ANALYSIS ON AUTOMATIC GENERATION OF BEPS MODELS FROM BIM MODEL

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ABSTRACT

The interlinking of enriched BIM data to Building Energy Performance Simulation (BEPS) models facilitates the data flow throughout the building life cycle. This seamless data transfer from BIM to BEPS models increases design efficiency. To investigate the interoperability between these models, this paper analyses different data transfer methodologies along with input data requirements for the simulation process. Based on the analysed knowledge, a methodology is adopted and demonstrated to identify the quality of the data transfer process. Furthermore, discussions are provided on identified efficiency gaps and future work.

INTRODUCTION AND BACKGROUND

The sustainable design of buildings is carried out by initiating an iterative energy analysis commencing in the early design stages of a project (CIC Research Group 2012). Building energy analysis assists engineers, designers and operators on providing more value on comfort and energy efficiency for occupants and building owners respectively (Sun, X.S., 2016). Currently, setting-up energy analysis models for a building at every stage of the project is time-consuming and labour intensive. Thus, BEPS for buildings is rarely introduced for all design stages of projects. However, the interlinking of BIM data with BEPS provides a better solution compared to traditional model generation for BEPS at every stage (Liu et al. 2018, Ramaji & Memari 2016).

BIM models are highly enriched with a large range of information regarding the product and process (Keller et al. 2006). Integrating and linking BIM models to BEPS models leads to significant changes in the design process by introducing building energy analysis in the early stages of the design (Karan et al. 2014, Guzman & Zhu 2014). There are numerous advantages by using an integrated modelling process (Moon et al. 2011, Bazjanac 2008), such as:

- BIM-based energy analysis allows iterative simulations for a wide range of scenarios to be performed within a short period.

- The time saving from the reproduction of the energy simulation model could be spent on simulation and design optimization.
- Changes in the BIM model can be easily reflected in the BEPS model.

Over the past decades, the development of the BIM concept focused on the enrichment and management of domain data along with its interoperability between fields (Karlapudi & Shetty 2019). Currently, the information in BIM models is managed and exchanged with other proprietary software using open standards, such as Industry Foundation Classes (IFC) or the Green Building XML (gbXML) meta-data-model (Ilhan & Yaman 2016, Lee et ai. 2012, Crowley & Watson 2000, Kim et al. 2015, Liebich & Wix 2000). The capabilities and popularity of these openBIM meta-data models motivated many AEC software vendors to implement the data exchange features in their tools.

A wide variety of promising attempts are proposed. Their capabilities for automatic generation of energy simulation models were investigated. Most of these generation processes involve a set of conversion tools or plugins such are Geometry Simplification Tool (GST), Green Building Studio (GBS), Openstudio and IFC2SKP. These tools are used to convert IFC or gbXML data schemas to the simulation engine input file formats (e.g. IDF, DOE-2.2, TRNSYS17, etc.). Research from Georgios, N.L., et al. (2017) showed that these tools are restricted to geometrical data generation in simulation tools and more likely to simple geometry. The research also presented the specific constraints and limitations in each transfer process. For example, missing floors and ceilings from the IDF converter tool, ignorance of slabs from IFC file in RIUSKA, etc (Georgios et al. 2017).

In the present work, all these research results are taken into consideration and a methodology which does not involve these meta-data conversions is proposed. Based on the methodology, the research initially focused on the detailed investigation of Information Requirements (IR) for energy simulations and maps these to the IFC and gbXML meta-data schemas. This process can help to identify advanced data

management capabilities for meta- model schemas. The proposed multi-stage methodology for the automatic generation of BEPS models is presented in Figure 1. Further explanations are provided in the coming sections. Furthermore, we present a use case for the application of the proposed methodology. Finally, demonstration results are intensively discussed and summarized.

METHODOLOGY

Figure 1 represents the proposed methodology for data transfer between BIM and BEPS models. The demonstration of data sharing is based on two interoperability file formats such as gbXML and IFC.
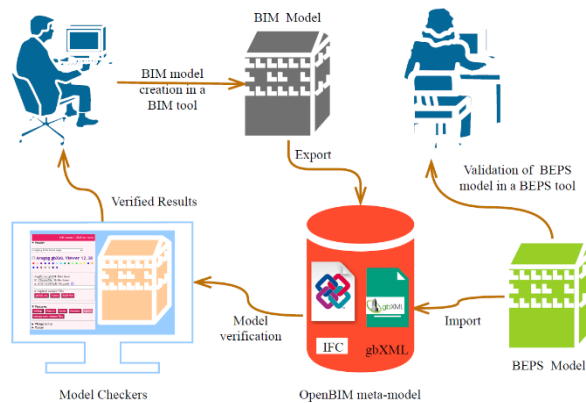

Figure 1: Framework for the demonstration

The results of the Information Requirements Analysis is summarized in Table 1. The table documents the mapping process between BEPS-requirements and the capabilities of openBIM meta-data models such as IFC and gbXML (Note that IFC-parameters are compared to IFC 4 Addendum 2 (2018)).

The IFC meta-model can be equipped with enormous data related to all disciplines of the construction industry (Laakso & Kiviniemi 2012), but all data is not necessary for a specific business process (Menzel et al. 2013). For this purpose, buildingSMART developed View Definitions to reduce and filter the required information to be exchanged for a particular business process. The relationships between the IFC parameters can be attained by the modelling concept called Objectified Relationships represented in Figure 3. The Inheritance Hierarchy is another important modelling principle of the IFC schema. It facilitates the introduction of hierarchies in the BIM model and supports the reuse of modelling concepts for subclasses (ISO 16739-1 2018). Please note that the symbol "XXX" used in Table 1 indicates the name of the IFC object such as the wall, window, door, etc. For example, Qto_XXXBaseQuantities in Table 1 should be interpreted as Qto_WallBaseQuantities, Qto_WindowBaseQuantities, etc. Similarly, the listed parameters of gbXML are considered from the hierarchy structure of the gbXML schema represented in Figure 2.

Table 1: Information Requirements (IR)

INFORMATION REQUIREMENT	PARAMETERS	
	IFC	GBXML
Site Data	IfcSite	Location
Latitude Longitude Elevation Address	IfcCompoundPlane AngleMeasue IfcLengthMeasure IfcPostalAddress	Latitude Longitude Elevation Name
Orientation (w.r.t True north)	IfcGeometricRepre-sentationContex, IfcDirection	Planar Geometry
Building Envelope (BE)	IfcBuilding	Building
Building Storey	IfcBuidingStorey	Building Storey
Wall	IfcWall	Surface
Roof	IfcRoof	Surface
Floor or Slab	IfcSlab	Surface
Opening	IfcOpeningElement	Opening
Door	IfcDoor	Opening
Window	IfcWindow	Opening
Shading, etc.	IfcShadingDevice	Surface
BE- type	IfcElementType	Surface Type
Distribution Element	IfcDistribution Element	
Geometry	IfcGeometricalRepre-sentationItemShape	Planar Geometry
Placement	IfcPlacement, IfcAxis2 Placement2D	Rectangular Geometry
BE Dimensions	IfcQuantitySet	
Length	Qto_XBQ - Length	Rectangular Geometry
Width	Qto_XBQ - Width	
Height	Qto_XBQ - Height	
BE Construction	IfcMaterialDefinition	Construction
Thickness	IfcMaterialLayesrSet - TotalThickness	Thickness
Layers	IfcMaterialLayer	Layer
Material	IfcMaterial	Material
BE Properties	IfcPropertySet	
Solar gain	IfcNormalisedRatio Measure	SolarHeat GainCoeff
Thermal mass	IfcProperty SingleValue	
U-value	IfcThermalTransimit-tanceMeasure	U-Value
R-Value	Inverse of U-value	R-value
Airtightness	IfcVolumetricFlow RateMeasure	Infiltration Flow
Zone	IfcZone	Zone

Legend: XBQ…XXXBaseQuantities

Table 1 (cont): Information Requirements (IR)

INFORMATION REQUIREMENT	PARAMETERS	
	IFC	GBXML
Space	IfcSpace	Space
Area	Qto-SBQ-NetFloorArea	Area
Volume	Qto_SBQ – Volume	Volume
Spatial zone	IfcSpatialZone	
Space Type	IfcSpaceType	SpaceType
Space properties	Pset_Space, etc.	Property details
Building System	IfcBuildingSystem	
Distribution system	IfcDistributedSystem	
Schedules		
Operation schedules	User-defined property sets	Week, and Day Schedule
Occupant schedule	Pset_SpaceOccupancy Requirements	
Weather Data	Pset_OutsideDesign Criteria	
Temperature	IfcThermodynamic TemperatureMeasure	
Solar Radiance	PEnum_Building ThermalExposure	
Wind Speed	IfcLinearVelocity Measure	
Wind Direction	IfcPlanAngle Measure	

Legend: SBQ… SpaceBaseQuantities

The gbXML meta-data model is 'data-rich' and capable of describing 500 types of building elements and attributes (gbXML 2020); each component is defined by its ReferenceId. The main concept of this ReferenceId is to create an identification for each component in the schema and to define the relationships between components based on this ReferenceId (Dong et al. 2007).
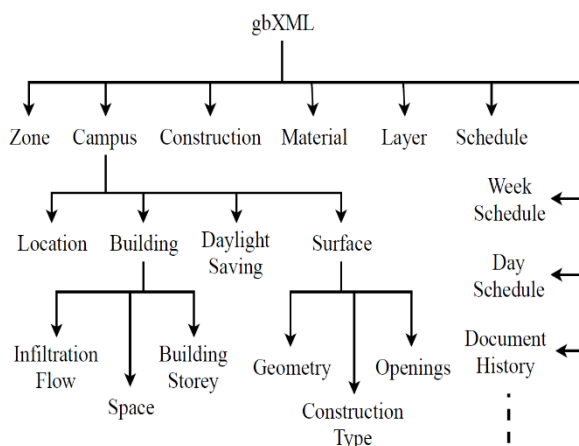

Figure 2: Hierarchy of information organized in gbXML Schema (gbXML, 2020)

Once after the needed requirements are clear, the BIM model is created and is incorporated with all required information to set-up a complex type of energy simulation model. The comprehensive BIM model is exported to the gbXML and IFC file formats. The gbXML file is now imported by the model view checker called Aragog gbXML viewer and similarly, the IFC file is imported by the SOLIBRI Model Viewer.
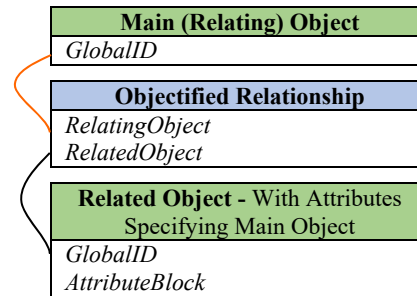

Figure 3: Objectified Relationship (ISO 16739:2013)

The purpose of the model viewer is to identify whether the model data has been exported to interoperability file formats correctly or not. These viewer tools represent the BIM model as a virtual model or analytical model, which is the same representation used for energy simulation. This helps the user to rectify the modelling errors in the initial stage of the data sharing process. After performing the verifications and modifications, the verified IFC or gbXML file is imported by the BEPS application (Bell. D 2014) for energy simulation.

METHODOLOGY DEMONSTRATION

Creation and export of BIM data

A three-storey simple office building is considered for the demonstration of data transfer between the BIM and the BEPS model. The BIM model is represented in Figure 4 was created using the BIM tool Revit (Autodesk. 2019). The BIM model incorporates all the necessary information as defined in Table 1. Each floor of the building is divided into three separate rooms and every room has been assigned by different spaces and its space types. Some of the additional energy parameters like area per person, light and power load density, power schedules, etc are defined based on space types.
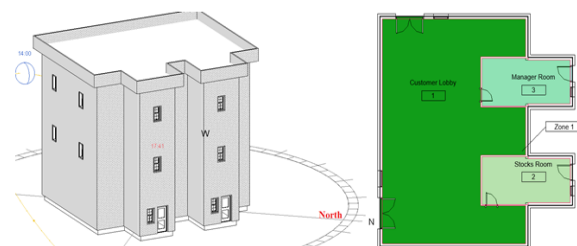

Figure 4: BIM Model

After the BIM model set-up, it was exported to openBIM meta-data file formats with the help of defined export specifications. The export process of modelled information from BIM to gbXML is performed using the category called "Based on Spaces". This export category facilitates the transfer of data related to geometry, construction, quantities (area and volume), spaces, space types and zones.

Table2:
BIM to IFC export specifications

EXPORT PARAMETER	SPECIFICATION
General	
IFC version	IFC4 Design Transfer View
File type	IFC
Phase to export	New Construction
Space boundary	2nd level
Project Origin	Project base point
Additional Content	
The category describes the 2D plans and external linked IFC files. These parameters are not considered since this information not necessary for the simulation process.	
Property Sets	
Export Revit property sets	Enable
Export IFC common property sets	Enable
Export base quantities	Enable
Level of Detail	
Level of detail for element g	high
Advanced	
The category describes the specific parts of the building, families, etc. Such minute data of the element is not necessary for the simulation process.	

The export process to IFC is specified by the parameters presented in Table 2. These export parameters are grouped into five categories, such as general, additional content, property sets, Level of Detail, and advanced. Table 2 summarises the information specification for the export process per category.

Verification of OpenBIM meta-data

After the successful completion of the export process, the data in the meta-data file formats are verified before importing into the simulation software. The intent of this validation process is to verify the quality of the exported data and to evaluate the need for correcting the inconsistencies in either the export or the modelling process. The model viewer tools are used for this verification process. Later on, the verified data is transferred to the BEPS tool IES VE (IES. 2020).

The Aragog gbXML Viewer 12.33 (From Ladybug Tools) is used as a model viewer for the verification of gbXML meta-data. This tool is based on the virtual environment and represents the 3-Dimensional (3D) elements of the building in terms of 2-Dimensional (2D) surfaces at the centre of the element. Figures 5 and 6 represent the export results from the gbXML viewer.
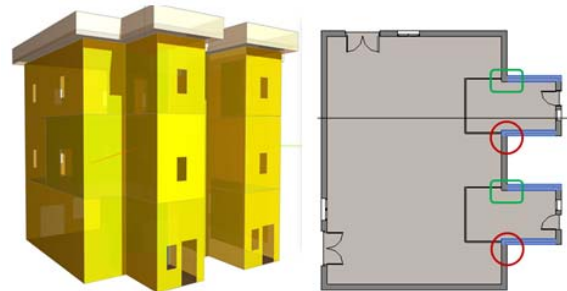

Figure 5: gbXML Model Viewer

From the thorough investigation of exported data in gbXML file, the following issues were identified.

Creation of tiny surfaces for walls, exactly at wall connections (refer Figure 5, 7).

Lack of connection between roof and external walls (refer Figure 6).
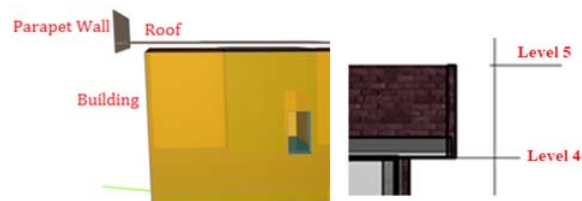

Figure 6: Model Viewer vs BIM Model

In Figure 7 (right image), it becomes clear that several tiny surfaces are created in every storey of the building exactly at the connections marked in Figure 5 (right image). It is even more interesting that the width of these tiny surfaces is exactly equal to the half of the wall thickness. After an in-depth investigation, the reason seems to be the geometrical concept adopted in the gbXML schema. The meta-data schema only reads the co-ordinates for the centerline and internal surface line of the wall and places 2D-surfaces exactly at the centerline of the wall. The co-ordinates of the internal surface line for each wall are used for area calculations.

In the demonstration case, the visualizer creates a 2D surface at the centerline of the walls until centre to centre of the wall connection. The further projected portion of the wall (half thickness) is considered as another wall element. Figure 7 represents the simulation model after the gbXML file was imported to the BEPS application. The tiny surfaces developed in this simulation model represent the projected

portions of the wall at connection points. Furthermore, all these tiny surfaces are treated as shading elements due to the concept defined in the simulation engine. This means, in the BEPS tool elements which are non-room bounding elements (i.e. they are not a part to create a closed-loop to define either room or space) are treated as shading elements.

Another issue observed in the gbXML export process is the incomplete connection between the roof and the remaining building elements in the model. It also identified that some portion of the parapet wall is extended down from the roof level. These issues are represented in Figure 6 (left image). Let's observe the BIM model (right image) in Figure 6. The external wall of the building is limited up to Level 4, as well the parapet wall and Roof construction start from Level 4. It means the base of the roof and parapet wall exists at Level 4, but according to the virtual environment concept, the element is represented as a 2D surface at its centre line. So, the roof surface is created at the centre line and this resulted in a gap between the roof and external wall with a width equal to the half of the roof thickness. Similarly, an extended part of the parapet wall from the roof surface to Level 4 (at the downside of the roof) is generated.
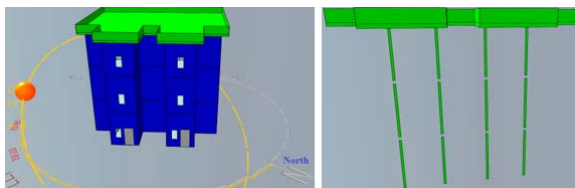

Figure 7: BEPS Model – gbXML import

Figure 7 also shows that the BEPS model imported the geometrical inconsistencies but the gap between the roof surface and the wall was automatically corrected. The BEPS application is adopted in a way that the creation of surfaces for roof, slab or floor is exactly at the position of levels defined in the BIM model.

The SOLIBRI Model Viewer tool is used to import the IFC file for data quality checking and verification of geometrical representations of building components. After in-depth investigations of data in the model viewer tool, it could be verified that all data was completely and successfully exported to IFC.

However, data were exported to IFC according to the BIM tool's proprietary data format. For example, the space type is defined as a typed spatial element in the IFC schema. In the exported IFC file the space type is represented as a property to space. The parapet wall and the roof extension (roof offset) are modelled in Level 4 of the building (BIM model). However, this needs to be treated as a shading device for energy analysis purposes. Nevertheless, these elements are represented as wall elements (for parapet wall) and roof elements (for an extended part of the roof) in the

Model Viewer (see Figure 8 – left image). It should be noticed that IFC is capable to model shading elements (using IFCShadingDevice).
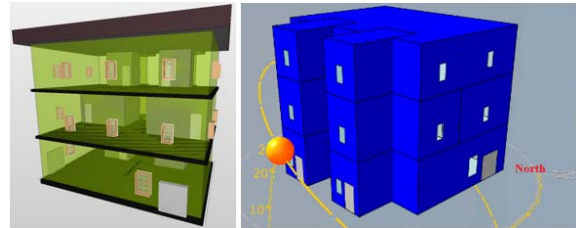

Figure 8: IFC - Model Viewer & BEPS Models

The data transfer process mostly depends on the BIM tool's proprietary data format. This causes inconsistencies in the generation of BEPS model. Figure 8 (right image) represents the BEPS model as stored in the simulation software. The model shows that shading devices are not part of the simulation model. A comprehensive discussion of these results is presented in the next sections.

BEPS model generation and validation

After the completion of openBIM data verification, the information is transferred to BEPS. The intent of the next verification step is to evaluate the quality of imported data and the data import capabilities of BEPS from gbXML and IFC. This validation process is carried out based on four different concepts and those are explained more comprehensively below.

Import statics:

The BEPS application generates a small report after every import of the BIM model and delivers import statistics. This report mainly focuses on the representation of the area and volume of each room or space, which are imported to BEPS applications. It also explains about surfaces, which define the room, and intersections between these surfaces. The report also provides some statistics regarding the number of surfaces and spaces of the BIM model, that were imported successfully. A comparison of volume-data between the BIM model and the BEPS model for the transfer process has been carried out. The difference in volume is presented in terms of percentage of volume difference with respect to the BIM model.

It can be observed that the volume difference is more than 10% for all the room types in the BEPS model. The increment of room volume in the BEPS model results from the volume calculation methodology. In the BIM model, the volume of the room was calculated based on the internal surfaces of the room bounding elements. It means for calculations only the internal distance between walls, roof and floor was considered. During the gbXML import process, the simulation tool imports co-ordinates related to both the centerline and the internal surface line of the element and places 2D

surfaces at the centerline. Similarly in the IFC import process, the simulation tool imports co-ordinates for the centerline of the elements. For volume calculations, the BEPS application uses the centerline method. It calculates the area between centre to centre of walls and multiplies this area with the height difference between levels for volume calculations.

Model Geometry and Orientation:

The geometry, location and orientation of the BEPS model generated from the gbXML import process can is also shown in Figure 7. The site location and all spaces of the building have been successfully imported to the BEPS application. Based on site location details, weather data can be acquired automatically within the BEPS application. The orientation of the building was also imported successfully (see the comparison between Figure 4 and Figure 7). The only issue results from the multiple tiny surfaces, which are defined as local shading devices created in each level (see Figure 7).

The BEPS model resulting from the IFC import process is shown in Figure 8 (right image). The data transfer methodology using IFC successfully imported the geometry, space and location details of the building to the BEPS application. However, the orientation of the BEPS model is different from the BIM model which can be understood by comparing Figures 4 and 8 (right image). The original orientation of the building is mentioned as 320 degrees to true north but the BEPS model is oriented at an angle of 40 degrees to the true north. An error regarding the direction of the model rotation in the IFC file causes this anomaly. The roof extension and the parapet wall are not imported from the BIM to the BEPS model, even though the details regarding these elements are contained in the IFC file. This is due to the fact that those elements are not bounded to any space in the BEPS model.

Construction details

The investigation of construction parameters in the BEPS model verified that all construction type names and thermal transmittance values (u-value) for each element were successfully imported from gbXML. However, the thickness and layered structure of construction elements were not imported. Information about element layers, thickness and material specifications modelled in BIM were successfully exported to gbXML; but the same is not being imported to the BEPS model from gbXML. Thus, the simulation application is failing to successfully import these construction details from gbXML files.

The evaluation of IFC-tools demonstrates, that these tools are capable to transfer construction details of all elements. The evaluation of the IFC import process to the BEPS model shows that the BEPS application is not importing any construction details from IFC. Literally, nothing has been observed in the construction parameters of the BEPS application.

Thermal Profile

In the gbXML data transfer process, the BEPS model successfully imported all space types defined in the BIM model. It also imported building services systems (HVAC) defined for each zone from the gbXML file. The simulation model did not import all other energy settings and information mentioned in the BIM model. Instead, it redirected to the information defined in the BEPS application library for energy analysis based on space types imported. For example, the space type "Bank Customer Area" has been assigned for a space called customer area in the BIM model, the BEPS model verified this imported space type and selected a space type called "Retail and Office" from its library. The energy settings like air exchange, internal gains, space condition, etc. are considered according to space type Retail or Office (in BEPS tool library).

The defined schedules for occupants and building operations (lighting, power supply) for each space types are not imported to the BEPS model. Generally, all these schedules are based on the space type and are editable too. It means, all these schedules are different from building to building even though the space type is the same. Thus, the BEPS application makes this schedule definition a user-defined task. Similarly, all imported data is editable, and it facilitates the user to modify and edit the information at any stage of the simulation.

Like the gbXML import process, the BEPS model successfully imports space types modelled in the BIM model. With the help of these space types, the BEPS application redirects to its libraries and assigns similar space types to the spaces in the BEPS model. We wish to highlight that the BEPS application interprets the space types differently, compared to the space types modelled in the IFC file, even though it is defined as a property to space. It thus contradicts to the IFC schema.

RESULTS AND DISCUSSION

The research started with the intent of evaluating the level of seamless data transfer from the BIM to BEPS models. This paper introduces a methodology to investigate and evaluate the interoperability between BIM and energy simulation with the help of IFC and gbXML file formats. The validation of this methodology was carried out using an example demonstration case. The quality and efficiency of the methodology are assessed based on the generated BEPS model data quality and preciseness.

The proposed methodology is applied to a simple use case model of a three-storey office building. The results from this evaluation show that both IFC and

gbXML meta-data schemas have their own advantages and disadvantages. Direct data sharing from BIM to BEPS models based on openBIM schemas is still not efficient because of the adopted concepts in both BIM and BEPS tools. It is understood that both tools use the same knowledge but the interpretation of this knowledge is different in the various applications. One can conclude that the introduction of further, more advanced technologies, such as integrated, real-time monitoring of occupants and devices seems still to be difficult (Menzel et al. 2008), since sharing the necessary basic information is still error-prone.

Construction and thermal profiles details are either inconsistent or completely failed to transfer. Especially, this is because of the lack of enough capabilities from the end tool to import data from the meta-model schemas. Apart from the end BEPS tool capabilities, gbXML schema causes issues in exporting building geometry (e.g. tiny surfaces in the model).

Another conceptual problem identified in the BEPS application is a lack of import capabilities for elements which are not bounded by any spaces. Since, e.g. all the shading elements are not bounded by any space, this is another unresolved problem in the import processes.

Furthermore, the BEPS model imports space types assigned to spaces as property. However, the information is overwritten with standard values and thus contradicts values defined in the IFC schema. Technically, such space type information could not only help BEPS applications to run several competency checks according to a different standard of specifications but could also be exploited in more advanced scenarios for energy service provision (Allan et al. 2009). This means there exist another case for future activities to improve the interoperability of software applications towards the development of digital twins in the AEC industry.

SUMMARY AND FUTURE WORK

Along with the comprehensive analysis of the methodology and the results from the demonstration process, a general review on the software interoperability in the AEC industry was carried out. It became clear that a diverse spectrum of information and different expertise in the building modelling process exists and must be harmonised. This diversity makes the process complex because of different knowledge interpretations about the same subject in different domains. The complete understanding of these interpretations is pivotal. It seems that such 'symptoms' are observed over more than a decade when comparing the result of this work with earlier work published (Keller et al. 2006).

However, it also became clear through the presented methodology that detailed work on attribute level is required to improve the interoperability between data models.

The probable solution is an in-depth investigation of approaches to use the semantic web and linked data concepts to reduce the need for human interaction required to harmonise openBIM data and to provide an opportunity to perform (semi)automated updates, changes and corrections to the data (Karlapudi et al. 2020).

Furthermore, the development of new workflows which would enable the engineers to transform BIM to BEPS models outside the proprietary authoring tools is required. Finally, it is also important to integrate further external data, e.g. climate data, material data from material manufacturers, occupant behaviour, sensor data, energy templates for decision making and information about Pre-fabricated components.

As said above, one possible solution is the adoption of semantic web technologies into the AEC industry. Such technologies may enable the description of the information in several distinct ways and make it possible to connect to each other with the help of connected graphs. Future research is focusing on achieving efficient data interoperability between AEC applications through the implementation of semantic web technologies and the Linked Data Paradigm (DIN EN ISO 21597-1. 2018).

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