Analytical Building Information Modeling: What is the Gap Between BIM and Energy Simulation Tools' Performance Feedback Loops?

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Abstract

Energy simulation tools have become acceptable means of predicting building performance within the major sets of standards and rating systems concerning sustainable design. Building Information Technology (BIT) is expected to further smooth the process and increase the design iteration speed in order to ensure higher building performance. However, current technology has demonstrated that there are still existing problems in this process. This paper focuses on current research in this area and discusses some crucial aspects of the feedback loops between BIM and energy simulation tools. It also proposes a potential path to resolve this issue although further research is necessary.

Keywords

Analytical Building Information Modeling, Energy Simulation, Information Feedback Loop, Building Information Technology.

1. INTRODUCTION

There are many benefits from using building information technology. For example, the technology enables the design team to detect conflicts and conduct 3D/4D/5D simulations prior to construction and provide real time project management. This helps reduce design errors and lessens the number of required change orders. These reductions help save time and money in the field. Yet, building information technology also alters the traditional team work structure and methods of collaboration needed for a project to run smoothly.

One of the anticipated benefits of using BIM is the ability to utilize the information enriched environment in order to impact expected performance of buildings by providing previously inaccessible information regarding predicted building performance at varying stages of the design process.(Krygiel & Nies 2008, pp.178-204; Eastman et al. 2008, pp.18; 149-206) Currently, several standards and rating systems have been established as guidelines to dictate acceptable performance levels of buildings all over the world, such as ASHRAE 90.1, LEED, and BREEAM. Among these evaluation standards and rating systems, some mandatory while others voluntary, energy efficiency is consistently a "must-have" item on the performance check list. As a result, the use and development of energy simulation tools has risen to be of the utmost importance as a means to validate the expected performance of a design. However, currently there exists a disconnection between the informational derivative potential of BIM and current practices in energy performance simulation. Traditionally, a virtual energy simulation model is created separately to validate the performance of a design. Ideally, with the advent of BIM technology, a building information model would not only be able to store information but also to utilize the information for various analyses inside or outside of a model – analytical BIM. Hence, building performance validation should be seamlessly facilitated by the BIM process by non-obstacle communication between the design model

and the energy simulation tool. Yet, due to the limited interoperability between BIM and current energy simulation tools, this process still requires repeated manual input of information. In seeking out solutions, this research first presents current interoperability levels between various BIM authoring tools and energy simulation tools. It also explores the design workflow and attempts to define levels of sophistication and detail required by the various stakeholders involved in the design performance validation process. By exploring related case studies, this research proposal seeks to provide possible direction for future research for the development of complete feedback loops between BIM and energy performance simulation.

2. CURRENT APPLICATION OF ENERGY SIMULATION TOOLS

The Whole Building Design Guide (Richard Paradis 2010) describes energy simulation tools as having the ability to size and select mechanical equipment and predict the annual energy consumption of a structure. Over the past 50 years there have been the development and use of over one hundred building energy programs. The core purpose of these tools is to provide the user with key building performance indicators such as energy use and demand, temperature, humidity, and cost. Not only have there been many software programs developed, but they have been increasing in sophistication, accuracy, and user friendliness in addition to being targeted at different stages of the design process from architectural schematic design to complex engineering calculations. While a number of comparative surveys of energy programs have been published, until Crawley's work in 2008, there was not a published comprehensive comparative survey of all major simulation tools. (Crawley et al. 2008)

Typically, within the modern architecture, engineering, and construction industry (AEC), there are many uses for energy simulation tools, including analyzing schematic geometry, sizing HVAC systems, predicting onsite renewable energy from photovoltaic panels, and calculating appropriate duct work dimensions. Specific tools require different levels of detailed information in order to operate and subsequently provide different levels of accuracy in the results. A recent article by Richard Paradis breaks down these tools into the following four categories (Richard Paradis 2010):

"1. Screening Tools: for use primarily during in budgeting and programming of retrofit projects.

2. *Architecture Design Tools: for use primarily during programming, schematic, and design development phases of new construction and major retrofits.*
3. *Engineering Design Tools: for use primarily during design development and construction documentation of new construction and major retrofits.*
4. *Economic Assessment Tools: for use throughout the design process."*(Richard Paradis 2010)

A fifth category, *Commissioning, Operations and Maintenance*, should be added that recognizes that energy simulations not only help in the original measurement and verification of systems when the building is occupied, but also might need to be redone over the lifetime of the building as occupancy patterns, remodeling, additions, HVAC overhauls, and other conditions warrant new calculations.

The above categories are not always separate and distinct. Some tools that have the ability to cover several categories, and others are extremely specialized. This paper will be focusing on the use of BIM technology and energy simulation tools specifically for category 2 during the schematic and design development phases within a project. Issues regarding the communication between BIM and category 2 tools and tools used for category 3 will also be explored.

While "none of the tools available today support the full scope of conceptual design services," energy simulations are often implemented during the design development phase in order to meet

designated requirements. Unfortunately, design development is not considered the best time for exploring the initial stage of any set of ideas as the many aspects of the design have already been established. Although a common method, this limits the impact of any new information or simulation results on the developing design. (Eastman et al. 2008, pp.158-167)

In order to use energy simulations to meet energy performance for major sustainability standards and rating systems such as ASHRAE or LEED, a model with design development levels of detail is required. Currently designers have two choices with regards to energy simulation. They can develop their design using BIM, import the design into an energy simulation tool, then modify the model in order to ensure compatibility before running the simulations. Modifications made to the model while must then be manually entered back into the BIM model. This is **not** an example of "round tripping;" where changes in one software program are easily mirrored into another. The other choice is to build a separate model within the energy simulation tool and corroborate the results with the BIM model manually. Unfortunately both of these solutions can often be time and labor intensive and lead to two models that might not be synchronized. This process becomes more complicated as the design progresses, resulting in either the introduction of third parties to provide simulations or the abandonment of energy simulations until they are required to demonstrate design performance to meet certain standards. It is apparent that both of these processes do not take full of what energy simulation can offer to the whole design process.

3. DISCUSSION OF THE CURRENT BIM AND ENERGY SIMULATION TOOLS

The purpose of energy simulations is to provide feedback regarding the impact of design decisions on the expected energy performance of the project. Whether these decisions are related to geometry, location of major openings, the size of mechanical systems, or types of glass, not only are analytical models for the purpose of predicting the behavior of the system, but the energy simulation models are also for the purpose of comparison of ideas and potential solutions towards creating a comfortable energy efficient building that meets the applicable energy codes. Exactly what is being compared directly affects the amount of detail needed to make the comparison. This paper will not be investigating that actual accuracy of energy simulation tools, but instead operates on the assumption that all energy simulations are estimates based on the information provided and should be treated as such.

Ideally the BIM model should reflect the amount of known data about a design, whether its only basic geometry or includes detailed wall construction assembly data. As the design progresses, the BIM model should become more complete or complex with the continual development of more information. Also, the cumulated information should be able to support various analyses to ensure the performance of the design. The ideal energy simulation tools should be able to extract the information within the BIM model as needed to perform the simulation in question. The more details extracted would then result in a more accurate simulation that is consistent with the model. Changes made in the simulation model should then be able to seamlessly feed back into the BIM model with minimal manual modifications needed. This would allow for real time feedback and allow energy simulations to impact design to its fullest capacity.

Unfortunately, the current status of BIM, energy simulation, and integration does not reflect this ideal situation. Some of the major issues found in this process are as follows:

1. Technology Disconnect. Design professionals are often unfamiliar with schematic energy simulation tools and instead rely on engineers who prefer the more accurate and more detailed energy simulations performed during design development.
2. Tool Interoperability. There is usually not a seamless integration between software programs; this leads to the loss of information between tools with the results being the need to manually modify models when going between BIM and energy simulation tools.

3. Feedback Loop. There is no way to make adjustments in the energy simulation tool that feed back into the design. Any changes made have to be tracked and then entered separately.

3.1 Technology Disconnection

Throughout the design phase of a project there are different elements under development. For example, a project does not decide on the wall assembly or skin before the orientation has been decided. At this preliminary stage, energy simulation tools are not a way of predicting energy bills, but rather they are a means of measuring the impact of specific design decisions on the overall energy performance of a design. For example, what the impact of a building's orientation on the site will be or how much energy will possibly be saved by using more efficient glass in the window versus a shading device. Energy simulations tools provide information that allows designers to make more informed decisions during their design development.

As is true with any tool, the results can only be as effective or as accurate as the user is competent using the tool. If designers are unable to utilize energy simulation tools during the schematic phase of design, then the contribution of energy simulations tools at this phase are minimized. In addition, when new technology is first introduced into a field, there exists a disconnection between the experience needed to use tools effectively and the actual ability to utilize new tools. Quite often younger members in the field know how to use the tools but lack the experience to make informed decisions or to understand how take information and feed it back into the design. On the other hand, more experienced members in the field often have the necessary expertise to understand implications of information, but lack the technical skills to fully utilize new tools or access the full spectrum of information available to them. As a result there are gaps in feedback loops until the industry as a whole is able to readjust itself to accommodate for new tools. The AEC industry is no exception to this condition and within the current industry there exists the full spectrum of designers generating their 2D architectural drawings by hand to those creating fully integrated BIM projects.

3.2 Tool Interoperability

In this section, it is assumed that there are multiple programs that need to share data, not a single federated model that is only concerned with intra-operability between its modules, although some of the issues faced with intra-operability are similar to those of tool interoperability. Interoperability is defined as the ability of two parties to communicate with each other without the loss or degradation of information. Typically within BIM this is used in reference of going from one software or type of tool to another. With regards to BIM interoperability issues can be categorized into three sections: syntactic, semantic, and geometry.

3.2.1 Syntactic Interoperability

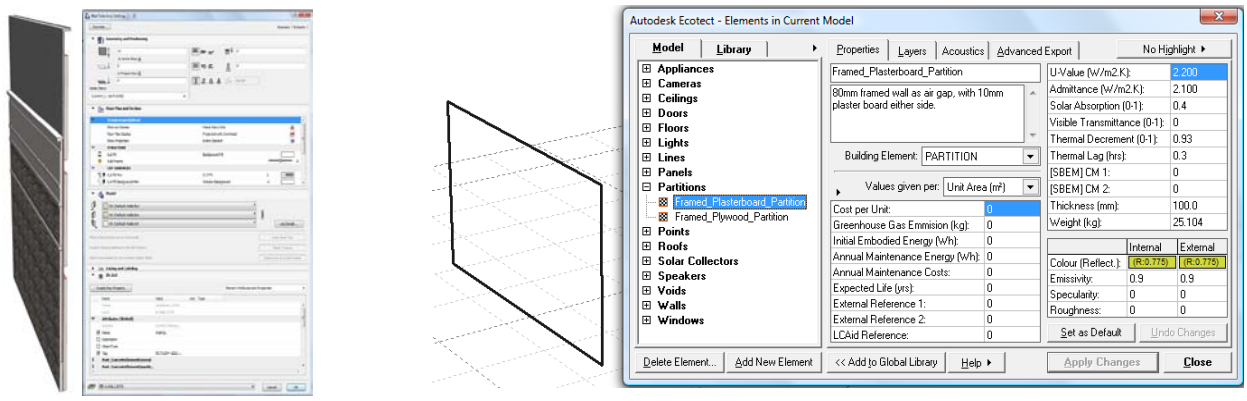
If two or more systems are able to effectively communicate with each other, they can be categorized as having syntactic interoperability. An appropriate analogy is that these systems use the same language and grammar. Since they speak the same language, the various systems can communicate with each other without misunderstanding or loss of data, a common problem between current major BIM authoring tools and energy simulation tools.

3.2.2 Semantic Interoperability

Semantic interoperability is the ability of different tools to automatically interpret information exchanged in order produce desired results. With regard to energy simulations, this translates to the ability for the simulation tool to extract all necessary data from the BIM model in order to perform the desired simulations.

While some energy simulation tools can use the geometry of the BIM model, currently often none of the material and construction properties can transfer from the BIM for energy simulation. (Sumedha Kumar 2008)

Additionally, often energy simulation tools are unable to filter out unnecessary information contained within the BIM model. Where the BIM model contains the majority of information related to a project, the energy simulation tool will usually need only a fraction of this information in order to be effective. For example, the BIM model may have a wall defined with all the layers necessary for construction. However, for current energy simulation tools, the overall U-value is the only necessary piece of information needed for the simulation.(See Figure 1) Also if that information is not explicitly stated, even if the U-value could be calculated from the information contained, the energy program might not be able to "discover" it. This results in labor intensive modifications needed to simplify the imported BIM model in order to ensure compatibility with the energy tool in question. The other choice is to build a new simplified model in order to run the simulations. Either way, energy simulations can become quite costly, and the work redundant.

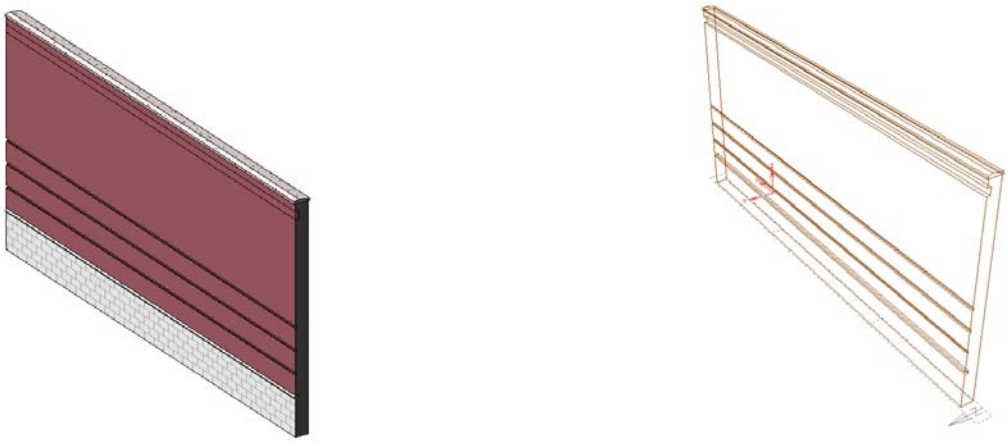


(a) **(b)**

Figure 1: Wall semantic information (a) in ArchiCAD: with all the construction assembly defined; (b) Autodesk Ecotect only needs the overall U-value for energy simulation.

3.2.3 Geometric Interoperability

Geometric interoperability is the capability of accurate geometry transfer from one program to another program. This is vitally important for quantity take-offs, clash detection, space analysis, and any other geometry-driven tasks. For most cases, the issues of geometric interoperability are easier to solve than semantic interoperability, especially since DWG and DXF formats have become almost ubiquitous as for 3D geometry and are supported by most of the BIM software. However, current energy tools, in order to perform simulations, define volumes by space rather than by geometry defining edges. As a result there is often a loss or incompatibility with how geometry from a BIM tool is imported into an energy simulation tool. For example, a wall within Revit is defined as a single entity with inherent layers, properties, and thickness. When geometry be imported directly into a simulation such as Ecotect, that same wall becomes defined as six separate faces that do not interact and must each be separately defined with regard to properties such as U-values before any simulations can be calculated. In addition, Ecotect will initially treat the space between the outer edges of the wall as a separate room, adding it to the energy calculation. As a result, major modifications and adjustments must be made to any imported model in order to preserve the geometry integrity and gain the results desired. (See Figure 2) Although the geometry exported from the BIM model in DWG or DXF format can still use for lighting and daylighting analysis, other analysis related to thermal and space cannot be validated with this geometry definition.



(a) **(b)**

Figure 2: (a) The original single wall geometry in Autodesk Revit Architecture; (b) The wall geometry exported from Revit in DXF format into Autodesk Ecotect; each geometry face becomes a partition in Autodesk Ecotect.

While some of these issues can be resolved by using IFC or gbXML formats in order to translate the geometry into space boundaries for energy simulation, these formats have yet to be developed in order to handle complex geometries. As a result, in order to import models, geometries often have to be simplified in order to be effective within energy simulation tools. For example, during the BIM Analytics 2010 symposium held at the University of Southern California, Jenna Knudsen and Alex Korter demonstrated how CO Architect needed to simplify their BIM model in order to run further simulations. According to Knudsen and Korter, there was too much information in the developed BIM model that their energy simulation tool either didn't know what to do with or simply discarded, resulting in necessary manual modifications before the model could be used for further energy simulations. (Knudsen & Korter 2010)

There are, however, a collection of energy simulation tools that are unable to even read the geometry provided by the BIM model. This means that in order to use these tools a new model must be built within the tool itself as there exists no interoperability between the tool and BIM.

While some of these interoperability issues can be overcome through original datum, resources to accomplish this are not typically found within a design office. Mitch Dec and Tianxin Xing presented an example of this at the BIM Analaytics 2010 symposium where they were able to streamline a Rivet model into eQuest. (Dec & Xing 2010) While this may be valuable enough for engineers who are performing more detailed energy simulations, this is not an efficient use of time for designers at the schematic or design development phase.

3.3 Feedback Loop

The design process is not linear. Ideas are bounced back and forth, choices are explored, more ideas are introduced, and the loop continues. Designers are constantly trying new ideas and evaluating previous ones throughout the entire design process. Energy simulation tools are meant to provide one more way to evaluate the impact of these ideas on the overall design. In order to maximize the effectiveness of energy simulation tools on the design process there must be a seamless way to go from BIM to energy simulation tools back to BIM.

An example of this seamless feedback loop is with regards to light and shadow studies within Autodesk Revit Architecture. Due to the rendering capabilities of Revit, designers are able to see the impact of openings in their design on the interior spaces, make adjustments, and immediately see the impact of those adjustments. (See Figure 3) This allows designers to evaluate and explore a variety of ideas regarding lighting in their designs throughout the entire design process. In addition, since

these adjustments are made directly to the BIM model they do not need to be re-entered at a later date, they are now a part of the project. This works especially well for shadow and preliminary interior lighting studies.

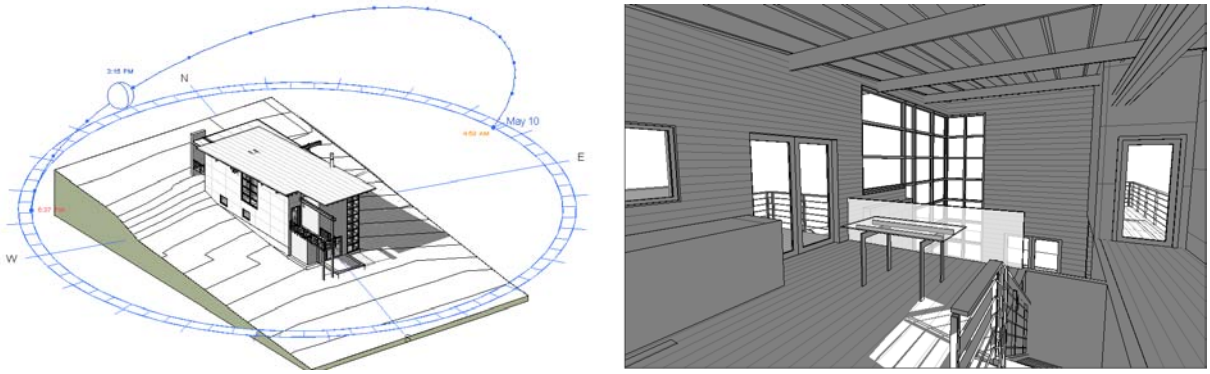


Figure 3: Solar and shadow studies in Autodesk Revit Architecture (Model shown is provided by the Revit sample project)(Autodesk, Inc. 2010)

This is an effective means of evaluating ideas because feedback information can be provided at all stages of design. During the schematic phase, designers can input simple geometry to test, gaining results pertinent to the design process. One example is the ability to calculate foot candles on surfaces and learning what changes different interior lighting systems make.

Energy simulations are similar regarding the validity of results yielded from schematic geometry studies all the way through to systems design and sizing. However, in order to be just as effective, designers need to be able to complete and analyze the results of energy simulation tools in the same fashion. Unfortunately there is currently no seamless feedback loop from energy simulation tools back into BIM. Any changes made to the design as a result of the energy simulations have to be manually entered into the BIM tool separately, requiring labor and time to complete. This limits how much information energy simulation models are able to contribute and when during the design process. The figure below illustrates the information exchange between a BIM model and lighting analysis tools. Clearly this process would be more fluid if the information exchange could be automated and filtered.

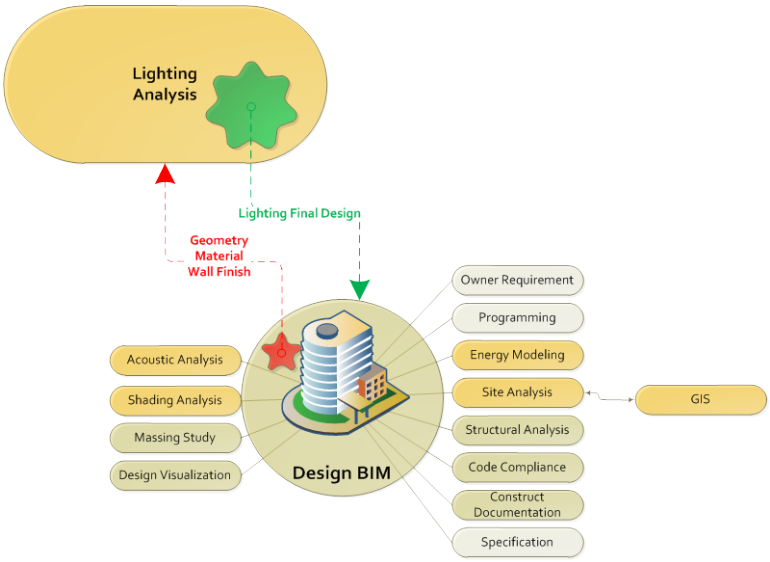


Figure 4: Information flow between design BIM and lighting analysis

4. CURRENT RESEARCH RELATED TO BIM AND ENERGY SIMULATION TOOLS

In order to resolve some of the issues inherent with BIM and energy simulations, various approaches are currently being researched. Four are discussed below:

1. Industry Foundation Class (IFC) as a data exchange format.
2. Embedded energy simulation tools within BIM tools.
3. Stand-along energy simulation tools that are more compatible with existing BIM tools.
4. gbXML (Green Building Studio XML) as a data exchange format.

4.1 Industry Foundation Class (IFC)

Currently the International Alliance for Interoperability (buildingSMART International 2010) and the National Building Information Modeling Standard (NIBS 2010) group are exploring the ability of using the Industry Foundation Class (IFC) file exchange format to solve the interoperability issues often found between BIM tools. Vladimir Bazjanac of Lawrence Berkeley National Laboratory, in particular, is exploring the use of IFC as a means of solving the interoperability issues between BIM tools and energy simulation tools. (Bazjanac 2003; Bazjanac 2004; Bazjanac 2005; Bazjanac 2008) Currently IFC can be exported from the BIM environments for input into energy analysis tools. However, there certain limitations in this approach, one of which is that current IFC has yet to mature to the point where it can contain all of the necessary information required for energy simulations. As a result, when exporting BIM to IFC, there may be a loss of pertinent energy-related building data.

4.2 Embedded Energy Simulation Tools

Software developers, such as Autodesk and Bentley, are starting to embed energy analysis tools directly into the BIM software environment or import the information into other software they own, thereby eliminating certain interoperability issues. While this approach eliminates the need to import and export building geometry and data through IFC or other formats, it does pose other issues. Currently the tools provided within the BIM software environment have been only able to perform energy simulations at the schematic massing phase. While very useful, there is the need to provide of way of performing more detailed energy simulations as well. (Malin 2008)

4.3 Stand-Alone Energy Simulation Tool

Stand-alone energy simulation tools have been available for years, but using them has typically been a costly, labor-intensive process in order to generate desired energy simulations. In addition, these tools are typically designed for engineers to provide detailed energy simulations that are used later in the design process for final documentation.

4.4 gbXML Format

Currently there is also the development of web-based simulation tools that utilize the open source formatting in order to provide interoperability. An example of this is Green Building Studio, which is attempting to also provide an alternative standard language rather than IFC. Green Building Studio uses Green Building XML (gbXML) file format that is being adopted by many in the heating, ventilating and air-conditioning (HVAC) industry (including Trane, Carrier & York International) in attempts to streamline the building design process and provide improved interoperability for project design teams. Several of the leading BIM applications enable users to generate BIM output in the gbXML format. Green Building Studio works with the gbXML file exported from various BIM applications and uses the building information to perform an energy evaluation with established tools such as DOE-2, eQuest, and Energy Plus. (Stumpf & Brucker 2008)

As with other stand-alone tools there are still issues of interoperability between BIM tools and gbXML where there is a loss of certain types of critical information. For example, instead of using the wall assembly defined by the BIM model gbXML will instead use a programmed default that must be altered manually. In the case of Green Building Studio, after running the simulation and editing parameters to produce a more energy efficient building, the changes cannot be exported to the BIM model.

5. SUMMARY AND SUGGESTIONS FOR FUTURE RESEARCH

The purpose of energy simulation tools is to provide the right people with the right information in order to influence decision making where and when it is most effective. In order to alter the building's geometry to create a more efficient use of energy, the designer must be able to compare the effect of different forms of the building quickly and efficiently. In order for engineers to see the overall impact of an AC system on the building performance, they must be able to compare that system's expected performance to others. In the world of energy simulation, it is all about comparison, first in making the systems more efficient and then in comparing those numbers with required building codes or voluntary certification such as LEED.

In order to maximize the impact of energy simulation tools on the building design process these tools must be integrated throughout the entire design process. Energy simulation tools must be capable of closing the feedback loop. For designers, this may mean using a tool that combines conceptual design and energy calculations in order to provide real time instant feedback at the schematic level or continuing to push software developers to provide a means of seamlessly going between energy simulation tools and BIM tools.

There are two paths of exploration with regards to closing the feedback loop between BIM tools and energy simulation tools: utilizing a common language (IFC, gbXML, etc.) between tools or embedding the ability to perform energy simulations within BIM tools directly. Enthusiastic support exists within some sectors for open standards such as IFC, (Ouellette 2010) whereas others see proprietary standards or embedded tools are a better solution. Within these two choices are a variety of approaches, some under research and others barely explored yet. There is also the strong possibility that the most practical solution lies somewhere between the two paths.

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7. NOTE

As a preamble of author's dissertation work, this paper provides the outline of current and future potential research directions regarding closing the feedback loops between BIM and energy simulation tools. It also presents the key component - the gap between BIM and energy simulation tools, which should be addressed in the current relevant education curriculum.

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