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BIM to Building Energy Performance Simulation: An Evaluation of Current Transfer Processes

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Abstract

For over 25 years, data exchange between architectural BIM-based designs and Building Energy Performance Simulation (BEPS) have been proposed as a solution to reduce the amount of manual and error prone rework required to create typical BEPS models. The current state of the art lacks an effective, universal and robust system of data collation, processing, quality assessment and analysis while interfacing with existing tool-chains through a streamlined data transfer process.

This paper investigates the reproducibility of current BIM to BEPS transfer processes through an experiment that compares these transfer processes, as used in industry, against each other. The experiment uses five residential archetype buildings and results from BEPS models in EnergyPlus indicate that there are many barriers, both technical and methodological, to achieving reproducible results between commonly available software tools. In some cases difficulties could not be overcome as the transformation process itself did not complete, leading to inconclusive results. In cases where successful transformations occurred, variations of up to 25.89% in annual energy consumption were discovered between processes. This hints to issues and limitations of the current processes and results.

Introduction

One key component in delivering energy efficient buildings is Building Energy Performance Simulation (BEPS) tools that predict the energy consumption and efficiency of new, existing and nZEB buildings. Such tools are one of many vital components required to deliver highly performing buildings. It is well known through analysis, that in reality, a building's measured energy consumption in use is very rarely identical to that of the predicted consumption (Hill and Jones, 2014; Turner and Frankel, 2008). This originates from many factors such as a lack of detailed data in the planning and early design stages which results in simplifications and assumptions being made regarding input data (de Wilde, 2014; Imam et al., 2017).

A major barrier and current data gap in industry is

limited interoperability between the various BIM software packages available and also between BIM and BEPS tools and the lack of a standardised data transfer process (Beazley et al., 2017; Maile et al., 2013; McCartney and Kiroff, 2011). Interoperability between BIM software refers to the ability of individual BIM packages to open and modify BIMs produced by other software and without data loss (McCartney and Kiroff, 2011). Interoperability between BIM and BEPS tools is currently limited, often resulting in architects designing a building in one model and an energy consultant remodelling the design from scratch within a BEPS environment (Beazley et al., 2017).

Although BuildingSMART has established the Industry Foundation Class (IFC) ISO standard for BIMs, further research indicates that the translation of IFC based models into other proprietary BIM systems is not fully accurate and some data is always lost (Rose and Bazjanac, 2015; McCartney and Kiroff, 2011; Suermann and R. Raymond Issa, 2009). The issue first appeared almost 25 years ago and has not been solved despite numerous research advances, new software tools and new versions of existing software tools such as ArchiCAD and Revit (Bazjanac, 2001). Interoperability has been found to be a major requirement in ensuring the AECO industry gains further efficiencies in the future use of BIM, highlighting the importance of different software packages being able to communicate with one another (McCartney and Kiroff, 2011). While the data transfer results clearly did improve during this time period. Early efforts did miss large portions of buildings as illustrated in (Maile et al., 2007), current studies still show limitations that hinder a smooth and easy data exchange in practise.

Of most interest to this study is the variation in predicted building energy consumption that arises as a result of different BIM-based CAD modelling software, data transfer processes and BEPS software. The issue of input assumptions and simplifications in the early design stage is one that can be addressed through focusing on the most influential parameters in the energy analysis process and ensuring accurate inputs values for these parameters (Egan et al., 2018), however, identifying the difference that arises when

using different data transfer processes is one that needs to be understood in order to make the predicted energy consumption more accurate and reliable.

The primary objective of this study is to undertake an evaluation of existing industry transfer processes between BIM and BEPS through the use of transfer schemas such as IFC. The intention is to evaluate the reliability and reproducibility of building energy analysis processes using a number of relatively simple residential archetype buildings in order to provide a quantitative and qualitative comparison.

The paper is structured as follows: Section 2 describes the relevant background to the domain of this paper while section 3 describes the methodology deployed. We then analyse the results and the conclusion examines the impact this work can have on the BIM to BEPS domain.

Background

The use of BIM and BEPS is at the core of this paper. As a result, we examine the background of this area and present the technical restrictions that require consideration before an experiment can be conducted.

The lack of a comprehensive understanding of the data transfer process between BIM and BEPS introduces the complexity of the interoperability challenge to hand (Dimitriou et al., 2016). BIMs are detailed 3D object-oriented representations of buildings. In the context of BEPS, detailed BIMs must be transformed into inputs for BEPS, which use a simplistic planar representation of surfaces. These planar representations align with one-dimensional heat transfer calculations that underpin typical BEPS engines and are called space boundaries. Such one-dimensional calculations assume that heat transfer is orthogonal to the space boundary and this results in box type zones and linear segmentation of curves, simplifying curved surfaces.

Space boundaries are special relationship objects in IFC that connect a space to its bounding elements (walls, doors, windows, slabs). The relationship also has a 2D geometry that represents the 'boundary plane' between the space and the bounding element. Second-level space boundaries, which are required for the BIM to BEPS data transfer process, are essentially surface pairs through which thermal energy exchange among buildings or building rooms and its outside environment occurs (Rose and Bazjanac, 2015).

Ideally, interoperability should facilitate a seamless exchange of data among software tools to eliminate the need for duplicate data generation (Moon et al., 2011). A number of recent advances that process space boundaries for BEPS input include those of Lilis et al. (2017); Rose and Bazjanac (2015); van Treeck and Rank (2007). In the case of Rose et. al., they use graph theory as the basis for their algorithm,

which processes complex building geometries by simplifying through a representation using solid-to-solid heat exchange graphs of 2D line drawings that connect space boundaries using the a number of different transmission line paths.

There are many file formats which exist for data transfer and exchange from BIM to facilitate the interoperability of building information with energy analysis; IFC and gbXML are two of the most widely acknowledged and most common schemas in the AECO industry. BuildingSMART manages the IFC data model which has the ability to represent elements of a building as objects with properties and references to other objects, and therefore, the IFC format can be managed and understood by various tools (Pinheiro et al., 2018). It is the only non-proprietary BIM based format that is an international standard and can describe the whole building life-cycle (Cemesova et al., 2015). IFC is more comprehensive and generic, when compared to gbXML and aims to represent the building project extensively over its entire life cycle (Dimitriou et al., 2016). A key limitation of this schema is that it does not focus only on an energy domain in the main specification and does not directly define information exchange requirements specific to different project stages and between different actors and software applications (Cemesova et al., 2015; Pinheiro et al., 2018).

The latter weakness has been recognised by the buildingSMART community and a new process called Model View Definition (MVD) addresses the exact definition of exchange requirements. On the other hand, the gbXML schema is said to be more straightforward, less complex and is focused on the properties of the building project that are related to BEPS, enabling easy incorporation of additional information for energy analysis (Dimitriou et al., 2016; Noack et al., 2017). The advantage of the gbXML schema is that it is supported by many BIMs, energy and web-based tools (Dimitriou et al., 2016). However, the key limitation of gbXML is that it uses a centre-line theory when calculating the buildings volume rather than using real 3D placement of the space boundaries. Centre-line theory is a method which adds half the wall thickness to the volume of the room and can lead to the volume differing by approximately 5% from the actual value and therefore, provides different and inconsistent results (Bazjanac et al., 2016). There has been momentum gathering toward a dedicated subset of IFC, called a Model View Definition (MVD), which identifies properties and specifies the exchange requirement to standardise BIM data for use in energy analysis including traditional BEPS (O'Donnell et al., 2013). This leads into another limitation of gbXML as it does not provide a methodology similar to IFC/MVD that allows subset definitions to support end user requirements (Pinheiro et al., 2018). Outcomes from non-standardised sub-

jective data transfer processes can widely vary from person to person, even given the same initial building design information (Imam et al., 2017). In order to overcome the issues in the AECOO industry, a common and standardised language and process needs to be put in place (Pinheiro et al., 2018).

Currently, the extraction of information and necessity to fix incomplete entries requires human intervention throughout the process which is very time consuming and considerably hinders the smooth seamless conversion process. However, the latest MVD process developments (based on IFC4) have potential as a possible solution for managing the detail required in coupling BIM and BEPS tools, but has not yet gained enough support throughout the complete tool-chain. A number of factors may cause differences in BEPS model inputs generated as part of an automated or semi-automated transformation process and these include: fundamental differences in data representations by the respective CAD tools and subsequent intermediate formats (BIM or other), limitations of various data transfer processes, simplifications required for transformation to the input format and any human interaction with the processes. Thus, it is important to identify the extent of variation in results due to user behaviour and also using different data transfer processes from commonly used BIM to BEPS tools. If the simulated theoretical energy consumption differs from one process to another, it is difficult to know which of the processes is more accurate or closer to the truth.

Methodology

This research evaluates a range of available BIM to BEPS (EnergyPlus) transfer processes using a set of residential archetype buildings (Figures 3) that include:

1. a semi-detached house;
2. a detached house;
3. a mid-floor apartment and a top-floor apartment (geometrically identical but on different floors);
4. and a bungalow.

This study aims to evaluate the impact, if any, of using different BIM to BEPS transformation processes and tool chains. The approach taken uses every effort to ensure identical inputs are used in the BIM-based CAD environments and within the BEPS interfaces. Each archetype is modelled in both BIM-based CAD tools (ArchiCAD and Revit), ensuring that identical geometric properties are used in both tools and the guidelines developed by Maile et al. (2013) are considered. The approach leverages 3D object oriented representations produced in Revit and ArchiCAD and uses a number of different transfer routes to transform this information into a suitable format for BEPS software interfaces to EnergyPlus (DesignBuilder and Simergy). It is important to note that conventional

BEPS tools use a simplistic planar representation of a building's surfaces and therefore, available automated processes for converting BIM to BEPS normally use a transfer schema either openly or in manner that is hidden from the end user. This research considers two schemas which are appropriate for this domain and these are IFC and gbXML. In addition a direct transfer from Revit to DesignBuilder via the Revit API is being looked at. Overall, the experiment has four main steps which are now explained in detail:

1. Generating archetype models in BIM based environments.
2. Carrying out the different BIM to BEPS transfer processes for each archetype.
3. Results comparison for each process.
4. Providing a detailed quantitative and qualitative analysis and conclusion on the reliability of the transfer processes.

Our approach uses different combinations of BIM-based CAD environments, schemas and different interfaces to the same BEPS engine (EnergyPlus). This results in seven different data transfer processes that capture all permissible tool chains within the boundaries of this research (Figures 1 and 2). We test each of the seven transformation process using each of the five different archetypes and the results from each processes-archetype combination is analysed and compared against the other processes for this archetype. The evaluation therefore quantifies the difference in predicted energy consumption for the same archetype through processes.

Archetype definition in BIM-based CAD Tools

We selected the Coordination View MVD when exporting IFC from both Revit and ArchiCAD in order to ensure consistency across model exports. The primary purpose of the Coordination View is to allow sharing of BIMs among the disciplines of architecture, structural engineering and building services (mechanical). This MVD contains definitions of spatial structure including space boundaries, building geometry and building service elements that are needed for coordinating design information among these disciplines and is supported by both ArchiCAD and Revit.

Transfer processes

In theory, the seven transfer processes are relatively straight forward in terms of model export and import using IFC and gbXML. However, when using an add-on or plug-in, the process tool chain becomes more complex and involves additional research and manual intervention in an attempt to bring the models to a level of quality at which they could be transferred. We observed that many of the models in the BEPS environment contained geometrical errors, predominantly on the second storey of the two-storey buildings and for irregularly shaped rooms.

Figure 1: Process Flow Diagram with Simergy as the BEPS Environment.

Figure 2: Process Flow Diagram with DesignBuilder as the BEPS Environment.

The difference in area between Revit and ArchiCAD models which were imported into DesignBuilder using gbXML, was another source of error and discrepancy in the processes. The issue arises due to the functionality within ArchiCAD gbXML plugin, Cadimage, which when creating the gbXML model, takes the outside face of the external wall as the reference line. This feature results in extra internal area and volume in the gbXML model instead of taking the model area and volume from the reference line that was specified when building the original model in ArchiCAD.

Simulation

We use DesignBuilder and Simergy as the BEPS interfaces. It is important to note that once we imported the IDF into each interface we exported it again as IDF. This is the same process each interfaces uses when executing a BEPS run. Further identical input data such as simulation parameter data, material and cross-section properties, run control settings, standardised internal loads and rudimentary HVAC systems were added as native IDF to all BEPS models. All BEPS models executed in the native EnergyPlus executable as opposed to within the interfaces, thus removing any bias from a particular interface, see the last process in Figures 1 and 2. This approach of using the EnergyPlus executable also allowed us to use a Dublin climate file for all simulation runs.

An interesting result of the fully completed data

transfers is that for DesignBuilder the gbXML route completed successfully whereas for Simergy the IFC route completed successfully. This does hint that different tools have different foci on which data transfer is more important. Another find was that while more models did simulate in DesignBuilder, it was unclear if limitations of the data transfer were just ignored in this case, compared to a more stringent simulation requirements in Simergy. Simergys IDF generation is dependent on high-quality input files, more specifically the relationships between each wall, contained openings and doors or windows. As these relationships were missing for some transfer processes, the door/window space boundaries are not included in the IDF. Another common issue was the incorrect tagging of external walls as internal, so that the space boundary generation either failed or was incorrect.

Result Analysis and Discussion

Table 1 shows an overview of the seven transfer routes. The RGD and RD processes generated identical results for an annual simulation run and was classified as a success, however, these results were expected seeing as both processes use the same BIM based environment (Revit), BEPS based environment (DesignBuilder) and transfer schema (gbXML). In process RD, the use of gbXML is hidden from the CAD tool user, so in principal both are identical data exchange process. The only difference was the plugin

(a) Semi-D Model Visualisation.

(b) Detached Model Visualisation.

(c) Apartment (Mid & Top) Model Visualisation.

(d) Bungalow Model Visualisation.

Figure 3: Archetype definition in BEPS Engine Design Builder.

feature added to Revit, although designed to reduce the time and work required by the user, was found to be less straight forward and was the source of more issues than when using the built-in gbXML export feature with manual import.

It was not possible to complete the data transfer routes RGS, AGD, AGS and AIS due to issues relating to poor quality of data transferred. For the routes that did complete, there was a large disparity in the results obtained from each data transfer route. The IFC and gbXML transfer schemas are based on different reference lines as is the reference line used by the Cadimage gbXML plugin. For the archetype models with different reference line geometries, the largest difference was found to be present in the AGD process for the bungalow and apartment archetypes. A resulting and significant increase in energy consumption relative to the increase in functional floor area for the AGS process is indicated by issues with the model's predicted energy consumption, especially for the top-floor apartment. This highlights the presence of geometrical errors in the final BEPS model after the AGD process was carried out.

From the perspective of predicted annual energy consumption (kWh), we observe a wide range of variability in the results obtained ranging from 1.5% to 25.89% between the different data transfer processes due to inconsistencies in the complex data transfer

and methodology on which the data transfer is based. An example of the results from one of the successful transfer processes can be seen graphically in Figures 5 4 with the energy consumption broken up into the component utilities; lighting, equipment, heating and water systems. The largest variability in annual theoretical energy consumption for the mid-floor apartment archetype model computed to 4.43% between processes AGD and RGD/RD, and for the top-floor apartment archetype model computed to 25.89% between processes AGD and RGD/RD.

The experiment shows that data transfer is possible but also illustrates a number of limitations with the BIM to BEPS transfer processes. The variability of achieved results indicates that in addition to fundamental differences between transfer processes, other limitations and errors contribute to the variation in results. To achieve more reliable and reproducible results, the quality of the transfer processes needs to increase as well as the transparency about limitations, simplifications and errors of the models and the respective transfers. For example, the difference in space boundary placements has implications on space area which influences other parameters and results.

Conclusion and Future Work

The aim of this study was to carry out an evaluation of the existing transfer processes between Building

Table 1: Transfer Route Summary Table with Colour Coding to Signify the Outcome of Each Process for Each Archetype Including a Brief Note on the Success or Failure.

Transfer Route	1) Semi-Detached House			2) Detached House			3) Single-storey Bungalow			4) Mid-floor apartment			5) Top-floor apartment		
	Export	Import	Simulates	Export	Import	Simulates	Export	Import	Simulates	Export	Import	Simulates	Export	Import	Simulates
RGD															
RD															
AGD															
RGS															
AGS															
RIS															
AIS															

Legend

Complete data transfer	R = Revit	S = Simergy	Export = Export from CAD Tool
Partially model transfer: some errors	A = ArchiCAD	D = DesignBuilder	Import = Import to simulation interface
Unsuitable data transfer	I = IFC		Sim. = Simulates in EnergyPlus
Not applicable			Results = Results generated by EnergyPlus

(a) Mid-floor apartment energy performance predictions.

(b) Top-floor apartment energy performance predictions.

(c) Bungalow energy performance predictions.

(d) Detached house energy performance predictions.

Figure 4: Calculated annual energy consumption from the successful transfer routes.

Figure 5: Calculated annual energy consumption for the semi-detached house archetype using for the successful transfer processes.

Information Modelling and Building Energy Performance Simulation (as represented by EnergyPlus). This, in turn led to a quantitative and qualitative evaluation of these methods by comparing resulting energy consumption of the five archetypes across seven transfer routes. The focus was to determine the current state of data transfer from BIM to BEPS.

This study shows that different transfer routes can produce different results and other transfer routes are difficult to successfully complete. Thus, it is difficult to consistently predict buildings' energy consumption due to the variation across different processes. This could be an additional factor for the differences in energy consumption of up to 25.89% when different transfer processes were used.

The results from the evaluation carried out in this paper add potential causes of uncertainty and unreliability to BEPS model generation by highlighting that, even with consistent initial BIM creation and input data, the application of different transfer processes leads to significantly different predictions of energy consumption. This indicates that improved data transfer as well as more transparency are needed to improve the overall results of these processes. It is also important to note that the archetypes are relatively small in terms of floor area and zone volume and do not include complicated geometrical features such as curtain walls or multi-height spaces.

We conclude that the outputs from BIM to BEPS data transfer are difficult to reproduce and depend on the transfer process chosen. The discrepancy arises from different practices and principles on which the data transfer processes are based and resulting differences in theoretical energy consumption. This has significant implications for the BEPS domain as significant questions arise in terms of model validity and trustworthiness.

It can be seen from this study that while some progress has been made in recent years, there are still limitations for some transfer routes and significant

differences between others. It is clear that software tools involved in those processes need to improve, but there is also a need for tools to check generated models and potentially correct common errors. These improvements could provide the basis to better guide users through the process and make them aware of limitations and errors that exist within both BIM and BEPS models.

The mixed nature of the results also indicate that there is no standardised process of data transfer from BIM to BEPS. As a result it is difficult to know which, if any, of the many processes are reliable. Even through using the same combination of BIM and BEPS environments, the data transferred using IFC can vary from user to user, due to the number of user-based options involved in the IFC export process and different ways to model buildings in CAD tools. Quality checking of user generated models in CAD tools would also support better results for these transfer routes. Until the quality of generated models does not improve in combination with limitations in the transfer processes, the information obtained through carrying out an energy analysis of a building using BIM and BEPS can be seen as subjective.

A key reflection from this work is that BIM to BEPS has been attempted for almost 25 years without meaningful uptake within the industry. Given the variable quality of export from the BIM-based CAD tools, direct API-based transformations based on the native CAD models may prove to be a more fruitful process in combination with additional quality checking as opposed to using intermediate formats such as IFC and gbXML.

Further work is required in designing much more robust software tools to enable the transparent transfer of the building data, transforming 3D object oriented representations of buildings into simplistic planar representation of surfaces, without loss of data along the way. Current developments in standardising this data transfer based on MVD may prove to add more reliability in the near future and thus start a standardisation of the BIM to BEPS data transfer process to allow it to be used to predict the energy consumption of a building as accurately as possible.

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