Dynamic – Building Information Modeling (Dynamic-BIM): An Interactive Platform for Building Energy Engineering Education

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ABSTRACT

Building Information Modeling (BIM) allows for the efficient program management of building design, construction, and operation. While powerful, BIM has several limitations with existing environments such as, disintegrated tools and technologies; static and/or single user environments; lack of a system based on just applied sustainability concepts, among others. This chapter discusses the development of a Dynamic-BIM platform, a multi-user integrative, collaborative, and extensible environment that enables energy and environmental impact. Additionally, this platform provides the much needed framework for a dynamic and interactive platform for building energy engineering education. The platform uses a generic reference architecture that is applicable to tighter coupling of integrative and collaborative environments for buildings and their environment. An extended version of this platform tracks all types of energies used by campus buildings representing a "campus energy map," both on a monthly and annual basis. Two applications of this platform are discussed in this chapter: (1) a prototype implementation of University of Florida (UF) campus buildings where energy data (electricity, chilled water, steam, and water) is visualized and (2) a prototype implementation of an educational building in the UF campus where data is collected in real-time and visualized. The learners' engagement and how they use the tool in the classroom setting to understand energy types and uses of campus buildings are discussed as well.

BACKGROUND

Building design, engineering, construction, and operation are complex processes that involve participation of multiple stakeholders in a coordinated manner for efficient use of human and natural resources. As a collaborative environment, Building Information Modeling (BIM) allows for the efficient program management of building design and construction. BIM is widely used for both small- and large-scale projects particularly in facilitating communication and decision-making among project team members. Besides, BIM has rich resource capability to extend to fourth and fifth dimensions, i.e., cost and schedule respectively. Among others, the greatest value of BIM to Architecture, Engineering, and Construction (AEC) industry are fewer errors, improved work quality, and reduction of disputes. Several organizations have directed the use of BIM for new and existing projects and, accordingly, in some cases, developed guidelines for implementation of BIM for new and existing buildings. The United States General Services Administration released the "BIM Guide for Energy Performance" as a method to strengthen the reliability, consistency, and usability of predicted building energy use and energy cost results (GSA, 2009). Others guidelines include, BIM standardization by Finland's Senate Properties (2007); Statsbygg (2011), the Norwegian government's key advisor in construction and property affairs; and the American Society of Heating, Refrigeration and Air-Conditioning Engineers' BIM Standard (2009).

Nevertheless, more work is needed to extend the capabilities of BIM to conduct *detailed* performance analyses related to energy engineering such as energy estimation using hourly energy simulation algorithms particularly EnergyPlus owing to its extensive capabilities; 3D conjugate heat and airflow analysis for design decision-making; data analytics and visualization, etc. Essentially, a dynamic platform that possesses the strengths of BIM within an integrative environment will not only enable rapid multi-scale analysis of building energy, but also provide the much needed framework for a dynamic and interactive platform for building energy engineering education. The development of this dynamic platform requires a combination of both integrative and collaborative environments. While integrative environments enable development of tools, collaborative environments (such as BIM) facilitate data sharing and effective communication among stakeholders. In the case of integrative environments, research efforts started in the early 1970's to support integration of a variety of tools for assessment of buildings. One critical component to support integration is the standard description of building product models to define individual data objects and relationships to object within the model, typically, in a hierarchical representation. Particularly for built environments, such integration led to the Industry Foundation Classes (IFC) which is based on object-based inheritance hierarchy. This file format provided a common ground for data interoperability, i.e., enabling data exchange between software. Since the design and implementation of standard product model representation, particularly the IFC, there has been remarkable surge in research efforts to integrate building performance analysis tools.

For the purposes of this chapter, it is crucial to understand the development of integration tools. Table 1 lists the various integration tools and frameworks. For assessing their capabilities, integrative tools are discussed using three criteria, namely, tool overview, performance analysis, and schema used. The tool overview criterion focuses on the methodology used in tool implementation, its analysis domain i.e., if the integrated tool is a standalone or web-based, and its abilities to conduct analysis based on artificial intelligence techniques such as simple rule-based, dynamic-constraint based, etc. The performance analysis criterion discusses various tools implemented and access to real-time sensor data. Lastly, the schema used in the tools refers to the product model language.

Pre-IFC Integration. One of the earliest attempts in tool integration is the Integrated Design Databases (IDD) using GLIDE (Eastman, 1979a; Eastman and Henrion, 1997) for design activities related to architecture and engineering. Although, this work did not initially focus on assessing building energy- and/or environmental-impacts, it paved way for the creation of a Design Information System or DIS (Eastman, 1979a). The Design Information System used abstraction hierarchies to support different design operations through analysis and synthesis models. This system not only allowed members of design team to access common data, but it permitted linkages to external analysis programs such as structural, thermal, cost, and piping and distribution sizing. An extension of this system led to Computer Aided Engineering and Architectural Design System or CAEADS (Eastman, 1979b) which, then, emerged as a fully developed system for architectural applications.

With greater emphasis on building energy efficiency in early 1970's, research focused on promoting energy efficiency at the drawing board, i.e., offering tools that designers can rely for performance related analysis. Notable among them include, Advanced Energy Design and Operations Technologies or AEDOT (Pohl et al., 1992) that used an Intelligent Computer-Aided Design System or ICADS (Pohl et al., 1998). Using a dynamic agent technology, the ICADS was improvised to develop the Knowledge-based Object-Agent Collaboration system or KOALA (Pohl, 1996). At this time, the concept of unified models was used in model representation. These unified models were used to identify design strategies by applying constraints as in the case of ARMILLA (Haller, 1985). Later, an A4 prototype of ARMILLA used a modular building approach (Gauchel et al., 1993).

In spite of several research attempts in integration tools in this early period of building performance analysis, there was no one binding model representation for data transfer between tools (i.e., researchers were using independently built schema for model representation and, subsequently, data transfer). Each of the tools relied on their own representation, and this posed difficulties for widespread development of tool integration for the purposes of building design and analysis. The development of EXPRESS language and, later, the formalization of STEP provided the necessary standard for such representation and spearheaded the integration efforts as discussed in the post-IFC era below.

Post-IFC Integration. Post- IFC, the integration tools took advantage of the standard product model representation which helped interoperability to a greater extent. The COMBINE (Augenbroe, 1992) and COMBINE-2 (Augenbroe, 1995) projects demonstrated the potential of linking existing tools such as energy, daylighting, and others. Model representation using EXPRESS language and later, the formalization of STEP, and now, the IFC standard, are significant steps in tool integration. EXPRESS language became the binding block of the Knowledge-based Design Support or KNODES (Rutherford, 1993). The Building Design Advisor (BDA) used process-logic control for automating activation processes (Papamichael, 1999). A Decision Desktop in BDA allowed designers to conduct multi-criteria analysis based on light illuminance, energy use, etc. Although effective, it did not offer automated geometry design variations, but instead assigned 'smart' values from a prototype database. A similar approach was attempted by Soebarto and Williamson (1999) in the development of a Designer Orientated Performance Evaluation approach used ENER-WIN software. This approach performed benefit-cost ratio for multi-criteria energy- and environmental- assessments.

Major advancement in integration tools was realized with SEMPER (Mahdavi et al., 1997). This environment provided an active, multi-aspect design environment. Later, this was expanded to web-based in SEMPER II or S2 (Lam et al., 2004). SEMPER enabled thermal, airflow, thermal comfort, lighting, and Life Cycle Assessment using the Shared Object Model schema. A similar progression was reached with the Design Analysis Integration (DAI) that offered a process-centric workbench to overcome the limitations of the data-centric interoperability approaches (Augenbroe and de Wilde, 2003). The inclusion of temporal databases with IFC to develop an open, dynamic, and temporal building model is yet another attempt to create intelligent, adaptable buildings in the Dynamic Building Model (Gryzbek et al., 2010). In this building model representation, IFC is improvised with dynamic capabilities of temporal databases in order to mine, learn, and dynamically respond to changes in building states.

Recent developments such as the Building Controls Virtual Test Bed or BCVTB (Wetter, 2011), SimModel (O'Donnell et al., 2011), and Simergy (See et al., 2011) represent significant milestones in integration efforts. While BCVTB provided the software environment for co-simulation and more, SimModel is expected to offer interoperability between BIM and energy simulation engines. Further, Simergy is expected to offer an intelligent decision support using EnergyPlus (2012). BCVTB enables co-simulation of analysis programs using a middleware instead of coupling them directly. In the case of the test bed, to give an example, the output of one simulation program can be used as an input into another program during run-time. Yet, runtime data exchange is not a substitute for data interoperability, rather it facilitates co-simulation. Besides, the test bed utilizes Modelica-based (2012) building component libraries. At present, the building component libraries (Wetter, 2011) are accessible for simulation via commercial software, such as Dymola (2012). Another recent work is the development of the Cyber-physical Building Energy Management System (CBEMS). This system uses a tiered integrated approach to energy, lighting, and plug-loads estimation integrated with policy learning / artificial intelligence techniques (Wang et al., 2011). This system supports several protocols for intelligent buildings such as BACnet, KNX, LonWorks, and ZigBee.

Table 1. Summary of integration tools.

Integration Tool	**Tool Overview**			**Performance Analysis**		**Schema**
	Approach	**Domain**	**Intelligence**	**Integrated Tools**	**Sensors**	
IDD using GLIDE	Abstraction hierarchies with analysis and synthesis models	Standalone	Rule-based	-	-	-
DIS & CAEADS	Design exploration using GLIDE and abstract representations	Standalone	Rule-based	Structural, Thermal, Cost, Piping and Distribution Sizing analyses	-	-
AEDOT using ICADS	Routine-based integration using a blackboard.	Standalone	Rule-based	Energy Standards, Building Mass, Daylighting	-	-
KOALA	Constraint- and functionality-based decision support system	Standalone	Object-(dynamic) agent technology	Similar to ICADS	-	-
ARMILLA	Constraint- based (centralized control) unified model; design strategies	Standalone	Dynamic constraint-based	Spatial layout and mechanical systems	-	-
A4 Prototype of ARMILLA [	Integrated modular building model approach	Standalone	Dynamic constraint-based	Same as ARMILLA	-	-
COMBINE , COMBINE-2	Integrated environment for energy and HVAC tools in COMBINE. Used Petri Nets concepts in COMBINE-2	Standalone	-	Energy, HVAC Tools	-	EXPRESS, STEP
KNODES	Knowledge-based design framework	Standalone	Knowledge-based system	Natural lighting; Energy (BREDEM); Energy design; Spatial analyzer; Structural; Costing	-	EXPRESS

BDA	Integrated environment for design process decision-making	Web-based	Process-logic control for automated activation of processes	Daylight (DElight); Energy (DOE-2); Lighting (Radiance); Airflow (COMIS); Cost (EAM)	-	BDA data metaschema
Designer Orientated Performance Evaluation	Multi-criteria Environmental assessment (uses criteria weightings)	Web-based	Benefit-cost ratio	Energy (ENER-WIN); Emissions; Thermal comfort; Costing; Environmental degradation	-	-
SEMPER	Active, multi-aspect design environment with dynamic links to performance evaluation tools	Standalone	KBES for providing thermal comfort feedback; investigative project technique	Thermal (NODEM); Airflow (Hybrid multi-zone, CFD); HVAC; Thermal Comfort (Algorithmic routines, KBES); Lighting (Radiosity); Acoustics (Hybrid stochastic); LCA (Eco-balance)	-	Shared Object Model
SEMPER II	Web-based active, multi-aspect design environment; used XML for data transfer	Web-based	Same as SEMPER	Same as SEMPER	-	Shared Object Model, XML
DAI	Four-layered process-centric workbench (design information, structure simulation models, analysis scenarios, and software tools)	Standalone (used IBM MQ Workflow engine)	Process modeling and enactment (analysis)	Thermal (EnergyPlus, PMV); Daylight autonomy (IDEA-L)	-	IFC, XML
Dynamic Building Model	Open, dynamic, and temporal building model for intelligent, adaptable buildings	Web-based	Inclusion of temporal databases in IFC to mine, learn, and dynamically respond	Thermal (test case)	Physical sensor	IFC
BCVTB, **SimModel ,** **Simergy**	BCVTB: Integrated building energy and control systems software;	Standalone	Matlab routines (e.g., optimization) is accessed	Thermal (EnergyPlus, Modelica library); Lighting	Wireless sensor networks (BACnet); Hardware	IFC, XML, BIM import / export; gbXML

	Equation-based object-oriented modeling for building controls; SimModel for data interoperability services; Simergy: Uses a comprehensive GUI, potentially, offering linkages to BCVTB and SimModel.		in BCVTB, provides greater flexibility	(Radiance); HVAC and controls (Modelica library); Controls (Simulink)	connectivity	
CBEMS	Web- and BEMS-basd four tier architecture (data acquisition and interface, automatic computing and executing, management, and monitoring)	Web-based	Policy learning (self-learning and self-computing), Nash equillibrium	Energy; Lighting; Plug-loads	Wireless sensor network uses multi-agent distributed systems (supports BACnet, KNX, LonWorks, ZigBee)	XML

Limitations in BIM

Even with advancements in BIM and building performance assessment tools independently, disconnect between design and analysis is largely prevalent. In some instances, only partial import of models developed in legacy BIM software is possible, thereby, prompting issues related to data transferability and integrity. Take for example, a double-skin façade with perforated external skin where the perforation sizes and shapes vary based on interior space-planning and orientations, figure 1. Although legacy BIM software can model this detail for fabrication purposes, in order to refine this scheme for thermal-airflow efficiency, and later, for adoption, it is essential to evaluate this detail in an integrated fashion using a conjugate 3D heat and airflow, and in relation to the whole building. At present, there are no provisions in BIM tools to conduct such analyses. There are only a handful of programs which are external to BIM that can import this detail for further exploration. In Integrated Environment Solutions' VE-Pro (2012) software, only a simplified representation of this envelope configuration and/or partial analysis is possible. Also, the BCVTB/Simergy/SimModel environment does not have the capability to import this sample and analyze it for conjugate thermal-airflow effects.

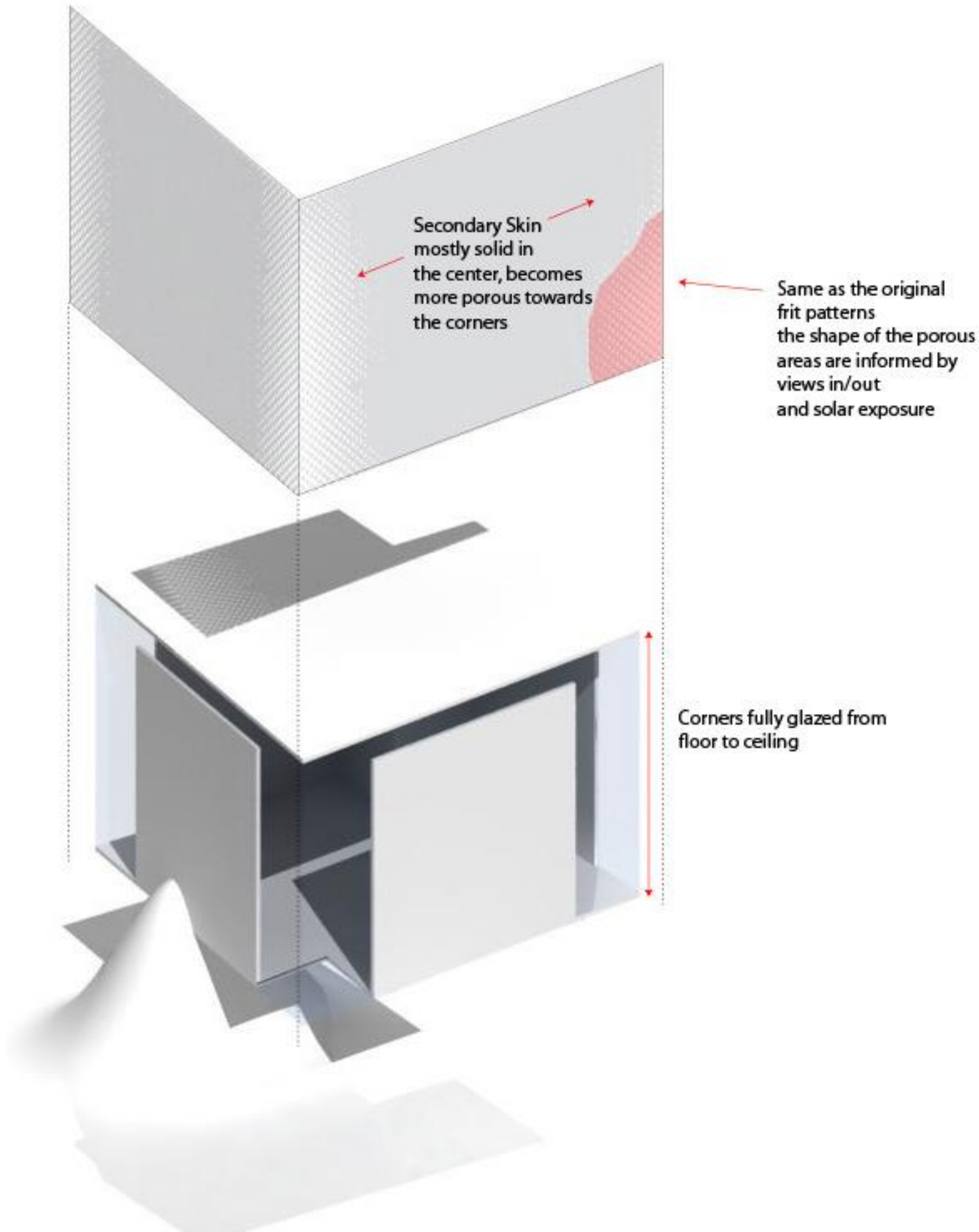

Figure 1. Sample double-skin façade. (Cade Museum competition project, Gainesville, FL). Image courtesy: MW Bender & Associates and Single Speed Design Architecture.

Moreover, some of the existing BIM tools, e.g., Revit MEP (2012), have modeling limitations related to granularity. In the case of modeling fenestration systems, which typically contain glazing, spacer, and desiccant, Revit's minimum tolerance setting (0.8mm) does not capture all minute details of a window-wall interface. Studies have shown issues related to thermal bridging that occur and alter the thermal performance of fenestration systems by up to 15% (Bhandari and Srinivasan, 2012). Conversely, Rhinoceros 3D captures this detail, figure 2, resulting in staring dissimilarities in model generation across BIM tools. Also, at present, none of the window manufacturers have BIM library files of their fenestration products that represent *actual* specifics of the window configuration, i.e., showing glazing, spacer, and desiccant components in their actual sizes. This can be attributed to the lack of demand for these BIM libraries from designers and engineers as there are no currently available tools that can seamlessly conduct 3D heat transfer analysis from within BIM. Currently, thermo-physical properties of windows and walls are input separately in energy and/or airflow analysis programs. In such scenarios, the heat transfers at the window-wall intersections are entirely ignored which may lead to erroneous results (Bhandari and Srinivasan, 2012). In most cases, it can be safely noted that the *use of BIM is akin to typical Computer Aided Design tool*, to generate construction documents, with few exceptions such as clash detection, simplified energy analysis, visualization including renderings, and data repository. In a nutshell, the power of BIM is yet to be unleashed.

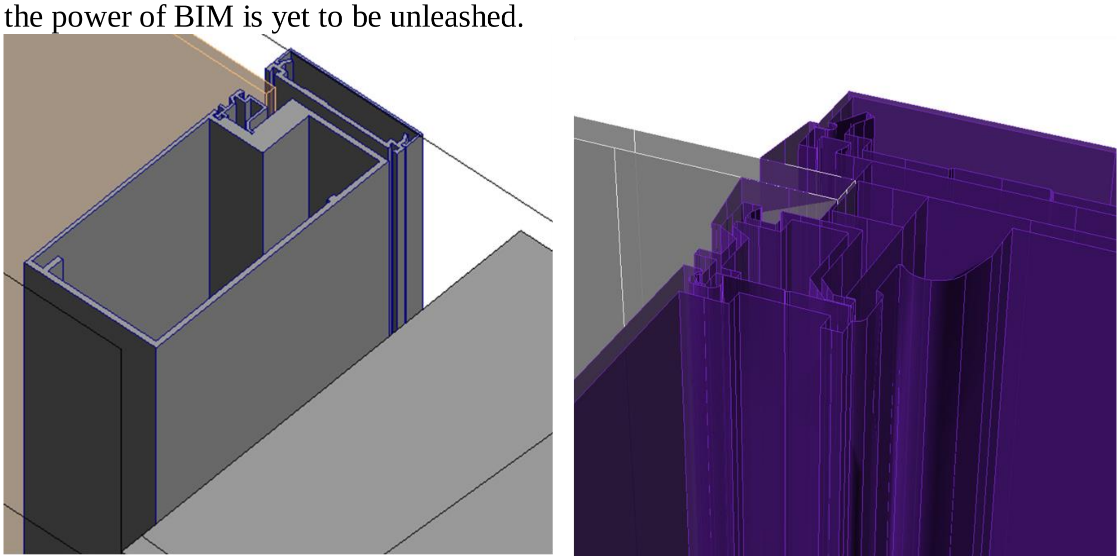

Figure 2. Window frame details: (a) Revit MEP, (b) Rhinoceros 3D.

As noted earlier, simplified performance assessments such as energy, airflow, daylighting, etc., may be conducted directly from within a small number of existing BIM tools such as Revit MEP, Rhinoceros 3D, etc. However, they are *not* comparable to full-scale simulations using standalone analysis tools. There are software tools that allow integrated building performance assessments such as VE-Pro (2012) which allows thermal and energy, three-dimensional airflow, and daylighting analyses; and EDSL's TAS software for integrated thermal and energy, two-dimensional airflow, and thermal comfort analyses (2012). However, these standalone software packages are not BIM tools, although some of these can import BIM files.

At the outset, while powerful, BIM has several limitations with existing environments such as, disintegrated tools and technologies; static and/or single user environments; lack of a system based on just applied sustainability concepts, among others. Although past and ongoing research efforts have established a strong foothold in the AEC community, coupling efforts are still evolving. What is missing is the "connecting glue" that supports stakeholders to design, engineer, construct, and maintain buildings and their environment in a single platform such that buildings, as discussed in Srinivasan et al (2012), seek self-sustenance with limited availability of energy and materials. Currently, this lack of integration translates to manual and/or semi-automated procedures of data transfer between tools and, possibly, the creation of redundant and, possibly, erroneous information. More importantly, this lack of integration could, undesirably impact energy efficiency, productivity, and competitiveness in the AEC industry, particularly, since buildings worldwide consume over 40% of all energy, making this a noteworthy problem.

At present, the real-time feedback approaches established in BIM relate entirely to construction project management updates such as project statuses, therefore, current BIM environment may be rendered as "static." In other words, although BIM comprises of an enormous database of the building structure, it is not active enough to conduct assessment of buildings including implementation of sensor data and/or control algorithms, in real-time. Such an approach could offer optimized solutions for sustainability in building and environment, as well as integrated energy and environmental assessments. With BIM's widespread adoption by architects and engineers, it must be acknowledged that continuous visualization and monitoring with real-time feedback systems integrated with BIM framework is necessary. A "dynamic" approach to BIM is essential to not only visually track material and energy flows, but also to respond to state changes for immediate feedback and action.

Furthermore, one of the critical components of sustainability is to enable all stakeholders to perform analyses, and to share and access information in an equitable manner with the aid of new technological developments. By extending the current capabilities of BIM, stakeholders can efficiently meet sustainability goals for their buildings. The estimated lifetime of an "as-built" BIM is one to three years, however, in most cases, BIM files are typically shelved after construction. To extend the life of BIM as well as to alleviate the issues of integration within a single platform, a novel Dynamic-BIM platform was proposed and developed. Among others, this platform will integrate to the BIM environment which is all too familiar to all stakeholders, and is currently the norm for most building projects worldwide. Such an approach will lessen the hassle of hopping from software to software or worrying about the limitations of one software over the other, including interoperability issues, or turning to the basics of new software.

This chapter discusses the Dynamic-BIM platform, a multi-user integrative, collaborative, and extensible environment that enables energy and environmental impact analysis and visualization of buildings and environment. The platform uses a generic reference architecture that is applicable to tighter coupling of integrative and collaborative environments for buildings and their environment. In addition, three applications of this platform are discussed in this chapter: (1) a prototype implementation of University of Florida campus buildings where energy data (electricity, chilled water, steam, and water) is visualized and (2) a prototype implementation of an educational building in the University of Florida campus where data is collected in real-time and visualized.

DYNAMIC-BIM PLATFORM

The critical component of the Dynamic-BIM platform began with the selection of an environment for seamless domain modeling, simulation, and visualization. That is, the environment selected for the Dynamic-BIM platform must suit the functional requirements as well as suitably fit in the overall system architecture. In the development of Dynamic-BIM environment, one of the early investigations tested the bi-directional data transfer between BIM and building performance assessment tools, more specifically, the Revit/Ptolemy interface. In a typical BIM to Building Energy Modeling (BEM) workflow, the necessary data input for energy analysis is parsed from a BIM to a BEM engine. BEM to BIM workflow transfers energy analysis data back to BIM for visualization. As a test, a Revit plugin was developed to connect the Revit software and Ptolemy model in order to assess forward and backward data transfer capabilities. The Ptolemy model was a modified base model from BCVTB. The test partially succeeded in transferring data from Revit to energy analysis via BCVTB. The energy analysis results were visualized in Revit using simple room geometry. For BEM execution, an automated EnergyPlus file generator from gbXML was developed and tested for simple geometries, and for the purposes of ensuring availability as an open-source tool. Currently, the EnergyPlus file generator does not export system-level information which, for this experiment, was manually inputted.

Preliminary tests showed that, for multi-user interaction and visualization in Dynamic-BIM, there were several limitations in Revit (Srinivasan et al., 2012; 2013a). Revit plugins have restricted accessibility to external programs owing to lack of multi-thread capability. Per the documentation, Revit's solution to connecting to external programs is to allow developers to create an 'OnIdle' function that Revit will call whenever it is in the 'idle' state. This is not ideal for interactive applications because the 'OnIdle' function is not called at any sort of predictable interval. For example, if the user leaves the mouse cursor still and is not providing any keyboard input, the 'OnIdle' function is never called and, therefore, the visualization is not updated. Presumably, this is because no Revit code is executed unless there is a user-interface event occurring e.g., moving the mouse or hovering the mouse cursor over a button. Additionally, inept text overlays also pose issues related to visualization of analysis results within Revit. One way to overcome such issues is to utilize a public-domain library that eliminates the dependence of software-dependent Application Programming Interfaces and enables data interoperability from any BIM software and using existing functionalities to extract data into the synthesis environment.

As more practitioners leverage computer-based simulation and data analysis, architectures have been developed to support connecting domain-specific modeling tools with the desired simulation and analysis tools and, in turn, with visualization tools. Realizing this pipeline often requires the integration of separate software packages, the coding of custom plug-ins, or both. Examples of such efforts can be found in scientific and engineering domains. Barseghiana et al (2010), for example, created a custom solution for oceanographers. In Kepler, a software package built on top of Ptolemy for creating and executing scientific workflows (Berkley et al., 2004), custom actors were added in order to collect, analyze, and visualize Sea Surface Temperatures obtained from satellite data. Custom visualization features included the ability to register the data points with Google Earth. An example in pharmacology is the Workbench created by Eissing et al (2011) for whole body simulation "across biological scales." In this Workbench, proprietary modeling and simulation platforms are used to model and visualize the results of biological simulations executed in other programs, including MATLAB.

Dynamic-BIM requires a similar integration of domain modeling, simulation, and visualization. Creation of the domain model can be achieved by mapping the building data in a format that can extract geometry, texture, and material thermo-physical properties. In the case of energy analysis, simulation can be performed in Ptolemy with the help of EnergyPlus actors. However, a graphical and interactive layer to allow a user to change simulation parameters and view the results in real-time situated within the virtual building and from within BIM is required. Two core requirements of this user-interface are the abilities to extract building data and to remotely invoke a simulation. To build the user interface layer, C++ programming language and the Open-source Graphics Rendering Engine or OGRE (2012) were preferred for Dynamic-BIM. C++ was chosen for its speed and power, especially with regards to computer graphics. OGRE was chosen because it is written in C++, open-source, highly customizable, and provided useful high-level functions to abstract low-level graphics rendering code. From any BIM authoring tool, using an external plugin installation, the OGRE-based environment can be accessed. Using this, the BIM is reconstructed geometrically in the Dynamic-BIM environment. Their texture and material thermo-physical properties are also transferred to this environment.

The Dynamic-BIM platform uses a generic reference architecture that is applicable to tighter coupling of integrative and collaborative environments for buildings and their environment. It comprises of four layers: physical world layer; sensor platform layer; dynamic environment layer; and application layer, figure 5. Buildings and their environment are part of the physical world layer. The sensor platform layer enables both sensing and activation of moveable systems in the physical world layer. The most critical of them all is the dynamic environment layer that houses the Dynamic-BIM platform discussed in the next section. Finally, the application layer bridges between users and the system using graphical user interfaces.

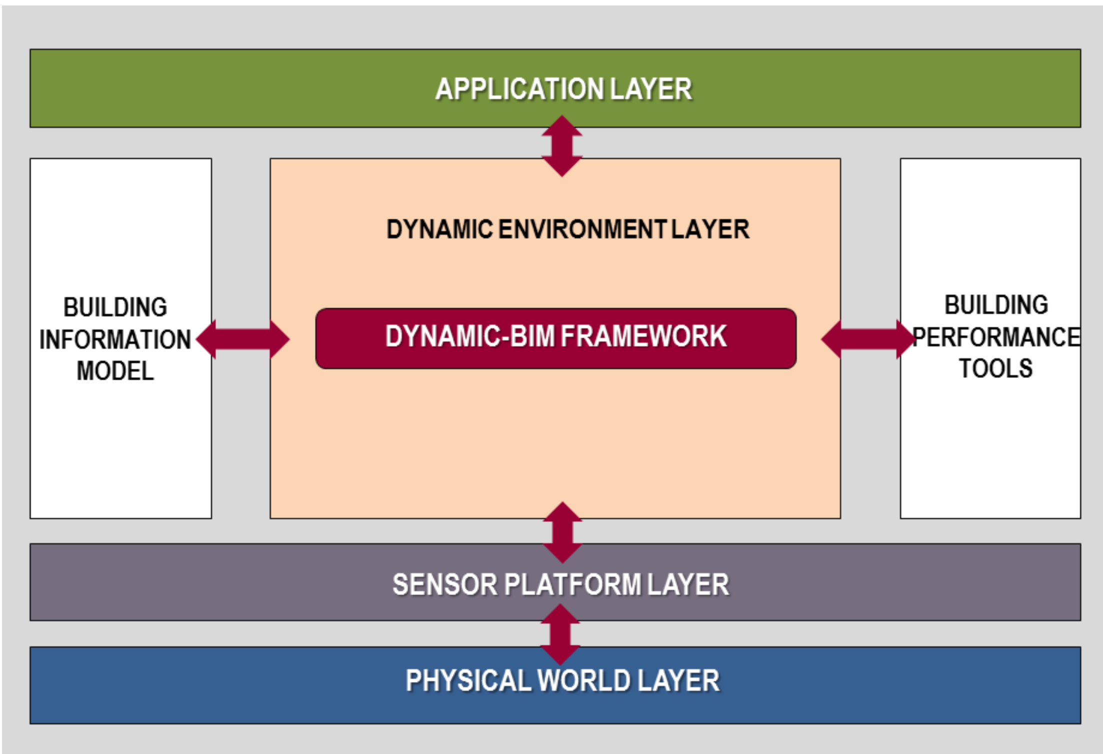

Figure 5. Generic Reference Architecture showing Dynamic-BIM platform for tighter coupling of integrative and collaborative environments.

DYNAMIC-BIM PLATFORM: ENERGY ENGINEERING APPLICATIONS

Although this platform is extensible, for the purposes of this chapter, two specific examples at two different scales are provided, i.e., neighborhood- and building-scales. While for neighborhood-scale, prototype implementation of University of Florida campus is discussed, for building-scale, this chapter provides an overview of energy data particularly real-time sensor data. The learners' engagement and how they use the tool in the classroom setting to understand energy types and uses of campus buildings are discussed as well.

Prototype Implementation at Neighborhood-Scale

For this prototype, University of Florida campus was chosen. UF campus energy system comprises of two components (1) model / data input interface and (2) Dynamic-BIM environment for analysis, navigation, and visualization. Using the input interface, individual building models and other related data are input in to the OGRE-based system using world coordinates (i.e., latitude and longitude). Currently, historical metered electricity data is used in this prototype. The slider can be used to visualize average energy use of campus buildings, figures 6 to 9. Work is in progress to connect to campus-wide Energy Enterprise System as well as to individual building's meter via BACnet. If sub-meter data (lighting, air-conditioning systems, plug loads, etc.) is available, it can be streamed in real-time to Dynamic-BIM-based energy system.

Currently work is underway to develop electricity usage scrutiny options that will include, (a) enthalpy (outside and use) evaluation, (b) degree-day normalization and analysis, (c) building level energy use intensity, (d) space-use type energy use intensity, (e) average energy use, (f) other uses such as exterior / street lighting, swimming pool heating, etc., for both electricity consumption and demand. Besides electricity, other energy uses (chilled water, water, steam, natural gas, fuel), energy resources (photovoltaic, solar thermal, wind, hydro-electricity), wastewater, etc. will be analyzed using this system. Dynamic-BIM environment and in-built gyroscopes and accelerometers in tablets enable navigation of campus buildings including "flying" above buildings. Future work will test the use of mobile technology, particularly tablets, to "point-and-shoot" at buildings to conduct energy analysis.

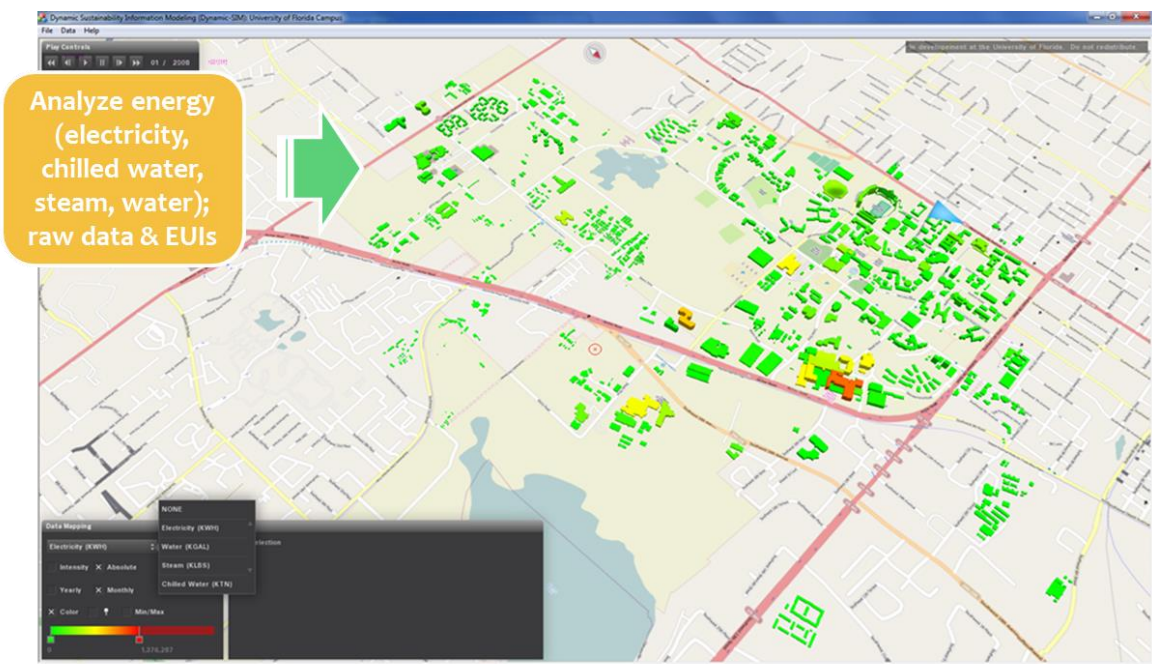

Figure 6. Bird's eye view of UF Campus, Gainesville, in Dynamic-SIM Workbench. Historic energy use data is used at building level at monthly and annual level.

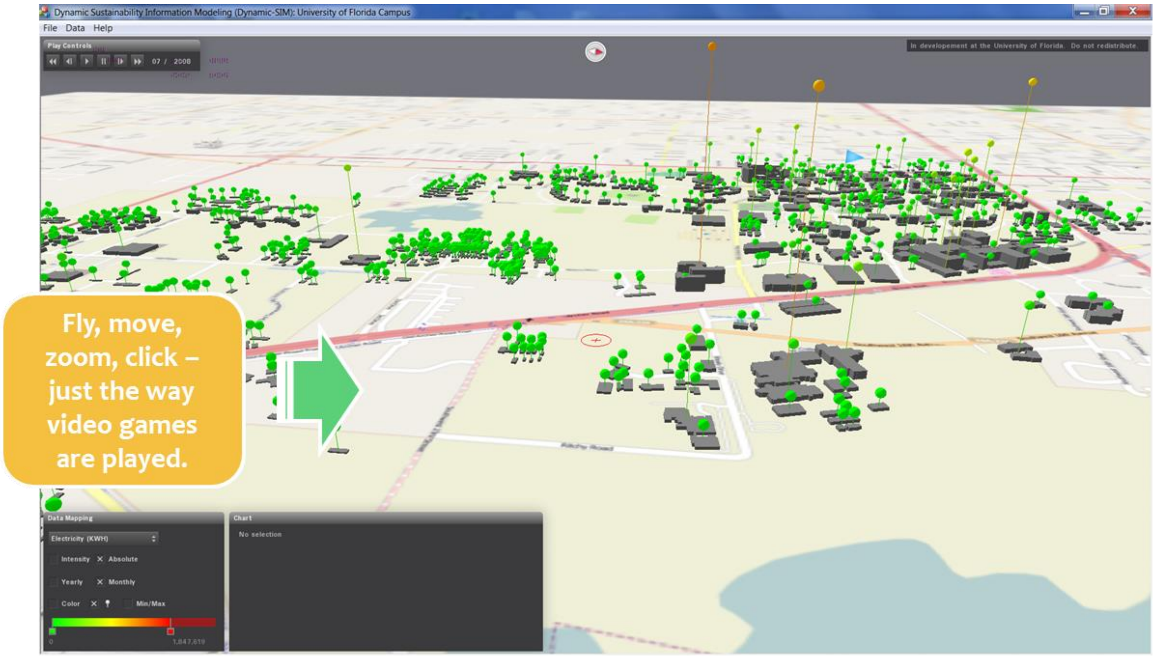

Figure 7. A "play" button enables engineers to visually evaluate energy use of buildings. A user interface allows data extraction and visualization seamlessly.

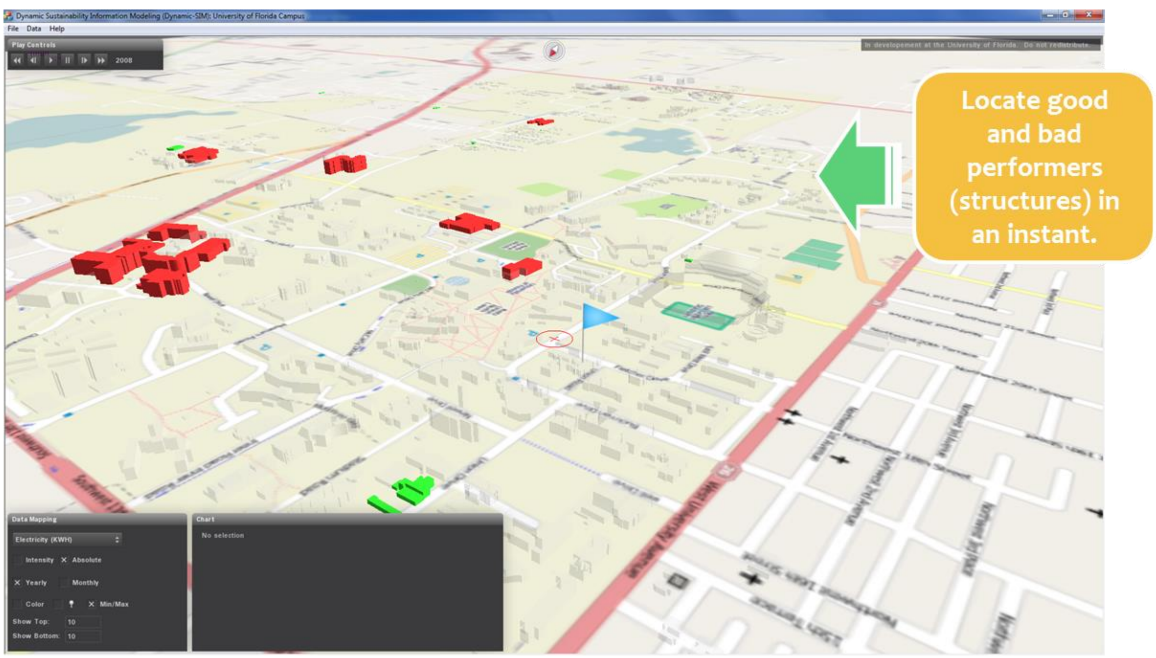

Figure 8. Users can identify good and bad performers in terms of energy use (electricity, chilled water, steam, and water) by month and/or year.

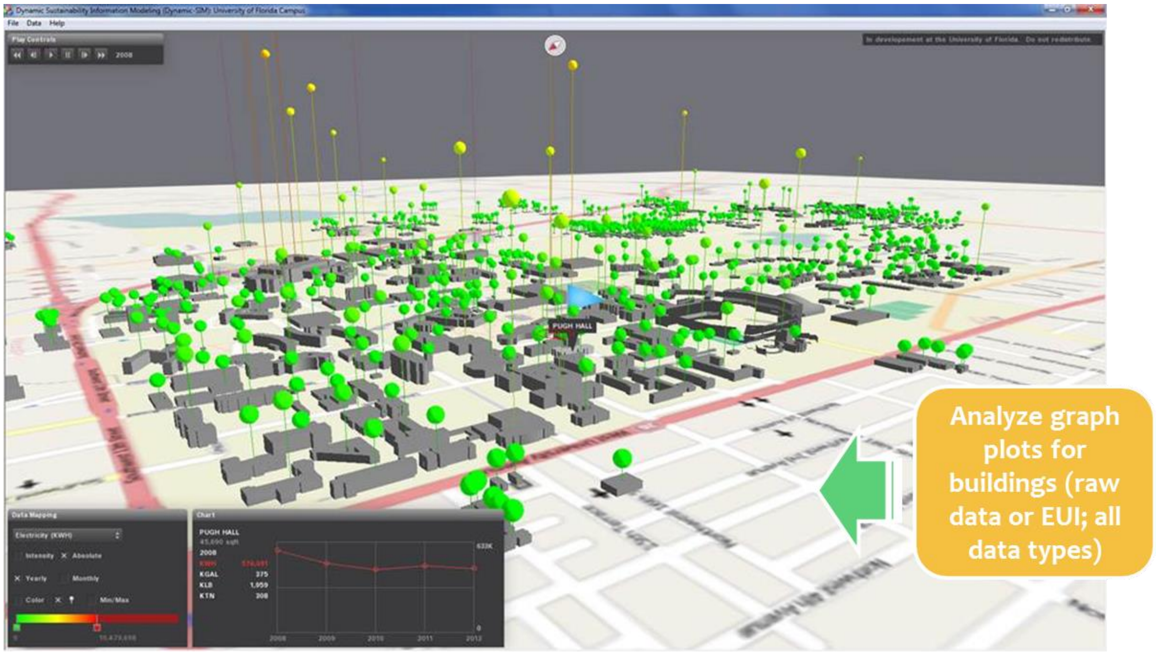

Figure 9. Individual building's energy use can be plotted for further analysis.

Prototype Implementation at Building-Scale

Dynamic-BIM platform allows seamless transfer to building-scale. Figures 10 and 11 show building-scale energy visualization of Pugh Hall building situated in UF campus. The location of this building is represented with a blue-colored flag in figure 9. A plugin was developed that extracted geometry and material data into a format that can be used in the OGRE-based environment. The first step of geometry extraction included sorting out the selected "elements" (i.e., walls, roofs, beams, etc.) and "family instances" (i.e., doors, windows, etc.); which were then transformed into "geometry object." Each of the geometry objects were, then, analyzed to retrieve all "solid objects" that consisted of faces and edges. All the faces and edges of a solid were triangulated and tessellated respectively to extract the nodes. Finally, the surfaces were mapped into regions. Piecewise Linear Complex (PLC) and the mapping were saved in ".ploy" file type, which were then imported to the Dynamic-BIM environment layer for visualization. As illustrated in figure 10, the in-built plugin flawlessly exports the geometry from BIM to aid interoperability with Dynamic-BIM platform.

As a next step, users can engage with the building in several ways particularly moving to different floor plans that show thermal zones. Figure 11 shows an example thermal zone in level two of Pugh Hall. Clicking the thermal zone shows real-time sensor data of several parameters including indoor air ambient temperature, request temperature, airflow rate, Variable Air Volume system vane position, etc. Future work will integrate Fault Detection and Diagnosis (FDDs) at building system- and component- levels, and forecasting algorithms.

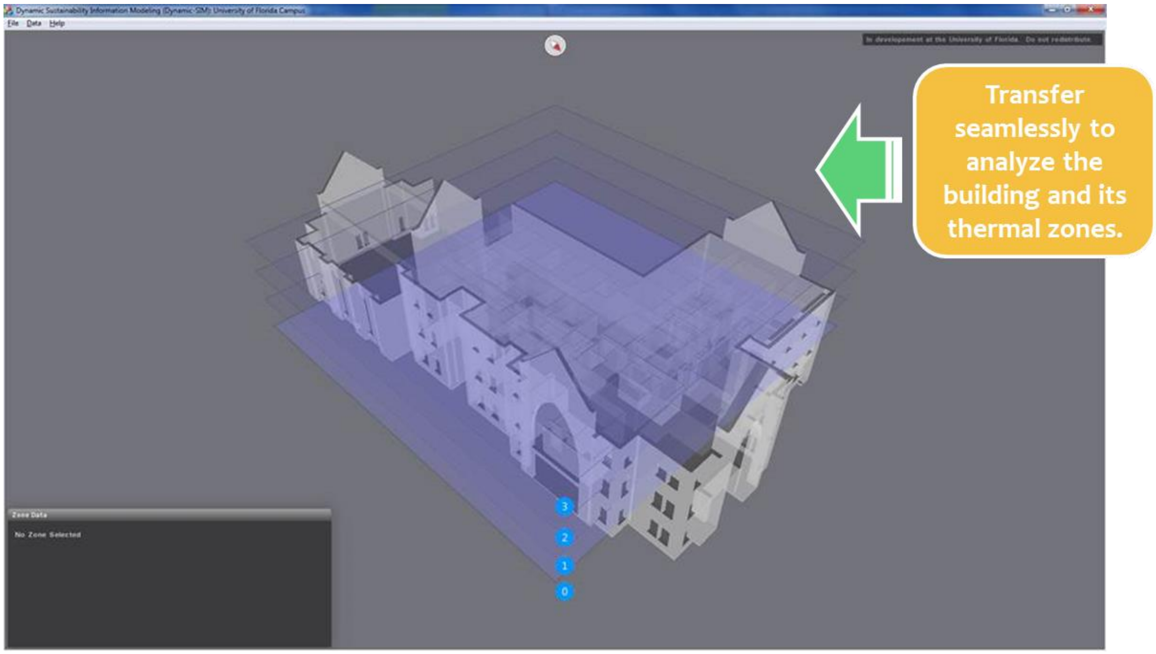

Figure 10. For building and HVAC zone level data extraction, individual building geometry was extracted using a plugin developed in-house, and seamlessly imported into the platform.

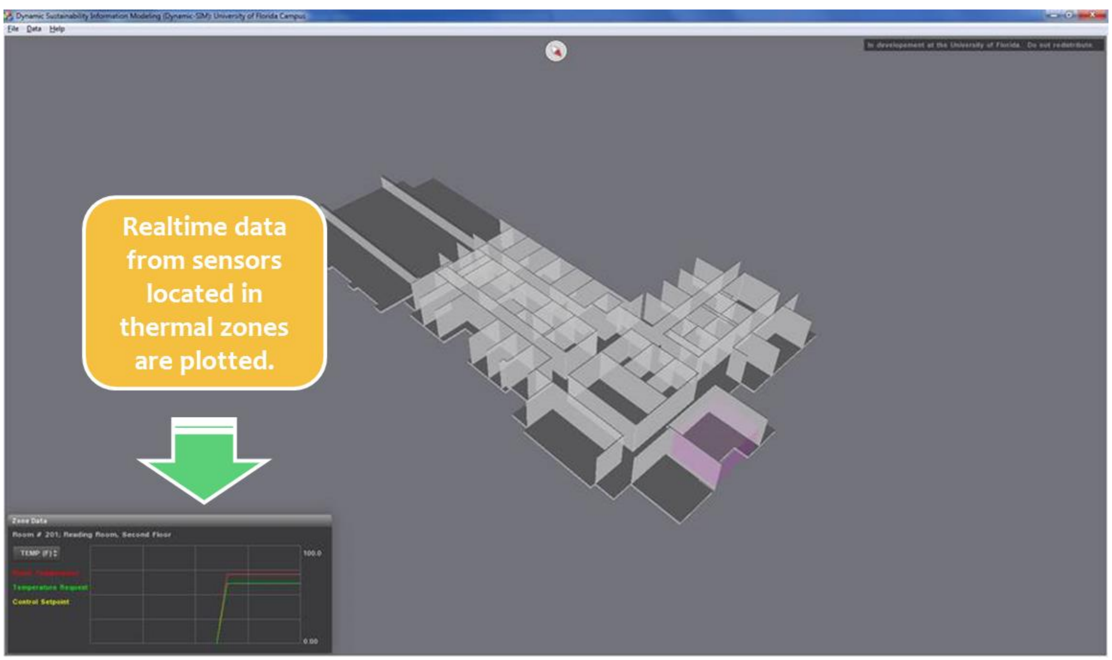

Figure 11. Real-time data from sensors situated in buildings (specific zone under investigation is colored) can be plotted as well.

CONCLUSIONS

This chapter discussed the development of Dynamic-BIM platform that is an integrative, collaborative, and extensible environment. In addition, this chapter discussed two applications of the framework namely, (1) at neighborhood-scale, a prototype implementation of a campus energy map where data is collected, assimilated, analyzed, and visualized; and (2) at building-scale, a prototype implementation of Pugh Hall building in UF campus showing real-time sensor data of a thermal zone. Among others, one of the key feature of this platform is intuitive user engagement of building energy data using device-specific sensor activation, for example, using of gyroscopes and accelerometers to “fly” or “walk” around buildings. Besides, seamless transfer from neighborhood- to building-scale is an important factor for active user engagement since users can “pin-point” and “click” the building to visualize detailed building thermal zones for further investigation. Preliminary works in the integration of 3D heat transfer (Srinivasan et al., 2014) and environmental analysis is underway (Srinivasan et al., 2013b; Srinivasan and Moe, 2015).

Greater tool integration specifically, real-time physical sensors, actuators, controllers, and control algorithms will enable on-the-fly simulations that can be conducted to design, operate, and maintain low energy buildings and beyond. In other words, a comprehensive commissioning exercise is feasible using Dynamic-BIM framework to save considerable time and effort. Visualizing, analyzing, and controlling building and its systems in a virtual environment will allow most of the necessary commissioning process to be conducted at ease. This not only extends the life of an “as-built” BIM, but also offers greater flexibility in conducting ongoing continuous commissioning. Also, currently, communication between the Dynamic-BIM prototype and Ptolemy is achieved through ports on the same machine. As we develop further, the ports approach could be potentially expanded to afford communications between different machines over the Internet. Such an approach would enable running the Dynamic-BIM in portable devices to support Virtual Commissioning (vCx) and Virtual Continuous Commissioning (vCCx) and fault detection of existing buildings. Other Dynamic-BIM framework applications include passive solar building design and construction; Net Zero building design and construction; real-time energy analysis of existing buildings; and auto-calibration of building energy performance, to name a few.

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