Bridging the gap:
Supporting data transparency from BIM to BEM

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ABSTRACT: The exchange of information between a digital building model and analytical software should be seamless so that designers can easily use their 3D models for simulation. However, many gaps exist between Building Information Modeling (BIM) authoring software and Building Energy Modeling (BEM) tools. One gap is the loss of data in the exchange between the design and energy simulation models. The data exchange is often done using Green Building XML (gbXML). This file format has the ability to hold both geometric and non-geometric data such as wall constructions and occupancy schedules. An initial step was to check that the data was actually being transferred correctly and completely between the BIM and energy analysis software before simulation. To test this, a simple model was exported from the BIM authoring software using gbXML and then imported to selected energy simulation tools. In some cases, the exchange of data was not complete or was inaccurate, and it was not transparent to the user what was being exported or imported. Generally, the biggest problem was the inability of the simulation software to import the necessary parameters. This is a major flaw in perceived software interoperability and a failure to uphold user expectations. Users might assume that the data transfer is accurate and base design decisions on faulty values, or users might decide that because not all parameters are being transferred, a BIM to BEM data exchange process is useless. One could show the user not only what is being exported, but also what is actually input as the file is loaded into the energy software. A methodology was created for the development of a *Data Transparency Tool* (DTT) that would allow the user to verify the data in the data models and then correct omissions. A demonstration version was produced to confirm the methodology.

KEYWORDS: Building Information Modeling, (BIM), Building Energy Modeling, (BEM), Interoperability, Gbxml

INTRODUCTION
Energy efficiency is more than ever a critical concern that should be addressed in the earliest stages of design. Explaining, understanding, and enhancing the data transfer between software would allow better design decisions through more accurate coordination between energy simulation and building modeling. This research examines building information modeling's (BIM's) role in project data transfer from design to energy simulation. BIM has proved to be a valuable asset overall in offices but seems to have interoperability issues. A methodology was proposed to identify some of these issues and then propose an enhancement through a *Data Transparency Tool* (DTT).

1.0 BACKGROUND

1.1. Building Information Modeling (BIM)
BIM is a widely encompassing term. For many, it is the logical successor to CAD, a 3D parametric modeling program with associative data and the ability to interoperate with other software. The United States General Services Administration (GSA) expanded the definition:

> The resulting Building Information Model is a data-rich, object-based, intelligent and parametric digital representation of the facility, from which views appropriate to various users' needs can be extracted and analyzed to generate feedback and improvement of the facility design (GSA 2007).

This definition focuses on the overwhelming potential of creating and using a coordinated database or multiple databases throughout the lifecycle of a building. The BIM is thus useful to many stakeholders at different times: the owner, government bodies, architects, engineers, consultants, construction managers, contractors, sub-contractors, facility managers, occupants, the general public, and others.

1.2. BIM as a useful base model for simulation
Increasingly, the computer has been used to predict building performance, and BIM is one pathway for providing both geometric information and other characteristics of the virtual building. Although BIM has become widely used in architecture firms for the 3D modeling of buildings and production of construction documents, the transfer of the 3D information to other software programs is not always seamless or

complete. This creates a gap between the design development and the energy analysis of different design decisions. As a consequence, energy conscious strategies that are determined early in the design process by the architect may not be used to their fullest potential. BIM is especially useful because architecture firms often have a digital building available that they can use. It can also later be shared with consultants as a base model for more detailed energy calculations.

1.3. BIM gap and interoperability

Project losses caused by interoperability are apparent. The US National Institute of Standards and Technology (NIST) issued a report in August 2004 that estimated that $15.8 billion was lost annually by the U.S. capital facilities industry due to inadequate software interoperability. The research included "design, engineering, facilities management and business processes software systems, and redundant paper records management across all facility life-cycle phases." The value was reached by comparing the actual costs with a hypothetical scenario in which the data exchange, management, and access were seamless (Gallaher et al. 2004).

There is an interoperability gap between 3D authoring software and energy simulation tools. The exchange of information between analytical software and the building model should be more seamless and allow for a complete feedback loop. Accuracy and completeness of data are important in its transfer between the BIM and energy simulation software for both the 3D geometry and the data (non-geometric).

1.4. Green Building XML schema (gbXML)

gbXML is an open schema developed specifically to transfer building geometry and thermal data and to enable interoperability between BIM authoring software and energy simulation tools. It was initially funded by the California Energy Commission PIER Program, Pacific Gas and Electric, and Green Building Studio. gbXML is now supported by the majority of the software vendors including Autodesk, Bentley, and Vectorworks (gbXML 2014). It has been checked for its degree of accuracy and completeness for a range of energy simulation programs. A gbXML file is a text-based file. It is divided into elements that define the document, the geometry, and the materials of the project in a hierarchical structure (Fig. 1).

Figure 1: The textual representation of a floor assembly from Revit (left), the representation in gbXML (center), the structure of the gbXML file (right).

1.5. BIM to BEM data flow

“Energy is a design topic, not a technology topic, but there are few of us who have always believed this” (AIA 2012). Therefore to become effective, energy efficiency should be a key factor in the design of buildings and consequently should be carefully analyzed throughout the design process. The BIM/BEM workflow should be seamless to support this analysis; unfortunately and as reported by the following results, it is not. Problems have been faced with both the use of gbXML and IFC (Industry Foundation Classes) as a method of interoperability.

Some researchers claim the lack of seamless connectivity between BIM and BEM tools is deeply rooted in their development. Claiming that BIM development focused on supporting critical building construction contexts, while BEM development concentrated on buildings elemental characteristics and their interactions (Srinivasan et al. 2012). While other researchers speculate that the main issues derive from BEM tools’ incapability to interpret object-oriented programming (OOP) and the resulting inability to map from an object-oriented design model. (Jeong et al. 2014)

Cunningham researched gbXML capability to transfer data between Revit MEP and Trace 700. He started by depicting the gbXML structure, how it organizes and represents the data, and typical challenges that are encountered creating accurate gbXML files. He also investigated the Extensible Markup Language (XML) schema of gbXML and highlighted its properties. XML is a treelike hierarchy of *elements;* these elements have attributes and values within an enforced structure. He reported that gbXML structure ensures compatibility only if the sending application and the receiving application support the same XML elements. Only 62% of the elements supported by Revit MEP export mechanism were mutually supported by Trace 700; only mutually information is transferred, and that could explain part of the data loss (Cunningham 2009). For example, specific attributes defined in Revit such as the *Design Cooling Temperature* would therefore not be transferred, as this element is not supported by Trace 700 import mechanism.

Kumar investigated the interoperability gap between BIM and BEM. The intent of her study was to "test whether BIM software, specifically Revit, was robust enough to allow seamless interoperability with analysis programs such as Ecotect and IES<VE>" (Kumar 2008). Her research tested the data transfer, apart from geometry, using three neutral file formats: DXF, gbXML and IFC. Kumar's research showed varying data loss between the properties of the selected families in Revit and their representation in IES<VE>. She then enhanced the Revit-IES interface by designing a "patch" file. This patch file was a Revit template that defined a set of Revit wall families that derived their values from the IES construction database and could be imported into a Revit project. By using the families identified in her patch file the user would be guaranteed an accurate precise data transfer between Revit and IES<VE>. The disadvantage of this approach is in its particular nature. It would only support a part of the data transfer and only when using those specific software programs and wall constructions.

Some researchers have expressed a preference for the gbXML schema over IFC. In their specific study it allowed for a less complex implementation for the development of their lighting schema and could carry building environmental sensing data although they conceded that IFC had a better approach for depicting building geometry (Dong, et al. 2007).

Howard and Bjork were harsh (or realistic) in their overview of the usefulness of IFC as a complete BIM standard citing numerous downsides including unrealistic view of a "single building model," lack of use of standards, complexity of the definition, and others, but they did hold out hope that significant success by key pioneers could change this outlook (Howard and Bjork 2007).

Still others had little problems in using the IFC format: "Operations were developed to traverse the IFC building model structure and apply the described operations to each anomalous condition encountered. The corrected building model generates the proper geometry needed for the IDF input to EnergyPlus" (Sanguinetti et al. 2014). Others have embraced it use and proposed a methodology for implementation including "populating IFC-based BIM with data; automated rule-based data transformation; rigorous model checking; building energy performance simulation; and analysis of results from simulation." (Bazjanac 2008) Other researchers are developing their own direct translators, for example from the Autodesk Revit software to the LBNL Modelica Buildings library (Yan 2014). Although of use in research, this is not a standard that could be used for wide spread industry adoption.

The common type of data models (IFC or gbXML) that BIM authoring tools export and the data models that the BEM tools import and export lead to the overall conclusion that gbXML is the preferred file format for data import (Fig. 2).

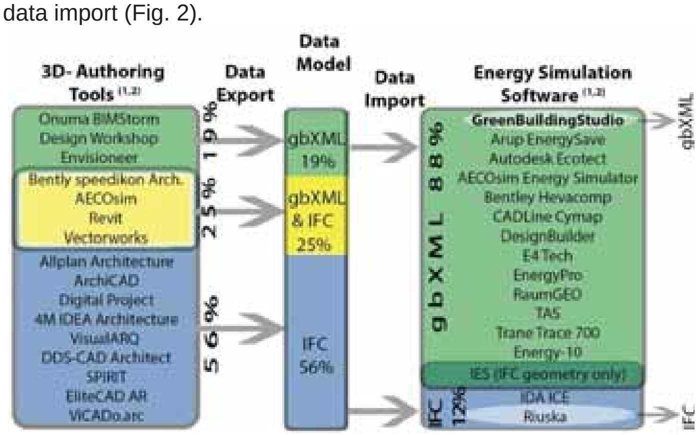

Figure 2: Types of data models (IFC or gbXML) that BIM authoring tools and energy simulation tools import and export; developed according to a web-search performed November 2014.

It is observed that neither IFC nor gbXML have unanimous software support to complete the data exchange. IFC has better support between the BIM authoring tools as 81% enable the export of data through it compared to 44% enable export through gbXML. While gbXML has better support between the BEM tools as 88% support its import versus only 12% are certified for IFC import. This means that the user has very limited options to transfer the data between BIM and BEM making the file transfer itself a challenge.

2.0 METHDOLOGY

The medium office building was chosen as the reference building. It was obtained from the U.S. Department of Energy (DOE) reference buildings website that contained IDF (EnergyPlus) descriptions for whole building energy analysis (DOE 2015). The office building is 3-storey, rectangular shaped with a steel frame structure and has continues strip windows with a 0.33 window to wall ratio. The IDF files from the DOE website specified all the relevant data relevant to energy simulation. These files were opened in EnergyPlus, and DXF files were exported with the geometry. The DXF files were imported into Autodesk Revit, both as a conceptual mass and detailed building model. The Revit model used slightly differs from the original IDF file (the area of the Revit model is $457m^2$ versus $463m^2$ in the original IDF file). This difference, however, will not affect the results as this deliverable is concerned with data transition and not the total energy consumption. A subset of critical parameters was chosen for testing the data transfer.

2.1. Case study building, subset of critical parameters

Critical parameters were selected to form a representative sample to determine whether or not the data was being transferred properly. The selected parameters covered various gbXML elements including: campus (location, building elements – areas, building story), space (ID, areas, volume), layer (R-value, thickness, conductivity, specific heat), window (overall conductance – U-Value, solar heat gain coefficient - SHGC, transmittance), and schedules.

2.2. Checking the building geometry for accuracy and completeness

The building model was inspected visually and numerically. The visual inspection compared the 3D model of both the DWG and the gbXML files using third party viewers. The numeric inspection verified that the area and volume of the model created in Revit remained the same in the gbXML export file and the BEM software interpretation of that gbXML file.

2.3. Checking the parameters for accuracy and completeness

The gbXML file data was compared against the original data input into Revit for the following divisions: a) location, building, and space elements; b) window and wall elements; and c) space attributes, density, load intensities, and schedules. The BEM software programs tested were Green Building Studio, EnergyPro, IES Pro, and eQuest.

3.0 RESULTS

The building geometry and a subset of data parameters were checked for completeness and accuracy.

3.1. Checking the building geometry for accuracy and completeness

None of the four energy simulation tools had the capability to import the DWG file, even minimally just to import the geometry.

Using gbXML the geometry visually imports correctly for this case study building, but with other building models users have reported missing surfaces, incorrect surface orientations, and other problems. These issues are sometimes due to a modeling or configuration error by the user, and in other cases it may have been an error in the export feature. McCallum of IES gave one example of a particular limitation with data models that did not work well with energy modeling requirements: “The geometry intended for energy modeling analysis –spaces and space boundaries- is drawn at the inside surfaces of walls and floors.” When that geometry is imported to the energy simulation tools the spaces are separated by air gaps (McCallum 2014). Having gaps, which should not be there, produces inaccurate results in the simulation. Other issues have occurred where window shades were being misinterpreted as roofing elements.

A further visual inspection was made to compare the geometrical representations of the gbXML and DWG files that are exported from the same model. To complete this, it was necessary to simplify the case study model and remove all the non-geometry data. First, a room made up of only walls with no floor or roof was modeled in Revit and then immediately exported into both gbXML and DWG. The DWG was directly imported into Sketch-up. To enable the import of gbXML file, gModeller was installed as an extension to Sketch-up. gModeller enabled the import of the gbXML file on the same project. The two models were then compared and found to be identical.

3.2. Checking the building data for accuracy and completeness (not geometry)

The gbXML file data was compared against the original data input in Revit, and the results are shown for the following divisions: a) location, building, and space elements; b) window and wall elements; and c) space attributes, density, load intensities, and schedules.

A) Location, building, and space elements

Green Building Studio, EnergyPro, and IES Pro generally worked well in importing the location, building, and space elements of the gbXML file. The weather file is was not included in the gbXML data, and users are required to input it manually.

- The data was exported correctly from Revit to the gbXML file.
- Upon importing the gbXML file, EnergyPro and IES Pro translated the address of the project. However GBS required manual input of the address before even attempting to import the gbXML. eQuest does not have the capability to import a gbXML file.

B) Window and wall elements

There was sporadic success with transferring the attributes of window and wall elements with Green Building Studio and IES Pro performing much better than EnergyPro (Fig. 3).

	Window					Wall								
						Name	Layer 1							
	Name	U-Value	SHGC	Window to wall ratio	Transmittance		Name	Roughness	Function	Conductivity (W/m-K)	Density (kg/m3)	Specific Heat (J/kg-K)	Thickness (m)	Thermal, Solar, Visible Absorbtance
IDF File Data	Window Non-res Fixed	1.23646	0.25	33%	NO Value	Steel Frame Res Ext Wall	Wood Siding	Medium Smooth	Outside Layer	0.11	544.62	1210	0.01	Value
Revit	Socal Window	3.13	0.21	Infered from Geometry	0.18 (default type)	Socal Steel Frame Non-res Ext Wall	Socal Wood Siding	NOT Entered	Exterior	0.11	544.62	1210	0.01	No refernce
gbXML	Socal Window	3.13	0.21	Infered from Geometry	0.18 (default type)	Socal Steel Frame Non-res Ext Wall	Socal Wood Siding	Function of the whole wall not layer	no refrence	0.11	544.62	1210	0.01	No refernce
Green Building Studio	Socal Window	3.13	0.21	Infered from Geometry	0.18 (default type)	Socal Steel Frame Non-res Ext Wall	Socal Wood Siding	Function of the whole wall not layer	no refrence	0.11	544.62	1210	0.01	No refernce
EnergyPro	Socal Window	[illegible]	[illegible]	Infered from Geometry	[illegible]	[illegible]	Default Wall with no reference to original wall or layers. Wood Framed Construction, 2x4 @ 16"							
IES Pro	Socal Window	[illegible]	0.57(g value) * 0.87(factor)=0.32	Infered from Geometry	0.18 (default type)	Socal Steel Frame Non-res Ext Wall	Socal Wood Siding	Function of the whole wall not layer	no refrence	0763 Btu.in/h.sqft.F = 0.11	34 lb/cft = 544.62	0.289 Btu/lb.F = 1210 J/kg.K	0.39" = 0.01 m	No refernce
eQuest	Doesn't import gbXML													

Figure 3: The results of the exchange data of the window element and the wall assembly of the material element.

- The thermal data in Revit was exported correctly into the gbXML file. Roughness and function of layer data however were not exported, as they do not relate to thermal properties. The gbXML file does not attempt to export any data that is not related specifically to geometry or thermal properties.
- GBS and IES imported the building envelope data correctly from gbXML file, but EnergyPro did not. The attributes of the assemblies were changed to the default values of the software as if no data has been input into the building information model.

C) Space attributes, density, load intensities, and schedules

Revit exported the data into the gbXML file, but for the most part, these parameters were not imported into any of the energy simulation programs (Fig. 4).

	Zone (in revit called Space type) Setting						
	area per person	sensible heat gain per person	lighting load intensity	power load intensity	occupancy schedule	lighting schedule	power schedule
Green Building Studio	264 people	unverified	10.76 W/m2	10.76 W/m2	Re-enter in GBS	Re-enter in GBS	Re-enter in GBS
EnergyPro	6.23 m2/ person	131.88 W/person	8.6 W/m2	undefined	undefined	undefined	undefined
IES Pro	undefined	undefined	undefined	undefined	On continuously	On continuously	On continuously
eQuest	Doesn't import gbXML						

Figure 4: The results of the exchange of data of the space attributes; people density, lighting and power load intensities, and building schedules. Only the imported values are shown.

4.0 DATA TRANSPARENCY TOOL (DTT)

4.1. Discussion

From looking at the results, a few findings are apparent about both the transfer of geometry and energy data. First, DWG is generally not a useful format for geometry transfer, not because it is not accurate, but because several energy programs do not import it. Second, gbXML is an adequate file format for this purpose but occasionally has problems with more complex or confusing geometry (for example, it might not be able to tell the difference between a window shade and a small roof). For data transfer, the results were worse. The gaps are both of inaccurate and incomplete transfer of data. It appears that the BIM authoring software export is functioning correctly to gbXML in most cases. However, the building energy software is not always taking full advantage of the information in the gbXML file to import it correctly. This may partially have to do with how the energy program is handling each specific piece of data as it is input.

To help alleviate some of these interoperability issues, it was decided to develop a tool that clearly showed what values were in a gbXML file. Unlike other gbXML readers, it would not show all the data in gbXML's hierarchy, but instead isolate the parameters that energy simulation software use and group them into the four DOE categories: *program, form, fabric, equipment* -- program (location, total area, internal loads, operating schedules, hot water demand, and ventilation requirements), form (geometry and orientation), fabric (construction types and thermal properties of the building elements), and equipment (the types, specification, and efficiency of the lighting, HVAC, and SWH systems) (Deru et al. 2011).

4.2. Features

The DTT's goal is to allow the user to verify the data in the data models and then correct inaccuracies. This is done by applying a transparency layer upon the IFC and gbXML files so that even the inexperienced user could understand them (Fig. 5). Three steps were needed to create the tool: matching gbXML elements with the selected variable set; creating a new XML schema that matches the variable set; and presenting the schema in a Microsoft Excel tool that would automatically populate the data.

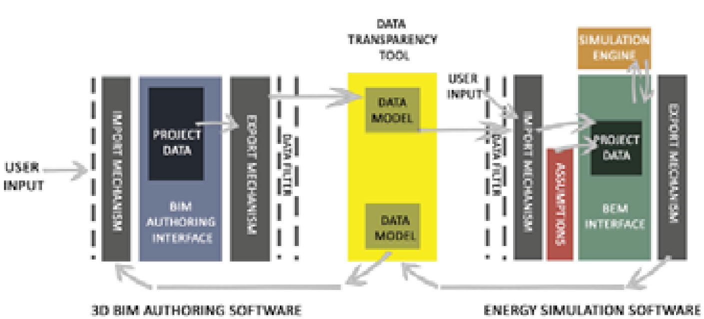

Figure 5: Diagram of the Data Transparency Tool (DTT)

The diagram of the BIM authoring software encompasses the user interface, import, and export mechanisms. The import and export mechanism include data filters that select partial data for export. When exporting from BIM to BEM not all the data in the model is exported because some of it is irrelevant. As an example of the filtering is the exclusion of elements such as furniture and attributes such as costs that are irrelevant for energy analysis, and therefore the software does not attempt to export them. The DTT sits between the BIM and the importing of the energy simulation software. In addition to the filters there are a set of assumption (defaults) that the BEM tool would use to fill out missing data in the data model and in some cases even override existing data in the data model. The tool could in the future also include a graphical comparison of the geometry being imported and exported. There are other tools for gbXML such as FZKViewer, DDS-CAD and plug ins such as gModeller plugin for Google Sketchup, but these are steered towards geometry visualization and not towards non-geometrical data representation.

4.3. Demonstration

A simple prototype of the tool was created. It was developed by creating a new XML schema that follows the hierarchy of variables defined by DOE. Using the new schema, the data is presented to the user in a Microsoft Excel interface. The original XML was accessed by opening a template gbXML file in Excel and accessing the source panel through the developer tab. The new XML schema was then created by dragging the element nodes from the *XML Source* pane to the workspace cells adhering to the defined variable set as basis for hierarchy. *Program, Form, Fabric* and *Equipment* therefore create the top levels of the hierarchy and encompass under them the related variables. This schema was then used to present the data model values. The Excel template contains four main tabs each of which corresponds with the variable set and its underlying elements. The user would simply import the gbXML file or IFCXML file to their corresponding DTT and the tool would automatically populate the values.

The final DTT is envisioned to eventually incorporate the following functions (Fig. 6).

- Import the different data models directly into the tool (gbMXL, IFC).
- Present the variables under the hierarchy of building energy categories (Program, Form, Fabric, and Equipment) to quickly inform the user of the contents of the file.
- Provide a graphic representation of the 3D model.
- Create a color-coded visualization corresponding to the defined energy categories.
- Analyse the completeness of data and alert the user of any missing data necessary for BEM.
- Review and validate the data. Confirm the variables are within accepted variable range; for example the value of the Solar Heat Gain Coefficient (SHGC) should be with the range zero to one.
- Generate a score for the imported gbXML file depending on the completeness and validity of data.
- Compare two gbXML files. The intent would be to show the file export from the BIM authoring software versus the same file immediately exported from the BEM software (this can not be done until software companies include an export feature from their energy software)

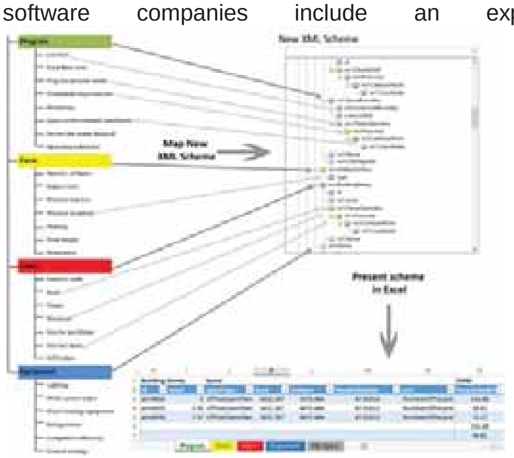

Figure 6: Diagram of methodology: mapping new XML schema based on the defined variable (left and upper right) and presenting the schema in the DTT Excel interface – partial screenshot (lower right corner).

CONCLUSION

BIM software should be able to export necessary information, and energy programs should be able to import it. This improves efficiency and frees up time that could be used for simulations to better the building design. The use of standard, preferably neutral file formats, would also allow the users to choose the appropriate software for their needs. The first step was to understand the current limitations of file transfer while considering how the transparency of data and “open” structured BIM data can be used to help bridge many of the BIM gaps that exist in the handover of information. This was tested with a base case building and a selection of parameters in one BIM and four BEM software programs. It has been shown that the export features work (although the results are not transparent to the user), and that data is lost in the import to the energy software. The development of a data transparency tool could help solve some of these problems by showing the user in a simple manner exactly what is being exported from the building information modeling software and imported into the energy software; a prototype was created in Excel. Then designers could have more confidence about the values of parameters that are being transferred from BIM to BEM.

ACKNOWLEDGEMENTS

The authors wish to acknowledge SoCalGas, TRC Solutions, and Skanska for partial funding for the BIM to BEM research. Thanks also to Jeff Oullette for his input.

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