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A Collaborative Issue Requires a Collaborative Solution:
The incompatibility of BIM and energy simulation software

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Introduction:

Sustainable design is reaching new heights in terms of importance and popularity as the world has begun to recognize and, now, prioritize the limitation and/or regulation of the consumption of finite resources. Gaining popular ground over the last half century, the environmental movement across the globe has inspired countless organizations and committees devoted to the ideas of sustainable development and sustainable design. Together these public, private, and nonprofit groups have delivered on regulatory policies and international standards worldwide[1]. As a result of the sustainable design concept popularity and subsequent mandates, the building design, construction, and management industries have accepted the challenge to gain the most potential from new and existing infrastructure in every stage of a building's lifecycle, through green building and building optimization, with both the ecological and economic implications of sustainable design in mind.

In order to meet the challenge to attain a building's full optimization potential through complex, energy efficient, and innovative designs - either in new construction or the redevelopment of existing infrastructure – a multi-disciplinary collaboration is essential, accompanied by a comprehensive range of software applications. Computer mediated communication is no longer a novelty but a necessity.

Facilitating these collaborative efforts, the use of high powered software applications allow us to share ideas and information globally and to work cohesively toward a single goal. However, the cooperation between disciplines is made difficult by the incompatibility of commonly used software applications and platforms.

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[1] Examples –
Organizations: The U.S Green Building Council: This not-for-profit organization, founded in 1993, was responsible for the development of Leadership in Energy and Environmental Design (LEED) in 2000 – an international standard for sustainable building.
Other standards: Energy star is an international standard for energy efficient consumer products (1992)
Acts/mandates/regulations:
The National Environmental Policy Act (U.S. 1970);
CalGreen - In 2010 California became the first US state to implement a statewide green building code.*(http://www.bsc.ca.gov/Home/CALGreen.aspx)*.
The Streamlining Energy Efficiancy for Schools Act of 2014 (H.R 4092;113th Congress)
European Parliament and Council Directive (2002/91) on energy performance in buildings (EU EPBD - recast in 2010) – set minimum energy standards for new buildings and requires a Building Energy Rating (BER) Certificate be provided at point of sale or rent for new and existing buildings.

For the purposes of this paper we will consider the modeling and simulation processes predominantly used by the building industry, in particular those used by the architecture, engineering, and construction super-domain (AEC) and those used by the energy domain. Each of these domains lean on building models with varying levels of detail and use cases. So, each discipline relies heavily on the ability to share and exchange information between their perspective modeling tools. The current state of interoperability between these tools demands a considerable amount data preparation and pre and post processing; arguably the standardization of information exchange or the standardization of data modeling languages is also necessary.

A considerable amount of time and effort is consumed manipulating existing models to meet most of the exchange requirements for each system, which can still result in exchange errors, inaccuracies, or erroneous simulation outcomes. Still collaborative efforts are being made to explore strategies and methods for well-structured, meaningful information exchange. A collaborative issue needs a collaborative solution.

Fragmentation to collaboration:

The integration of information from our fragmented industry is an essential component of building design. Due to increasing specialization and fragmentation within the design industry, no single individual has the capability to undertake the overall design and construction of a facility. *Building design is a complex, multi-disciplinary engineering activity that requires making difficult compromises to achieve a balance between competing objectives such as safety, reliability, performance and cost* (Ren et al., 2011). The architectural, engineering, and construction (AEC) domains can be even further broken down into mechanical, structural, and electrical engineers, energy experts, materials specialists, and building physicists; this is to name but a few of those responsible for imparting knowledge and data to designers from other disciplines and project stakeholders. Just some of the recognized reasons for project collaboration include optimizing functions, minimizing costs and reducing mistakes (Ren et al., 2011).

To facilitate any collective effort, communication between entities is aided by information communication technologies (ICT) and interoperable software applications which allow us to share ideas and information globally, and work cohesively toward a single goal or on a single project. This is no different for the building industry. In order for this collaboration to take place in an accurate and dually efficient fashion, the software applications that support the building industry need to be interoperable or compatible at the very least. Currently the building industry is trending heavily toward the use of Building Information Management systems (BIM) and, due to the overwhelming promotion of sustainable design, Building Energy Performance Simulation applications (BEPS).

Collaboration complications:

The cooperation between disciplines is made difficult by the incompatibility of commonly used software applications, which are generally not holistic in nature; opportunities for design efficiency and potentially energy efficiency are lost as well.

Across the broad scope of the building industry many tools are being utilized. Though many of these applications are conceptually very similar, and therefore have similar components and functions, on a semantic level they are very different – having different system architecture, definitions, and formats – making them difficult to correspond. Also, designers from separate domains may have differing modeling methods and objectives, or approaches to the utilization of the software application, which makes a difference in the way information is processed and organized , resulting in further incompatibilities. These variances lead to inefficiencies like recreating models in other programs (fully or partially), or fixing semantic differences between proprietary data models to allow for exchange of information. These are time consuming and costly endeavors that are a gateway for potential errors or gaps in information (Monteiro et al., 2013).

Systems:

BIM Process Applications:

Building Information Modeling (BIM) has been adopted by the AEC industry due to the broad scope of capabilities the process provides during the building lifecycle: conceptual design, detailed design, analysis, documentation, fabrication, multi-dimensional visualization, construction logistics, operation and maintenance, renovation, and demolition. Initially BIM was used by building developers who were already accustomed to modeling their designs using CAD programs. So, naturally these designers used BIM applications as drafting tools for 3D visualization that just happened to have the added benefit of providing pertinent information to complete cost analyses; this as opposed to grasping BIM's full capacity to represent all of the physical and functional characteristics of a building. However, since the adoption of BIM by the AEC industry in the late 1980s, the rate of BIM use has increased rapidly. According to the *Smart Market Report: Multi-Year Trend Analysis and User Ratings (2007–2012),"* a report produced by McGraw-Hill Construction, the use of BIM by the AEC industry has grown from 17% in 2007 to 71% in 2012 in North America and Europe is now beginning to exceed these rates of BIM use.

The AEC industry has come to realize the wide range of applications for BIM, which include, but are certainly not limited to design, visualization, simulation, documentation, sustainable analysis, cost estimation, scheduling, operation and maintenance, and asset management. BIM is recognized as an effective and efficient method of streamlining planning and coordination between all project stakeholders and is expected *to improve data integrity, intelligent documentation, distributed access and retrieval of building data, and high quality project outcome* (Gu et al., 2010). Large software development companies - i.e. Autodesk (Revit), Bently Systems (Bently Architecture), Graphisoft (ArchiCAD) - have promoted the adoption of BIM services in the AEC industry and, with that, the use of their respective proprietary BIM applications.

Throughout the building life-cycle, BIM can draw a more accurate picture of the proposed building for the use by architects, MEP engineers, structural and civil engineers, project managers, facilities managers, and other stakeholders. In theory, BIM is intended as a holistic modeling scheme, encompassing all domains which are building related. Therefore BIM ideally has the capability to handle basic Building Energy Performance Simulations (BEPS) (Nasyrov et al., 2014); however, models intended for use by the AEC community do not meet the requirements to carry out such actions. Also, developing a single software application capable of storing and produce such a wide range of data would be challenging at best.

For the purposes of energy simulation, energy specialists within the building industry have adopted BEPS applications and plugins, e.g. IES Virtual Environment, EnergyPlus, DOE-2, DesignBuilder, etc. (more tools can be found at the U.S. Department of Energy - *Building Energy Software Tools Directory*).

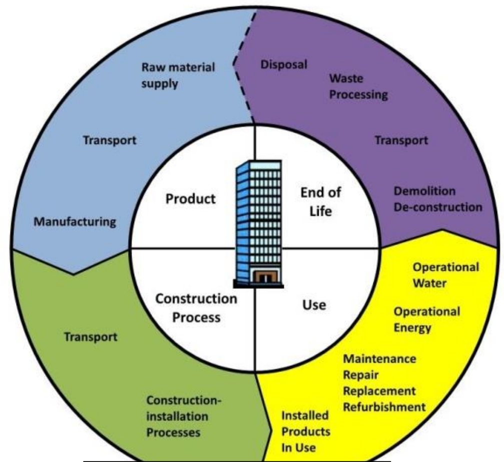

Figure 1. Building life-cycle

BEPS Process Applications:

Energy performance simulation programs are powerful tools to study energy performance and thermal comfort during the building's life-cycle (Maile et al., 2007).

Similar to BIM, the use of BEPS from the early design phase can draw a more accurate picture of the building's optimization potential allowing for the comparison of various design options. During building conception BEPS can be used to help designers achieve lower energy consumption without compromising thermal comfort - based on architectural and MEP design alternatives, occupancy, location, and various use cases (Gudnason et al., 2014) – as well as energy simulators can also help define control strategies for building automation.

Though many BIM tools can provide some of the basic functions of energy analysis, BEPS tools can take a more comprehensive view and are capable of producing more energy related simulation data during not only the early stages, but also throughout the life-cycle of a building. For example, because building optimization strategies are constantly evolving, Facility Management companies can continue to use BEPS tools for a variety of reasons during the operation of the building, e.g. building optimization, space utilization, lighting, heating, occupancy based decisions, material exchanges and other related renovations.

Although early design stages can be the most critical for decisions related to long term energy savings, this opportunity is often missed due to the high cost of completing a comprehensive energy analysis (Nasyrov et al., 2014); a sentiment that may have been attributed to the use of BIM 30 years ago.

These considerable expenses can be indirectly credited to the incompatibility between BIM and BEPS tools, or the lack of a true holistic single application. Though there is a significant overlap in the necessary information to complete both BIM and BEPS models, a BIM model created to fulfill the needs of the AEC domains does not meet the exchange requirements of a BEPS model application. Therefore, an energy specialist looking to analyze the potential or ongoing energy consumption of a facility must recreate the building model in a separate BEPS system, or manipulate and augment the available information to meet the exchange requirements.

Incompatibilities:

An article by Ghang Lee in the Journal of Computing in Civil Engineering: *What information can or cannot be exchanged?* suggests that the reasons behind system incompatibility can be broken up into four categories:

1) *The inadequate coverage of a data model, or an exchange format*. The most widely used standard for *data sharing in the construction and facility management industries*, with respect to BIM applications - the Industry Foundation Classes (IFC) schema - does not fully support all intended data exchange scenarios (Lee, 2011). 2) *Problems related to system translators*. Translators import and export information between formats. A common criticism of IFC is that there is loss of information with each import–export process, which can lead to erroneous results, and ultimately, incorrect quantities and estimations (Monteiro et al., 2013). This may be a result of deficient development guidelines for information translation. 3) System bugs. 4) Issues resulting from a software application's target domain. Generally, software applications have special features and constraints dependent upon the application's intended use cases and ideal end users. Consequently, they have dissimilar information requirements or capacities (Gudnason et al., 2014).

Standardizing information exchange:

Though some might argue for the standardization of modeling practices, this would take an exorbitant effort. Building models are created for a litany of domains in the building industry, with varying levels of detail and use cases. Requiring one to follow a modeling procedure to suit the needs of those outside of their domain would be unnecessarily challenging. Instead a standardization of information exchange or the standardization of data modeling languages would allow interoperability through open standards.

The IFC schema, developed and maintained by BuildingSMART International, is registered with International Organization for Standardization (ISO) as *ISO 16739:2013-Industry Foundation Classes (IFC) for data sharing in the construction and facility management industries* (ISO, 2013). One reason it was developed was to tackle the complex requirements for information exchange between building models of various formats, with varying proprietary data, which are being utilized by an assortment of building industry domains (e.g. architecture, MEP, energy Performance simulation, etc.) for the purposes of multi-disciplinary collaboration. This is partially accomplished by standardization of common modeling elements (slabs, spaces, bounding boxes, space fillers, material data), input data (loads associated with building elements or electrical components, orientation factors for environmental impacts, product lifecycle information) and the data produced by the tools (energy simulation data, loads and gains within a developed space, cost related data, space use data). The IFC format should allow for the exchange of this information.

The IFC schema, defines a collection of objects and instances that can be made into a building model using either the EXPRESS or IFCXML modeling languages. Since its conception, IFC continues to grow and add *new concepts to the IFC specification in order to capture more exchange use cases and to improve existing definitions reflecting the lessons learnt from implementation and usage* (BuildingSMART, 2014a). These program additions are intended, in part, to expand IFC to include exchange requirements specific to the energy analysis domain. Ideally, IFC should allow free flow of information.

Since the acceptance of IFC by the building industry, AEC software companies have embraced IFC, creating avenues for compatibilities between their own BIM database’s proprietary classification systems, or structures, and IFC's. According to an article in Automation in Construction (Monteiro et al., 2013) the compatibility of proprietary data with IFC can be achieved in two major ways: 1) IFC is adopted as the base point for the development of the proprietary format. 2) Import/export translators permitting the adjustment of a model to minimize loss of information in the case that the proprietary format follows a different architecture.

Exchange of Information within BIM Applications:

The current state of exchangeability relies heavily on the considerable data preparation and the pre and post processing of data.

Because the exchange requirements for BIM applications are similar, the exchange of information between BIM applications seems generally doable without too much information loss, which would leading to incorrect quantities and estimations. However, some objects and building elements may not exchange well between model formats. IFC specification contains definitions needed to represent the most commonly used AEC-related objects and components and their associated properties, but due to the abundance of possible combinations of these details IFC cannot possible amass the necessary database to cover everything. So, if there is no representation for a set of properties within an object or an object itself, IFC developers create mechanisms to allow users to either add their specific properties to IFC objects (Property Sets), or in the case that an IFC object does not match up to the proprietary data structure, an IFC Proxy is created and that object can then be remapped to its original location manually (Monteiro et al., 2013).

In the case of information exchange between BIM and BEPS, there are instances of object clarification for each system, but further stand-alone BIM applications do not meet the exchange requirements for BEPS due to lack of necessary data or the visual representation of shared data only useable by those outside the energy domain.

Exchange of Information - BIM to BEPS Applications:

System bug s during data translation will be a reoccurring problem with transfers to and from proprietary platforms with IFC, but because IFC is widely accepted by the AEC community, it is a good starting point for the interoperability between BIM and BEPS applications. Though, generally, BEPS software does not support IFC, it does support gbXML, an open source format based on XML developed for data exchange for energy simulation (Nasyrov et al., 2014), which can and must then be converted to IFC format.

Theoretically one can transfer pertinent information from BIM to BEPS; however the information necessary for energy simulation is incomplete or ill-fitting. BEPS demands a higher level of detail and dissimilar geometry than that of a model developed for, say, architectural reasons. In addition to undefined objects or properties, which can ideally be supplemented using IFC and data mapping, the exchange requirements for BEPS include, but are not limited to, the exact building geometry and spaces boundaries (in order to capture thermal zones), the building systems (such as HVAC or electrical), facility use, occupancy and other building operation information, building features (architectural aspects), materials information, site location information (environmental site conditions, including weather and climate conditions, landscape, bordering land use, and building orientation), and the quantification and qualification of all loads.

An illustration of current exchange:

Geometry:

The transfer of geometrical information from a BIM model to a BEPS application is challenging for multiple reasons. The geometrical data needed for architectural purposes are of differing quality than that required for the purposes of BEPS.

For example, BEPS requires a higher level of detail of volume for every space in a building, both functional (occupied spaces) and non-functional (technical spaces). The specific coordinates of each building object must be accurate to avoid gaps or holes not in line with a proper thermal or energy analysis. In addition to volumetric accuracy, these spaces need to be clearly delineated by second level space boundaries which are covered under Model View Definitions (MVD).

The IFC MVD, Coordination View, Space Boundary add-on view describes second level space boundaries for the specific use in thermal and energy analysis, as opposed to first level space boundaries, which require less detail and are created with architectural purposes in mind (BuildingSMART, 2014b). Reconstructing a model with the appropriate second level space boundaries is one of the processing tasks required for information exchange, and is a time consuming and costly procedure.

As a solution to this problem one could hypothetically create AEC BIM models using the second level boundaries or create a second MVD for each model, however this would be highly excessive work for someone who will not need this level of detail for their own purposes, assuming that they have the knowledge or foresight to do so.

According to BuildingSMART International, the proper MVD – *which translates the [appropriate] exchange requirements into a specification for a given exchange format* (BuildingSMART, 2014c) can satisfy the geometrical exchange requirements for energy simulation. However, as of the IFC version 2x3, the information necessary for a complete MVD specific to energy analysis is not yet complete (Nasyrov et al., 2014).

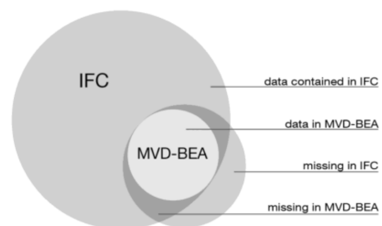

Figure 2. IFC V. MVD-BEA (Nasyrov et al., 2014)

Another method for converting geometrical representations is , as part of the processing of a model prior to data exchange, to use “preprocessor” or “middleware” tools, such as *SketchUp* or *Geometry Simplification Tool (GST)* or the *Space Boundary Tool (SBT)*, that would allow the translation of IFC information and/or simplification of certain building properties in IFC format from that used in an architectural BIM context, so that they might be suitable for an energy simulation tool (Nasyrov et al., 2014).

While using these third party tools is ideal to simplify the translation of geometrical building characteristics, building material properties, which are also an exchange requirement for energy simulation, are not being imported into these tools nor are they able to be imported into many energy simulation tools, regardless of a tool's IFC compatibility and the use of IFC material property definitions within BuildSMART's Data Dictionary. As stated above: in most cases material properties, or property sets, must be added in manually (Nasyrov et al., 2014).

This information is best demonstrated in a test suite presented in *Building information models as input for building energy performance simulation – the current state of industrial implementations* - see Figure 3.

Table 1. Results of the test suite.

Software Data	EnergyPlus SBT	EnergyPlus SketchUp	Symergy (EnergyPlus engine)	Ecotect Analysis	Green Building Studio
Geometry	+	+	+	+	+
Material Properties	+/−	−	−	−	++
Building Systems	−	−	+	−	−
Building Operation Information	−	−	−	−	++
Building Systems	−	−	−	−	++

Not (−), partly (+/−), imperfect (+), and fully (++) implemented.

Figure 3. Results of the test suite (Nasyrov et al., 2014)

New solutions for multi-disciplinary collaboration:

A considerable amount of time and effort is consumed manipulating existing BIM models to meet most of the exchange requirements for energy simulation, as reviewed previously. These tasks include redefining objects, creating property sets, data mapping, the use of third party tools for translating and data checking, and many more stages of processing. Even considering the service provided by the IFC schema, this amount of data handling may result in mistakes and/or inaccuracies. It's little wonder why energy analysts would choose to recreate a model from the ground up.

So, why not just go to a single system solution (a one stop shop)? Although some of the larger companies seem to be making the attempt to corner the market with holistic solutions comprised of proprietary base systems and system compatible plug-ins, supporting such endeavors adds little incentive for companies to make their proprietary software compatible with other systems in a constantly evolving field, especially those which are open source. Yet, energy enhanced BIM (eeBIM) as a holistic system design for the sake of multi-stakeholder collaboration is ideal.

BIM based integration platform:

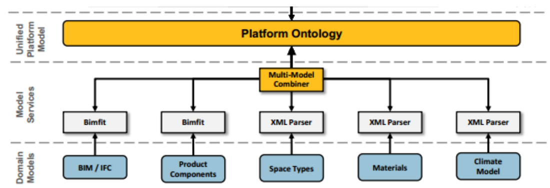

Figure 4. Multi-model integration approach in the ISES platform (ISES, 2014b)

As a solution to apparent complications with information exchange, some collaborative projects have proposed the development of a multi-model platform and data ontology. The idea, or rather ideas, behind the multi-model platform and ontology is similar to that of a knowledge management solution or a BIM server, or perhaps a cross bred vision of the two: an all-encompassing collection of multi-disciplinary building data, capable of integrating multiple models, model components, definitions, properties, real time site or operations data, and all other relevant information. Additionally, these segments, or those applicable by a user's given discipline could ideally be used at runtime.

This platform for the integration of BIM and non-BIM data, using a variety of formats, would give a substantially broader implementation scope providing for dynamic interdisciplinary collaboration. However, In order for the incorporation of all these fragments to work, a few challenges must be met:

A minimum level of compatibility needs to be realized with respect to data properties (naming convention, precision, and units) and technological properties (formatting, platforms, and interfaces). Libraries of source information need to be developed and maintained. Some of these libraries are in existence, i.e. BuildingSMART Data Dictionary, but are limited; for the data within these libraries to be affective in the ontology that is suggested, it needs to be translatable from one data model to the next. Also, the framework must allow for current data, like weather or other environmental conditions.

Maintenance of the data for such a framework will be increasingly demanding as systems are constantly evolving and becoming more precise. Moreover, if something is overlooked or not included, the entire model/simulation is compromised. Any simulation result can only be as accurate as the input data for the simulation (Maile et al., 2007).

Alliances such as the HESMOS Project and the ISES Project have committed to integration based collaboration solutions. HESMOS applies a link model concept, using a BIM-based "kernel." As stated by the HESMOS Project description: *An innovative [service-oriented architecture (SOA)] around the kernel functionality of BIM-based CAD/FM will be applied. Information interoperability will be achieved by enhancing BIM with energy and emissions features to a new sharable eeBIM. Intelligent access methods and a specialized ontology will be developed to enable multi-system integration and management [of information critical for energy simulation]* (HESMOS, 2014). The platform would enable multi-model projects capable of filtering the vast information *to query specific multi-model properties or prepare input for a specialized application* (Grunewald, 2010).

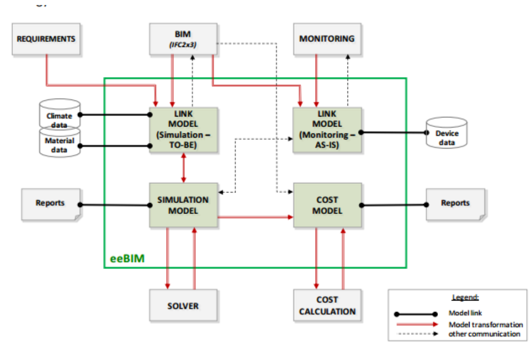

Figure 5. Principal model link and transformations in eeBIM (ISES, 2014b)

These HESMOS contributions are further extended via an ISES developed ontology platform. One of the focuses of ISES is the *Interoperability between energy analysis tools and product and building design tools*; an objective is to *provide them with an interoperability structure on ontology-extended BIM and SOA basis through development of a new model and system ontology based on description logic with semi- automatic simulation model configuration capabilities* (ISES, 2014a*).*

The way forward:

Globally, solutions to sustainable design problems will continue to evolve along with the improving technological options for solving them.

The interoperability of high powered software applications, developed to meet the challenge of innovative and efficient building designs, plays a significant role in the collaboration that is so essential to these projects; this is as complex a topic as that statement suggests, providing an open field for future research. A collaborative issue needs a collaborative solution.

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Figures:

Figure 1. Building life-cycle

Figure 2. IFC V. MVD-BEA, Nasyrov, V., Stratbücker, S., Ritter, F., Borrmann, A. Hua, S., Lindauer, M. (2014), Building information models as input for building energy performance simulation – the current state of industrial implements, eWork and eBusiness in Architecture, Engineering and Construction: ECPPM 2014, p. 479-486

Figure 3. Results of the test suite, Nasyrov, V., Stratbücker, S., Ritter, F., Borrmann, A. Hua, S., Lindauer, M. (2014), Building information models as input for building energy performance simulation – the current state of industrial implements, *eWork and eBusiness in Architecture, Engineering and Construction: ECPPM 2014*, p. 479-486

Figure 4. Multi-model integration approach in the ISES platform, ISES (2014b), Deliverable 5.1: Prototype of the multi-model integration services, http://ises.eu-project.info/documents/ISES-D5.1.pdf

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