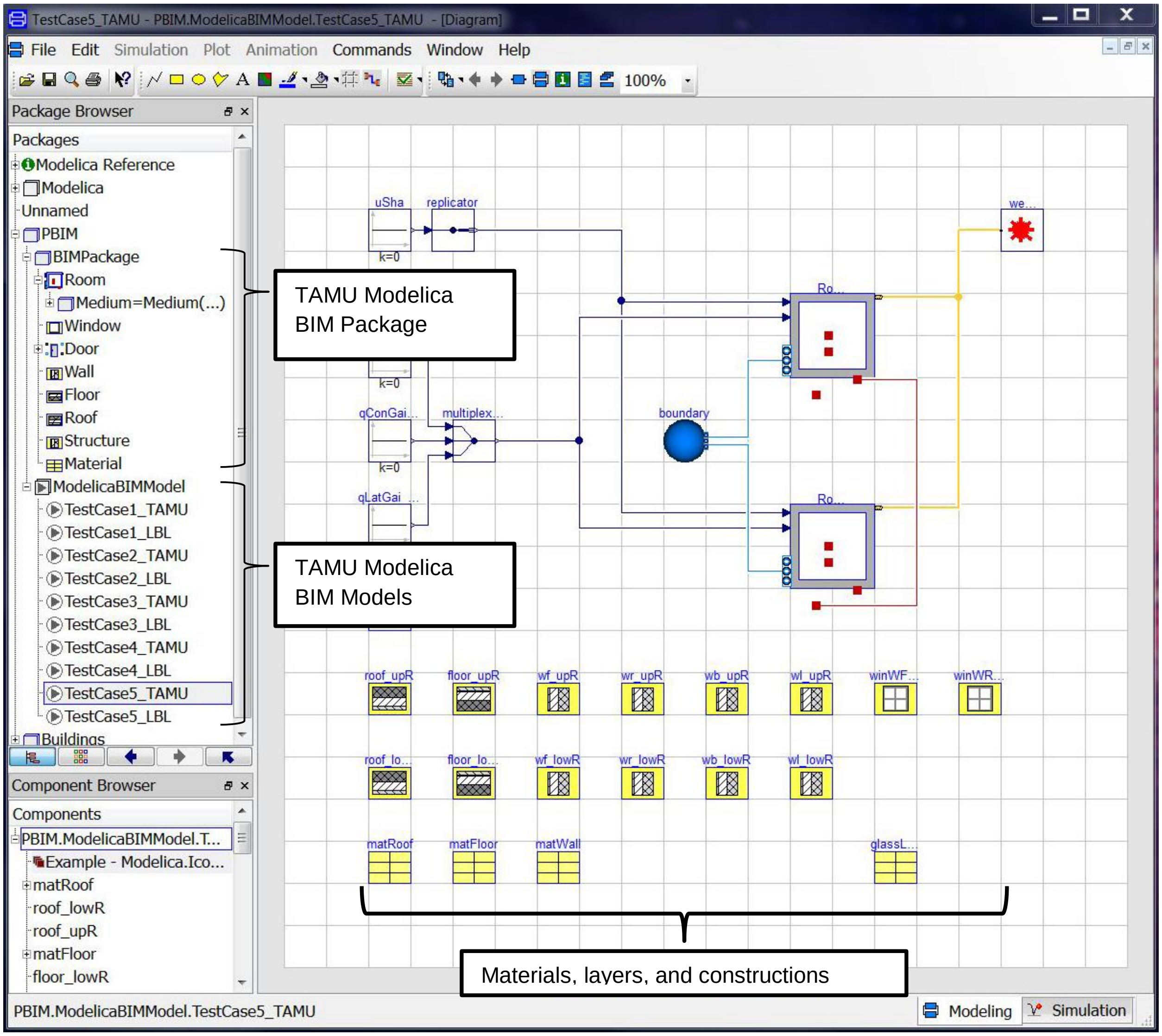

Figure 1. TAMU Modelica BIM Package and BIM Model Samples

Figure 2 shows the process of the prototype from a user's point of view, and Figure 3 shows the workflow of BIM to Thermal Modeling in PBIM.

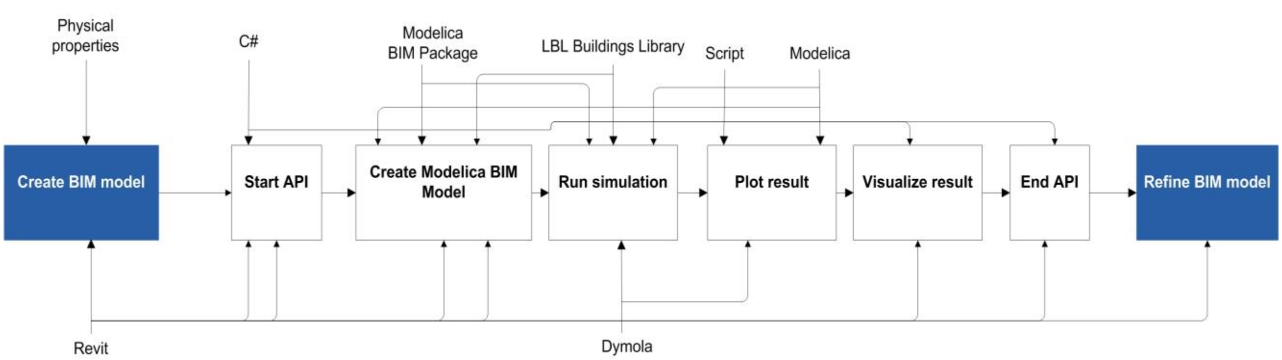

Figure 2. Process diagram of the prototype from a user's point of view.

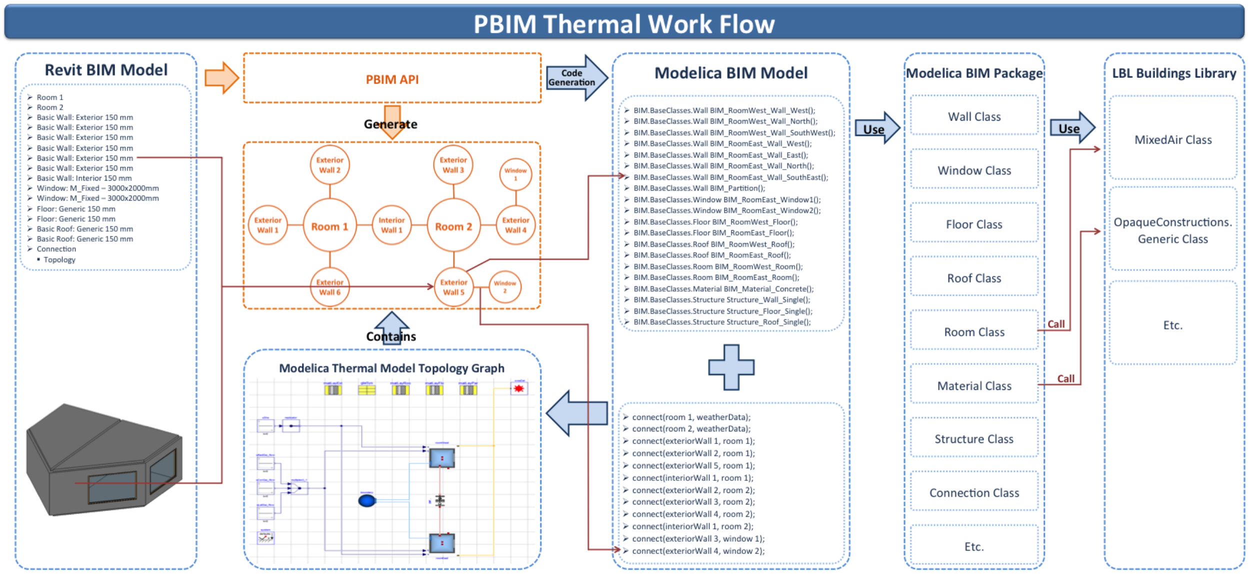

Figure 3. Workflow of the prototype

Figure 4 shows a sample result of a room's temperature data (blue) in comparison with the exterior temperature data (red) after running a simulation.

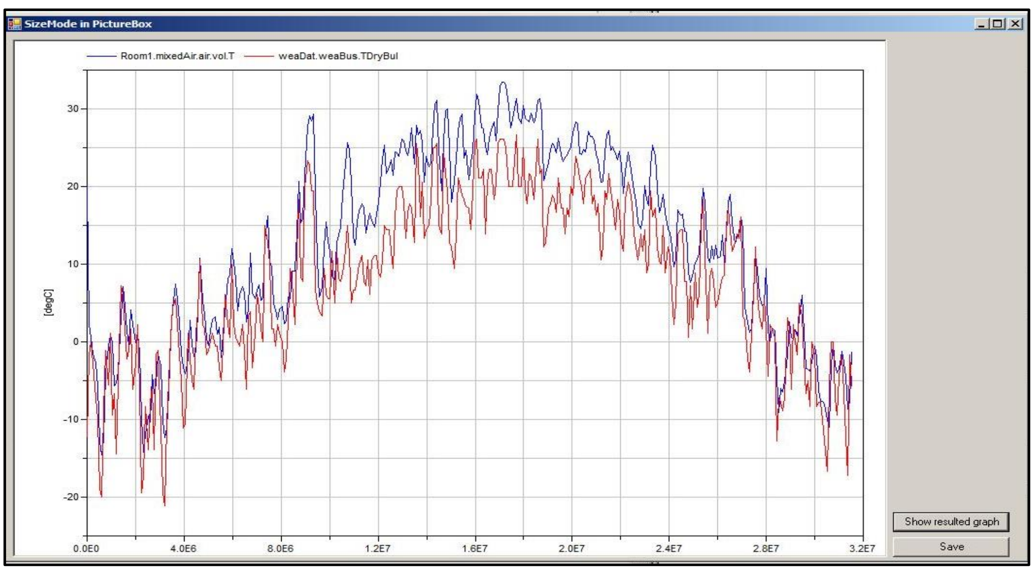

Figure 4. Result data after running the prototype's simulation

To map required information from BIM to energy model, three main data processes are developed in the prototype: retrieving existing parameters directly from BIM, calculating parameters that are needed in the energy models from BIM, and adding missing parameters that are important for energy modeling from BIM.

b) BIM to Daylighting

For daylighting modeling, we have developed a prototype for translating a BIM model to Radiance - a daylighting simulation tool. The prototype was developed using Revit Application Program Interface

(API) and C Sharp (C#) programming language. We identified that the BIM model's materials data do not have certain information that is necessary for the daylighting simulation. To bridge the gap we have developed a spreadsheet that contains BIM material names and corresponding parameters necessary for daylighting simulation for each material. Also we have developed a way to add the material property information necessary for daylighting simulation into the BIM model. This was accomplished using a custom add-in module of the prototype. The prototype translates a given BIM model into input files of Radiance. Once the input file is created we can run it in Radiance to perform a daylight simulation   The prototype has four custom programs which were developed using Revit API and C# programing language.

- The first add-in program creates a file to add custome parameters to a BIM model.
- The second add-in program adds two custome shared parameters for materials in the BIM material database.
- The third add-in program adds values to custome shared parameters of each material from an external database.
- Finally, the fourth add-in program translates geometry and material properties into Radiance input files.

Figure 5 shows a sample model of wall with a window in the context of a sun path specific to the location of the building. Figure 6 shows the simulation result for the simple model. More complex models including the Stanford Solar Decathlon 2013 project models are being tested.

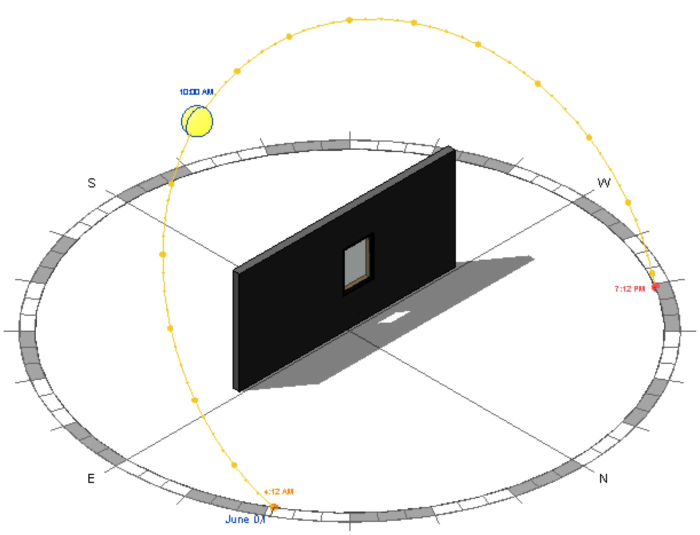

Figure 5. Revit building component sample with a sun path specific to the location.

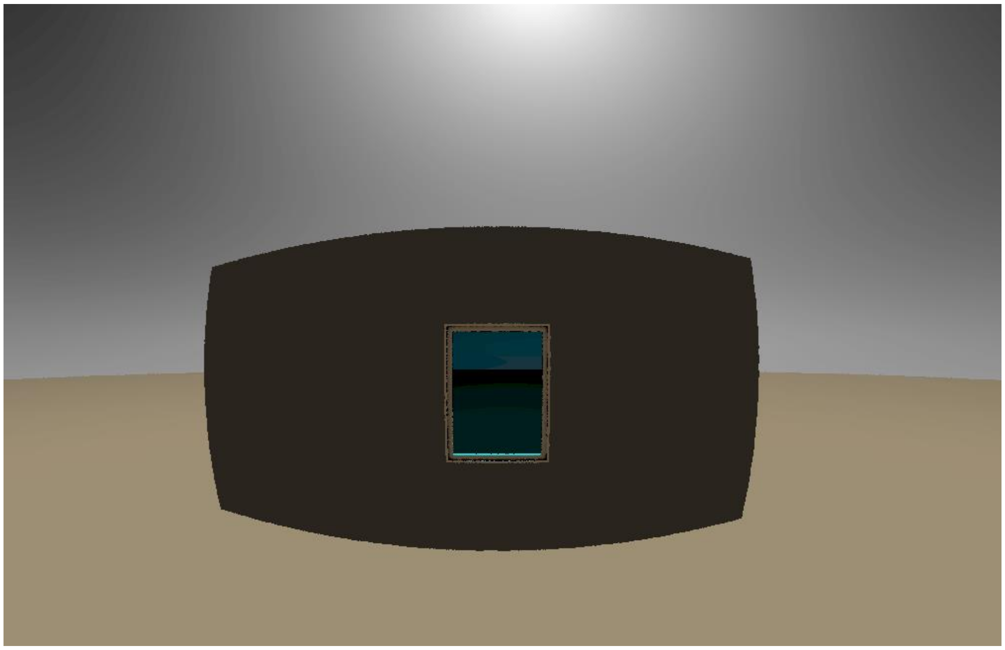

Figure 6. Radiance rendering of the wall.

c) BIM to BiPV

We developed a Building Integrated Photovoltaic (BiPV) prototype in a BIM platform (Autodesk Revit) to calculate solar position and determine the amount of solar insolation from given time and location information with a graphical user interface. We have developed a model to calculate the direct component of solar insolation by testing and using a solar insolation model proposed in literature. The proposed model can be integrated into BIM to automatically calculate solar position and the amount of solar insolation based on user inputs of time and location. We plan to compare this prototype with the PV F-Chart method and other PV modeling methods.

1.3 Experiments

We have done various experiments with our prototypes. Experiments that validate our thermal simulations are described below. Other experiments for daylighting and BiPV modeling are ongoing.

Each test case of PBIM consists of a TAMU model and a LBL model. While the LBL model is created using the LBL Buildings Library only, the TAMU models are developed as follows:

- Building topology, such as room configurations, building component geometry, materials, layers, and constructions, is built with the TAMU Modelica BIM Package.
- Energy components, such as boundary conditions, weather data, and other external heat gain sources, are built with the LBL Buildings library.

The TAMU and the LBL models have different code structures and different components; therefore it is required to validate modeling accuracy of the PBIM prototype. To do so, we have conducted a series of experiments for simulation result comparisons. The experiments yielded identical simulation results from paired two models of each test case. It implies that our energy modeling methods, such as encapsulation of calculation modules and a rearrangement of a model code in Modelica, do not affect the simulation results.

Meanwhile, another experiment was performed for the comparison of Modelica and DOE 2.1e results. Based on an existing sample model in the LBL Buildings Library, we generated a simplified building model with the following configurations:

- The room is located in Chicago. USA_IL_Chicago-OHare.Intl.AP.725300_TMY3 is used as the weather file.
- The room is lifted up from the earth, so the floor slab is not attached to the ground.
- This one room model consists of a roof, a floor, and four walls.
- No windows and doors are installed.
- All building components are made up of a 200mm concrete construction.

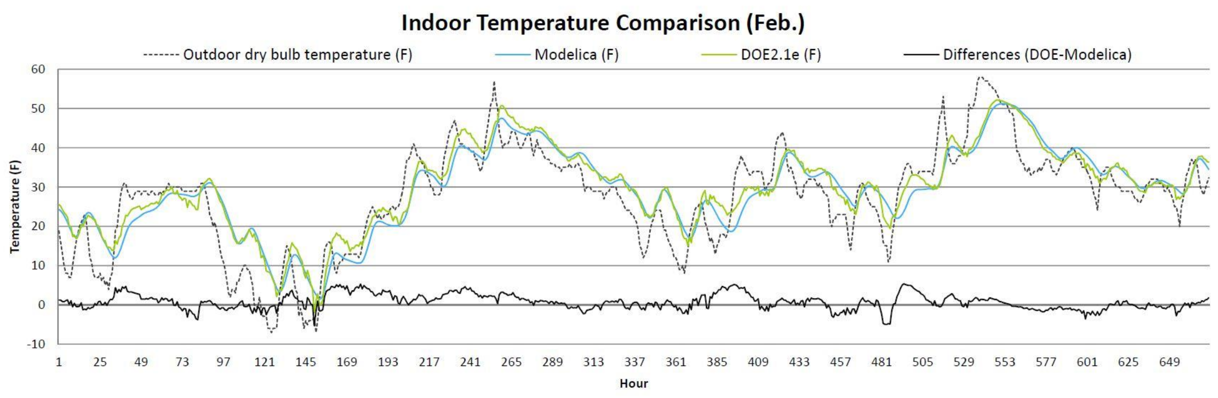

Figure 7. A simulation result comparison with a Modelica and a DOE model.

Simulation results show that two models yield a similar pattern in indoor temperature changes (Figure 7) and that the factors causing temperature differences need to be investigated. Further model calibrations are ongoing.

2 Major education activities

Our major education activities include:

1) The project provided research subjects and support for Ph.D. studies. Five Ph.D. dissertations in solar building design, daylighting simulation, BIM for urban design, building data modeling, and building embodied energy are in progress. These dissertations are closely related to this project. Most of the students have passed their Preliminary Exams.

2) Graduate level Directed Study courses in related topics are offered to students working in this project.

3) A new BIM class that integrates energy simulation is currently taught by Dr. Mark Clayton.

4) Students have attended weekly project meetings with faculty members, in which the students present their research and dissertation work that is related to the project.

5) We are currently working with Stanford University's Solar Decathlon 2013 Team. We are testing our prototypes with their building models. The aims are to use the simulation results to inform their design and use their data to validate our modeling and simulation. The collaboration is expected to enhance students' design and research in both universities.

Major Findings

What are your major findings from the activities identified above?

Our major findings include:

1) BIM can be used as an interface for energy simulations. The project shows that we can

   a. automatically or semi-automatically generate energy models from BIM,

   b. dynamically change energy models using semantically rich information in BIM,

   c. effectively store and manage energy model information in BIM's parameters,

   d. execute external simulation engines using BIM's API without leaving the BIM interface, and

   e. improve visualization of simulation results.

2) With the capabilities of object-oriented programming in Modelica, we could encapsulate third-party energy simulation modules and transfer parameters throughout encapsulated modules of the TAMU PBIM prototype. Also, multiple encapsulations of calculation modules could yield identical simulation results as shown in our experiments with test case models.

3) There is difference in the representation of the building geometry and materials between BIM and Thermal/Daylighting modeling which needs to simplified and mapped correctly.

4) Initial results show that BIM models created in Revit can be converted into Modelica thermal models and Radiance/DAYSIM daylighting models, through automated steps with high efficiency and accuracy.

Contributions

1 Contributions within discipline

How have your findings, techniques you developed or extended, or other products from your project contributed to the principal disciplinary field(s) of the project? Please enter or update as appropriate.

Our findings demonstrated that the new PBIM methods have the potential to facilitate the integration of BIM and building energy simulations that can assist informed decision-making of solar building design. The findings also demonstrated the capability for reducing the interoperability problem that exists between architecture models and energy simulation models.

2 Contributions to other disciplines

How have your findings, techniques you developed or extended, or other products from your project contributed to disciplines other than your own (or disciplines of colleagues and associates not covered under "Contributions within Discipline")? Please enter or update as appropriate.

The project is cross-disciplinary in the fields of architecture, building science, and computer science. The contributions of the project help integrate architecture and building science with computer science. In addition, our methods demonstrated that specific domain modeling (in our case, BIM) can be integrated into more general physical simulation (in our case, building energy). In terms of computer science, this research provides a case study of translating one OOP-based model (BIM) into another OOP-based model (Modelica models), with different semantics and ontologies.

3 Contributions to human resource development

How have results from your project contributed to human resource development in science, engineering, and technology? Please enter or update as appropriate.

Our project helped prepare students in architecture and building science for academic and professional careers in sustainable building design and research. The research also motivated some undergraduate students to study BIM and energy related topics at Texas A&M University. More Ph.D. applicants are applying to join our research group recently.

4 Contributions to resources for research and education

How have results from your project contributed to physical, institutional, and information resources for research and education (beyond producing specific products reported elsewhere)? Please enter or update as appropriate.

Our project produced software prototypes of PBIM, new daylighting sample models, PV component models, and solar building test models, which can contribute to the information resources for research and education in solar building design and simulation, as well as general building energy simulation.

5 Contributions beyond science and engineering

How have results from your project contributed to the public welfare beyond science and engineering (e.g., by inspiring commercialized technology or informing regulatory policy)? Please enter or update as appropriate.

The resulting prototypes, models, and methods can be used for creating commercialized software tools for solar building design and simulation. One of the related Ph.D. dissertation research projects – BIM's application in urban planning, has the potential to inspire urban planning code formation.

Acknowledgement

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References

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