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Building Envelope Thermal Performance Assessment Using Visual Programming and BIM, based on ETTV requirement of Green Mark and GreenRE

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ABSTRACT

Accomplishment of green building design requirements and the achievement of the targeted credit points under a specific green rating system are known to be a task that is very challenging. Building Information Modeling (BIM) design process and tools have already made considerable advancements in green building design and performance analysis. However, Green building design process is still lack of tools and workflows that can provide real-time feedback of building sustainability and rating during the design stage. In this paper, a new workflow of green building design assessment and rating is proposed based on the integration of Visual Programming Language (VPL) and BIM. Thus, the aim of this study is to develop a BIM-VPL based tool for building envelope design and assessment support. The focus performance metric in this research is building Envelope Thermal Transfer Value (ETTV) which is an Energy Efficiency (EE) prerequisite requirement (up to 15 credits) in both Green Mark and GreenRE rating systems. The development of the tool begins first by creating a generic integration framework between BIM-VPL functionalities and ETTV requirements. Then, data is extracted from the BIM 3D model and managed using Revit, Excel and Dynamo for visual scripting. A sample project consisting of a hypothetical residential building is run and its envelope ETTV performance and rating score are obtained for the validation of the tool. This tool will support project team in building envelope design and assessment by allowing them to select the most appropriate façade configuration according to its performance efficiency and the green rating. Furthermore, this tool serves as proof of concept that building sustainability rating and compliance checking can be automatically processed through customized workflows developed based on BIM and VPL technologies.

1. Introduction

Building industry across the world is investing more in environmentally friendly buildings that can provide both high performance and long term cost saving (Jrade and Jalaei, 2013). In the light of this issue, building practitioners have realized the importance of creating consistent metrics for the quantitative and qualitative evaluation of building performance in order to efficiently guide the design and construction of green buildings (Wu, 2010). As a result, many countries around the world have recently adopted different Green Building Rating Systems (GBRS) such as LEED (US), BREEAM (UK), Green Mark (Singapore), GreenRE (Malaysia) to assess and benchmark building sustainability according to predefined sustainability criteria and performance standards.

Design by nature is a complex process especially when project team have to achieve additional objectives related to sustainability such as energy efficiency and rating scores. For example, when designing a green building and seeking for a green certification, design decision making become very time consuming due to the fact that collecting, managing and documenting the relevant data is a very labour process

(Wu, 2010; Wong and Kuan, 2014; Jalaei and Jrade, 2015; Ilhan and Yaman, 2016; Lim *et al.*, 2016). Furthermore, designers tend to rely on previous experience outcomes to make design decision. Therefore, project team may create several design options and then mentally testing them against past cases to select what they think it is the best solution (Sukreet and Kensek, 2014). However, it is argued to be very important to take the appropriate steps in order to automate the process of gathering the necessary information for building environmental analysis (Biswas *et al.* 2013).

BIM is now revolutionizing the construction industry and it has become the standard in several countries around the world. Because of its various advantages, BIM adoption has gained more interest in the Malaysian and Singaporean building industry as well. Furthermore, road maps for BIM implementation in both countries are currently in progress (BCA, 2013; CIDB, 2014).

Different from the traditional CAD-based design process, BIM provides designers the tools and the process that support Decision-Making in the very early design stages with less deal of human

intervention (Azhar *et al.*, 2011; Jalaci and Jrade, 2015; Ilhan and Yaman, 2016). Furthermore, BIM design process is based on one data-rich digital model that can be used to perform numerous analysis through building life cycle. Hence project team are able to use BIM tools to evaluate the performance of different design options in short time and achieve building sustainability goals more efficiently. In addition, with the integration of new building design technologies to BIM such as Visual Programming, designers are able to develop their own analysis tool and customize the design workflow to serve their needs instead of relying on solutions provided by software companies.

This paper aims to develop a BIM-VPL based tool for building Envelope Thermal Transmittance Value (ETTV) assessment and rating. For this purpose, a generic integration framework between ETTV requirement and BIM-VPL functionalities is first developed. Then, the ETTV tool is developed based on this integration framework. The proposed workflow is focusing on the earliest stages of design, when Decision Making for envelope configuration and façade design is made. Different from other ETTV available assessment methods, this tool is directly linked to the BIM conceptual model and relies on the embedded information within the model component. Hence it automatically extracts the required data from the BIM model and performs the necessary calculation and rating of design envelop ETTV in real-time. The applicability of tools is demonstrated through the use of a hypothetical residential building, while ETTV assessment results are compared to manual calculations.

2. Theoretical Background

2.1 Green Building Rating System

In the last two decades, building industry has become more interested in promoting green building concept. For this purpose, many policies, laws, regulations and standards have been created to encourage sustainable innovations in terms of products and processes (Steurer and Hametner, 2013). Additionally, many green building rating systems have been adopted in many counties around the world in order to provide the project team a comprehensive guideline for implementing sustainability practices in whole building lifecycle. According to the green building research institute GBRI, a green rating system is defined as “a set of prerequisites and requirements that a project team must fulfil in order to receive certification” (GBRI, 2015). Green rating systems cover different criteria and levels of sustainability that indicate how many credit points a project team should fulfil. In this study, two green rating systems are concerned, namely Green mark & GreenRE for residential building.

2.2 Green Mark and GreenRE

Green Mark and GreenRE are green building rating systems developed respectively in Singapore (2008) and Malaysia (2013). GreenRE and Green mark rating systems are quite similar in term of sustainability criteria and their process of certification. Both rating systems cover six main pillars related to building sustainability as follows; Energy Efficiency (EE), Water Efficiency (WE), Indoor Environmental quality (IEQ), Environmental Protection, Carbon Emission of development and other Green Features (Green Mark Singapore, 2010; REHDA, 2015). Each pillar has sub-categories weighted with credit points. Hence, the final building sustainability rating is associated to the sum of all credit points of the sub-categories. Finally, based on the earned credit points, a provisional green certification is issued for building design before its construction.

2.3 Envelope Thermal Transmittance Value (ETTV).

ETTV is one of the prerequisite requirements in both Green Mark and GreenRE, which means project team should fulfil its minimum requirement in order to be eligible for a green certification. Similar to OTTV, ETTV takes into consideration the three basic components of heat gain through building envelope (Building construction and Authority 2004).

- heat conduction through opaque walls,
- heat conduction through fenestration glazing,
- solar radiation through fenestration glazing,

The ETTV requirements is simple, no simulation is required and applies only to air-conditioned buildings. It aims at achieving the design of building envelope to cut down external heat gain and hence reduce the cooling load of the air-conditioning system. When it comes to residential buildings project the ETTV is referred as RETV. In this case the computation of ETTV for residential buildings (RETV) for both GreenRE and Green Mark is based on the methodology specified in the code on Envelope Thermal Performance for building by BCA (Building construction and Authority 2004). ETTV for residential buildings equation is given as Envelope Thermal Transfer Value.

$$ETTV = 12 \times (1 - WWR) \times U_w + 3.4 \times WWR \times U_f + 211 \times WWR \times CF \times SC$$

Where:

ETTV: envelope thermal transfer value (W/m²)

WWR: window-to-wall ratio (fenestration area/gross area of exterior wall)

U_w: thermal transmittance of opaque wall (W/m² °K)

U_f: thermal transmittance of fenestration (W/m² °K)

CF: correction factor for solar heat gain through fenestration

SC: shading coefficient of fenestration

ETTV credit point target is one of the most challenging task for project team to achieve due to its dependency on a huge amount of information related to building envelope configurations and materials. According to Inhabit (specialist engineering consulting group): “ETTV compliance presents design challenges for architects, builders and suppliers in Singapore’s building and construction market ... ETTV has to be considered more closely when undertaking any design decisions that influence the façade outcome” (Inhabitgroup, 2016).

A web-based tool called ‘ETTV façade designer’ was developed for the Singaporean market by Inhabit for Green Mark rating system which aims to minimize the time and energy spent on the process of designing building envelop under the ETTV requirement (Inhabitgroup, 2016). However, this tool is not integrated to building information and it gives only preliminary insights on building ETTV performance.

Recently, a model for OTTV assessment was developed by Lim *et al.* (2016) as a part of integrating BIM to Green Building Index (GBI) of Malaysia. This model is based on manual extraction of the data from the BIM model using scheduling (Revit functionality), and the export of data to external software for calculation.

2.4 BIM for Sustainable Building Design

The integration of BIM concept to green building has gained mountainous interest from scholars and practitioners interested in both BIM and building sustainability issues (Azhar and Brown, 2009; Bank *et al.*, 2010; Wong and Kuan, 2014). In this research area, several studies

have investigated how energy performance can be optimized using both BIM (process and tools) and multi-objective optimization algorithms (Asl *et al.*, 2011; Lim *et al.*, 2015), BIM for Daylighting optimization (Kota *et al.*, 2014) and BIM for Green material selection (Akanmu, Asfari and Olatunji, 2015).

Studies have also investigated how BIM can be integrated with Green Building Rating Systems in order to facilitate building sustainability assessment, potential achievable credit points and the provision of the necessary documents for green building certification (Wu, 2010; Azhar *et al.*, 2011; Wong and Kuan, 2014; Ilhan and Yaman, 2016). Nevertheless, research in this areas is still limited in comparison to other sustainability related issues. This is mainly due to several technical factors such as BIM interoperability issues in the one hand and the lack of integration between BIM authoring tools and green materials databases on the other hand (Wu, 2010; Wong and Kuan, 2014; Ilhan and Yaman, 2016).

2.5 Visual Programming Language (VPL) for Building Design

In last decade, building practitioners (specially architects and engineers) become more interested in Visual Programming tools that allow them to create customized, flexible, and powerful form-generating algorithms without having to first learn how to write code (Kensek, 2015). Several of these Visual Programming based tools available in the market are Grasshopper, Dynamo and Marionette.

Previously, the application of Visual Programming was focused on algorithmic and generative approaches to generate and manipulate shapes by rules and constraints (Leitão, Santos and Lopes, 2012). The development of BIM process and tools in building design has created new opportunities of using VPL such as the manipulation of the embed information within the BIM model. Thus, BIM-VPL users are now able to automate many task in their BIM design workflow by developing custom scripts for data management and generate links among multiple applications for further studies and analysis (Autodesk, 2016).

Grasshopper is one of the leading Visual Programming tools in building industry. It is an open source community-driven tool which is linked to Rhino (CAD-based tool) via a plug-in. Grasshopper is a very powerful tool especially for the generation of complex geometries. It also can perform a bunch of environmental analysis and performance optimization due to its linkage to several simulation engines and its large library of pre-designed packages. Although, compared to Dynamo, Grasshopper has just recently become connected to the BIM design environment of ArchiCAD. However, since its first release Dynamo was connected to the BIM authoring tool Revit.

2.5.1 Dynamo

Dynamo is an open source Visual Programming tool dedicated to improve building design process and workflows in both computational design and Building Information Modelling (BIM) fields (Autodesk, 2016). It provides designers with the means for constructing programmatic relationships using a Graphical User Interface (GUI) (Vandezande and Krygiel, 2015). Thus, rather than writing 'code' from scratch, the user is able to assemble custom relationships by connecting pre-packaged nodes together to make a custom algorithm. It can be noticed that Dynamo platform is inspired by previous Visual Programming tools such as Grasshopper (Kensek and Noble, 2014). The capability of

Dynamo in manipulating the parameters of the BIM authoring tool Revit added an extra level of associativity and created new opportunities for cross-platform and cross-discipline collaboration (Kensek and Noble, 2014). Several type of data can be handled using Dynamo such as parameters values, family geometry and family placement. By creating new elements in Revit using Dynamo, the user can adjust its parameters manually within Revit. Moreover, the same Dynamo script can be reused for different projects (Sharon Jamison, 2014).

According to Sgambelluri, the power of Dynamo resides in its accomplishment of two major tasks: the creation of parametric relationships within design geometry and its ability to read from external databases (Marcello Sgambelluri, 2015). For example, the integration of Dynamo to Revit allows Dynamo to manipulate and manage all the parameter of the BIM model. Hence, Dynamo is able to read and write back data to and from the Revit database via the Revit API (Marcello Sgambelluri, 2015). Recently new promising functionalities such as 'Dynamo Player' have been included in Revit 2017.1 (Autodesk, 2017). Dynamo Player allows users without any programming skills to run Dynamo scripts with only one button click.

2.5.2 VPL for Building Performance Analysis

Several studies have implemented Visual Programming tool for building performance analysis such as: Energy Efficiency and daylighting optimization (Asl *et al.*, 2011), Structural analysis (Makris *et al.*, 2013), Acoustical analysis (Andrea Vannini, 2015) and more. In this area, Edwin Guerra (2014) proposed a simplified problem solving workflow for Dynamo which covers 3 key steps: identify the problem to explore, develop Dynamo definition and explore. Nevertheless, still there is no comprehensive VPL based model or workflow for building sustainability analysis. Furthermore, only few of these studies integrate the BIM concept in their workflows.

Kensek (2015) argued that Visual programming tool can support sustainable design studies in the early stages of building design. Several studies (Asl *et al.*, 2011; Kensek and Kahn, 2013; Kensek, 2015; Kim *et al.*, 2015; Konis, Gamas and Kensek, 2016) implemented Visual Programming tools to create frameworks and workflows related to building performance analysis. For example, (Konis, Gamas and Kensek, 2016) developed a framework for building passive performance optimization for early design stage. The framework implements a simulation-based parametric modeling workflow to optimize several aspects of building envelop configuration. In this workflow, Grasshopper has been used to manipulate design parameters and for optimization.

Façade design and shading optimization is one of the hottest topics related to the implementation of VPL and BIM in sustainable building analysis. For instance, Kensek (2015) illustrated in three case studies how BIM and VPL can be used to design parametric shading device for complex façades and perform energy simulation. A similar research conducted by Kim *et al.* (2015) proposed a new methodology analyzing energy performance for complex kinetic façades. In the same scope but with different approach, a new trend of studies become interested in integrating BIM and Visual Programming tools to environmental hardware. For instance, Kensek & Kahn (2013) tested the feasibility of connecting environmental sensors to the BIM model in the one hand and if changing the BIM model parameters could affect the physical

model on the other hand. This study aimed to investigate if visual/physical prototypes can be used as the basis of mocking-ups intelligent façade systems before constructing full size one.

3. Methodology

Based on (Jalaei, 2015; Lim et al, 2016; Wu, 2010) correspondent researches, the development of the ETTV assessment model begins first by creating a generic integration framework that matches up both BIM-VPL functionalities and ETTV requirements which is stipulated in the Green rating system guide (Green Mark and GreenRE). The purpose of this framework is to create a strategy for data extraction/management and to find out possible automation workflows for further development of the ETTV assessment tool. For this purpose, two major tasks are established as follows:

Firstly, the evaluation of the ETTV requirement consists of interpreting all the relevant criteria such as ETTV's equation data request (Input) and the accompanying description stipulated in Green Mark and GreenRE guides. The ETTV requirement and its method of calculation is more detailed in the Envelope Thermal Transfer Value for Buildings Guidelines (Building construction and Authority, 2004). The next step, is to screen available functionalities in the BIM authoring tool Autodesk Revit. Hence, see if ETTV's data request can be automatically extracted from the 3D BIM model then fed to its equation using Revit functionalities. In case when no functionality is available, gaps are identified and further development are done using Visual Programming scripting.

For the development of the model, Autodesk Revit was used to design the BIM 3D model. Revit is a very popular BIM authoring tools in building industry. On the other hand, Dynamo was selected because of its flexibility in managing the BIM data, automating design workflows and more importantly its integration to Revit as a plug-in.

3.1 BIM-VPL Based RETV Integration Framework

The framework consists the foundation of the development of the ETTV assessment and rating tool. First the ETTV requirement is evaluated then matched up with BIM-VPL functionalities.

According to the ETTV equation and description given in the ETTV guide (Building construction and Authority, 2004), it can be noticed that ETTV is mainly depended on building façade orientation and windows-to-wall ratio. Since no functionality is available in Revit to detect façade orientation and WWR ratio, this two features are developed using Dynamo scripting. By using the new developed scripts, any wall/window orientation in the design environment of Revit can be detect automatically when running the script. Furthermore, area of walls and windows of each façade can be extracted using the same workflow for WWR calculation.

Some information relevant to ETTV equation are already available in Revit objects parameters. For example, U_f parameter can be found under the thermal proprieties of any windows object in Revit. In addition, U_w of the walls is calculated automatically in Revit according to the thermal proprieties of each material layers that compose walls structure. However, Dynamo scripts are developed to extract this information from the conceptual BIM model for ETTV assessment purpose.

Addition match up of BIM-VPL functionalities and ETTV requirements are summarized in the Table 1.

Table 1: BIM-VPL functionalities match up with ETTV requirement

Required functionality/ information	Available in Revit ?	Developed in this research ?
<i>Project True North</i>	Yes	-
<i>Auto wall orientation detection</i>	No	Yes
<i>Auto Windows orientation detection</i>	No	Yes
<i>Auto curtain wall orientation detection</i>	No	No
<i>Include in ETTV calculation parameter</i>	No	Yes
<i>Orientation parameter</i>	No	Yes
<i>Wall, fenestration thermal properties</i>	Yes	Yes
<i>SC2: Effective shading coefficient of external shading devices</i>	No	No

3.2 BIM-VPL Based ETTV Model Development

The ETTV model development is based on both ETTV evaluation results and BIM-VPL functionalities match up discussed in the previous paragraphs. It is developed in order to guarantee an efficient assistance of building envelop design under the requirement of RETV stipulated in Green Mark and GreenRE guides. Accordingly, designers can get live feedback of the thermal transmittance value of several envelope design option. Furthermore, the linkage of the design environment to Dynamo scripts is expected to speed up the design process by allowing designers to avoid assessment rework and more importantly to allow designer to focus more on design ideas instead of benchmarking and chasing credit points. Figure 1 shows the main part of the proposed model.

3.2.1 Revit Template and Building Component Library

A key step in the development of the ETTV assessment tool, is the customization of the BIM design environment of the BIM authoring tool. For this purpose, an ETTV template is created using Autodesk Revit. The template is designed and customized based on the evaluation of ETTV criteria discussed previously. Thus, it contains all building components that designer will use in designing building envelop with ETTV related data (dimensions, thermal properties...etc.). Besides, new parameters are created in the template such as 'wall/window orientation' and 'Exclude from RETV calculation' using the shared parameter functionality in Revit (Figure 2).

According to (Jalaei and Jrade, 2015; Ilhan and Yaman, 2016), a green building data base of building component and material is needed for sustainable design. In this research a database for building component is developed. Building components were downloaded from BIM object websites. However, several system components such as walls were created by duplicating the existing types.

3.2.2 Information Availability Checker

Exporting/Importing data from a program to another is still unstable and mainly relies on data exchange file format such as gbXML of IFC. This is often referring as 'Interoperability issue'. A strategy which can be employed to control the 3D BIM model information is to use automated checking of information by making use of rules (Coenders,

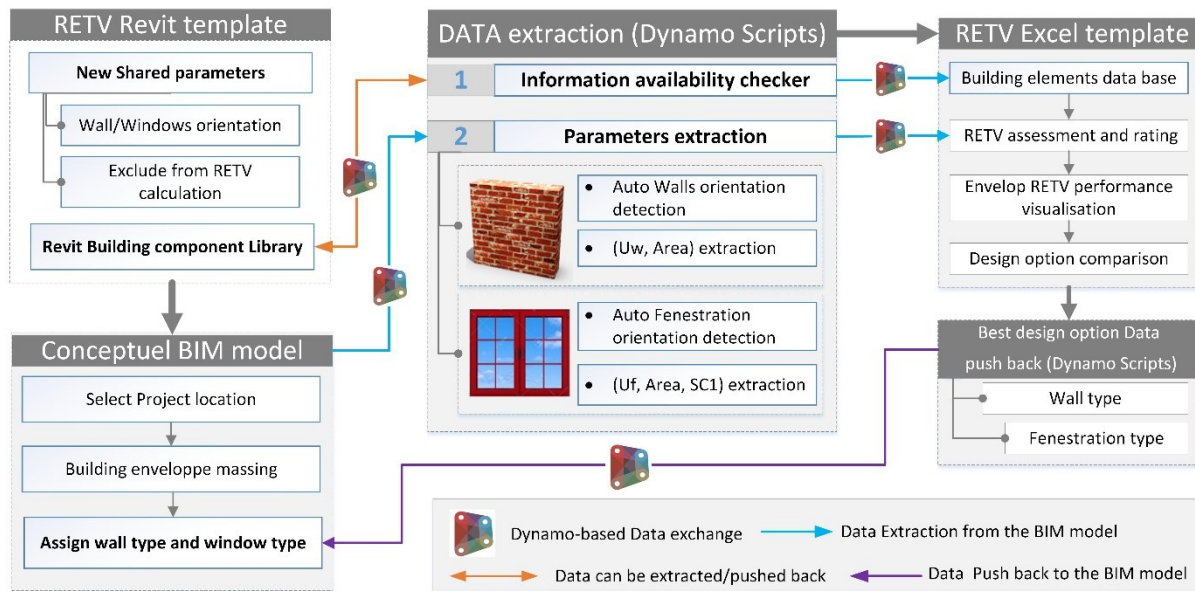


Figure 1: Proposed BIM-VPL based model for ETTV assessment and rating

2009). This study is not based on information exchange using file format but using instead Visual Programming to develop customized rules during data extraction that can inform the user about the reliability of the results. Unfortunately, information exchange using Visual Programming tool such as Dynamo is known to be not yet fully stable (Kensek, 2015). This instability may lead to errors in the final output.

On the other hand, when designers are developing a BIM 3D model, sometimes they may design costume components or download external ones from web-based BIM objects library such as National BIM Library (NBS). In this case, it is possible to have some missed information in the parameters of the new components such as thermal proprieties or cost. Since, the final analysis output of the ETTV tool is mainly relying on the availability and the accuracy of the input information, it is argued to be necessary to give the chance to the user to check if all required data are available before running the ETTV assessment. Accordingly, in this research an information checker model is developed using Dynamo 1.2.1 scripting, thus it can extract the relevant information form the existing component in the Revit library then exporting them to an Excel spreadsheet. This extracted

information are component's parameters related to ETTV requirement (Wall and Windows Areas, U_w , U_f , etc.). By using Excel condition functions, user can be informed if any important information is missing before running the ETTV assessment. If all required information are available, the user is ready to pursue the next step. In the contrary, if any additional information is missing, the user can type it manually then run the relevant script to push it back automatically to the specific component existing in the Revit library.

3.2.3 Excel Template: Assessment and Rating

The excel template is created to host the information extracted for the BIM conceptual model via Dynamo and perform the relevant calculations. The extracted information are mainly Revit elements parameters such as (wall/window ID, wall/window area, wall/window U value...etc.) see Fig. 4.

The ETTV assessment and rating can be performed after importing the requirement information by a click of a button. Hence the use can make several modifications in model then compare the ETTV performance and rating.

Identity Data	
Image	
Comments	
Mark	
Phasing	
Phase Created	New Construc...
Phase Demolished	None
Green Building Properties	
Exclude From RETV Calculation	<input type="checkbox"/>
Wall Orientation	South
Other	
Flux Id	

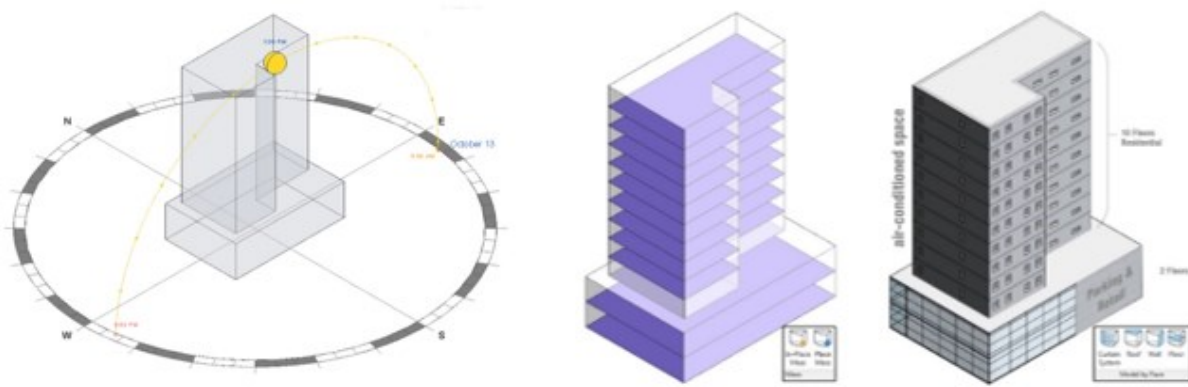
Figure 2: New shared parameters are created under Green building Properties

4. Validation of the Model

In this study, the validation of the proposed model is based on testing the whole workflow on a sample project. Then results are discussed and limitation are identified for further future development of the present tool.

As mentioned previously in the methodology section. This study implement Revit 2017.1 as the BIM authoring tool and Dynamo V.1.2.1 as the Visual Programming tool. It is important to consider the versions of the tool as both of these tools are in rapid development and some functionalities may not be available in previous versions.

Sample Project: Since the ETTV equation is dedicated for the tropical climate, particularly for Malaysia (GreenRE) and Singapore (Green Mark), the location of the project in the Revit template was set to Johor Bahru because this location presents both two countries climate



(a) Initial conceptual mass of the sample residential building

(b) Conceptual model: walls and windows types are assigned

Figure 3: BIM model of the Hypothetical residential building

conditions as well as the solar path. Then a hypothetical residential building sample is designed in two phases:

First a conceptual mass of the hypothetical residential building is created in the ETTV template. The proposed building design has (4) façades with four (4) cardinal orientations (N, S, E, W) and twelve (12) levels, while the first two (2) levels are assumed to contain parking and retail spaces, however the (ten) 10 other levels of the building present centrally air-conditioned residential space with a total gross area of 2593 m² as shown in Figure 3. For the purpose of this study the RETV is calculated only for the air-conditioned residential spaces (10 floors).

After designing the initial conceptual model of the building, walls and floors were assigned to the relevant faces of building envelop by using 'model by face' functionality which is available in Revit then, different type of windows were allocated to the four façades using Revit

components library.

Before exporting the information related to ETTV requirement using the developed Dynamo script, it is encouraged to design only the elements that belong to building envelop, otherwise Dynamo scripts will extract all the information of all building element existing in the design environment. However, a parameter called "Exclude from ETTV calculation" is created in order to allow the user to manually exclude the elements that do not belong to building envelop such as interior walls as illustrated in Figure 4.

5. Result and Discussion

ETTV assessment and rating starts by developing the conceptual design model in the Revit template. By using conceptual mass editing features provided in Revit, designers are able to create the initial mass of the

Import North Façade Information		Delete Information		North Façade				RETV ASSESSMENT ACCORDING TO Building and Construction Authority						
				Area (m ²)		696.51								
				RETV (W/m ²)		27.14		WWR		16%				
				Heat Conduction Through opaque walls				Heat Conduction Through glass windows						
				12(1 - WWR) U _w		1.06		3.4(WWR)U _f		211(WWR)(CF)(SC)				
				Total Wall area (m ²)		584.91		Total Windows area (m ²)		111.60				
				ΣAw. U _w		61.74		ΣAf. U _f		411.65				
				ΣAw. U _w		61.74		ΣAf. U _f		411.65				
Solar Radiation through glass windows		24.07		ΣAf. SC		99.32								
Wall Type	Wall ID	Wall area (m ²)	U _w (w/m ² ·K)	Aw. U _w	Windows Type	Windows ID	Windows Area (m ²)	U _f	Af. U _f	CF	SC	SC1	SC2	Af. SC
Exterior - Block on Mtl. Stud	311543	584.91	0.11	61.74	Family Type: 1830 x 1220mm, Family: M_Sliding with Trim	313582	1.86	3.69	6.86	0.80	0.89	0.89	1.00	1.66
0.00	0	0.00	0.00	0.00	Family Type: 1830 x 1220mm, Family: M_Sliding with Trim	313615	1.86	3.69	6.86	0.80	0.89	0.89	1.00	1.66
0.00	0	0.00	0.00	0.00	Family Type: 1830 x 1220mm, Family: M_Sliding with Trim	313631	1.86	3.69	6.86	0.80	0.89	0.89	1.00	1.66
0.00	0	0.00	0.00	0.00	Family Type: 1830 x 1220mm, Family: M_Sliding with Trim	313665	1.86	3.69	6.86	0.80	0.89	0.89	1.00	1.66
0.00	0	0.00	0.00	0.00	Family Type: 1830 x 1220mm, Family: M_Sliding with Trim	313691	1.86	3.69	6.86	0.80	0.89	0.89	1.00	1.66
0.00	0	0.00	0.00	0.00	Family Type: 1830 x 1220mm, Family: M_Sliding with Trim	313729	1.86	3.69	6.86	0.80	0.89	0.89	1.00	1.66
0.00	0	0.00	0.00	0.00	Family Type: 1830 x 1220mm, Family: M_Sliding with Trim	313800	1.86	3.69	6.86	0.80	0.89	0.89	1.00	1.66
0.00	0	0.00	0.00	0.00	Family Type: 1830 x 1220mm, Family: M_Sliding with Trim	313831	1.86	3.69	6.86	0.80	0.89	0.89	1.00	1.66
0.00	0	0.00	0.00	0.00	Family Type: 1830 x 1220mm, Family: M_Sliding with Trim	313832	1.86	3.69	6.86	0.80	0.89	0.89	1.00	1.66
0.00	0	0.00	0.00	0.00	Family Type: 1830 x 1220mm, Family: M_Sliding with Trim	313833	1.86	3.69	6.86	0.80	0.89	0.89	1.00	1.66
0.00	0	0.00	0.00	0.00	Family Type: 1830 x 1220mm, Family: M_Sliding with Trim	313834	1.86	3.69	6.86	0.80	0.89	0.89	1.00	1.66
0.00	0	0.00	0.00	0.00	Family Type: 1830 x 1220mm, Family: M_Sliding with Trim	313835	1.86	3.69	6.86	0.80	0.89	0.89	1.00	1.66
0.00	0	0.00	0.00	0.00	Family Type: 1830 x 1220mm, Family: M_Sliding with Trim	313860	1.86	3.69	6.86	0.80	0.89	0.89	1.00	1.66
0.00	0	0.00	0.00	0.00	Family Type: 1830 x 1220mm, Family: M_Sliding with Trim	313861	1.86	3.69	6.86	0.80	0.89	0.89	1.00	1.66
0.00	0	0.00	0.00	0.00	Family Type: 1830 x 1220mm, Family: M_Sliding with Trim	313862	1.86	3.69	6.86	0.80	0.89	0.89	1.00	1.66
0.00	0	0.00	0.00	0.00	Family Type: 1830 x 1220mm, Family: M_Sliding with Trim	313863	1.86	3.69	6.86	0.80	0.89	0.89	1.00	1.66
0.00	0	0.00	0.00	0.00	Family Type: 1830 x 1220mm, Family: M_Sliding with Trim	313864	1.86	3.69	6.86	0.80	0.89	0.89	1.00	1.66
0.00	0	0.00	0.00	0.00	Family Type: 1830 x 1220mm, Family: M_Sliding with Trim	313865	1.86	3.69	6.86	0.80	0.89	0.89	1.00	1.66
0.00	0	0.00	0.00	0.00	Family Type: 1830 x 1220mm, Family: M_Sliding with Trim	313870	1.86	3.69	6.86	0.80	0.89	0.89	1.00	1.66
0.00	0	0.00	0.00	0.00	Family Type: 1830 x 1220mm, Family: M_Sliding with Trim	313871	1.86	3.69	6.86	0.80	0.89	0.89	1.00	1.66
0.00	0	0.00	0.00	0.00	Family Type: 1830 x 1220mm, Family: M_Sliding with Trim	313872	1.86	3.69	6.86	0.80	0.89	0.89	1.00	1.66
0.00	0	0.00	0.00	0.00	Family Type: 1830 x 1220mm, Family: M_Sliding with Trim	313873	1.86	3.69	6.86	0.80	0.89	0.89	1.00	1.66
0.00	0	0.00	0.00	0.00	Family Type: 1830 x 1220mm, Family: M_Sliding with Trim	313874	1.86	3.69	6.86	0.80	0.89	0.89	1.00	1.66
0.00	0	0.00	0.00	0.00	Family Type: 1830 x 1220mm, Family: M_Sliding with Trim	313875	1.86	3.69	6.86	0.80	0.89	0.89	1.00	1.66
0.00	0	0.00	0.00	0.00	Family Type: 1830 x 1220mm, Family: M_Sliding with Trim	313880	1.86	3.69	6.86	0.80	0.89	0.89	1.00	1.66
0.00	0	0.00	0.00	0.00	Family Type: 1830 x 1220mm, Family: M_Sliding with Trim	313881	1.86	3.69	6.86	0.80	0.89	0.89	1.00	1.66
0.00	0	0.00	0.00	0.00	Family Type: 1830 x 1220mm, Family: M_Sliding with Trim	313882	1.86	3.69	6.86	0.80	0.89	0.89	1.00	1.66
0.00	0	0.00	0.00	0.00	Family Type: 1830 x 1220mm, Family: M_Sliding with Trim	313883	1.86	3.69	6.86	0.80	0.89	0.89	1.00	1.66
0.00	0	0.00	0.00	0.00	Family Type: 1830 x 1220mm, Family: M_Sliding with Trim	313884	1.86	3.69	6.86	0.80	0.89	0.89	1.00	1.66
0.00	0	0.00	0.00	0.00	Family Type: 1830 x 1220mm, Family: M_Sliding with Trim	313885	1.86	3.69	6.86	0.80	0.89	0.89	1.00	1.66
0.00	0	0.00	0.00	0.00	Family Type: 1830 x 1220mm, Family: M_Sliding with Trim	313890	1.86	3.69	6.86	0.80	0.89	0.89	1.00	1.66
0.00	0	0.00	0.00	0.00	Family Type: 1830 x 1220mm, Family: M_Sliding with Trim	313891	1.86	3.69	6.86	0.80	0.89	0.89	1.00	1.66
0.00	0	0.00	0.00	0.00	Family Type: 1830 x 1220mm, Family: M_Sliding with Trim	313897	1.86	3.69	6.86	0.80	0.89	0.89	1.00	1.66

Figure 4: Excel template hosts the extracted data from the BIM model

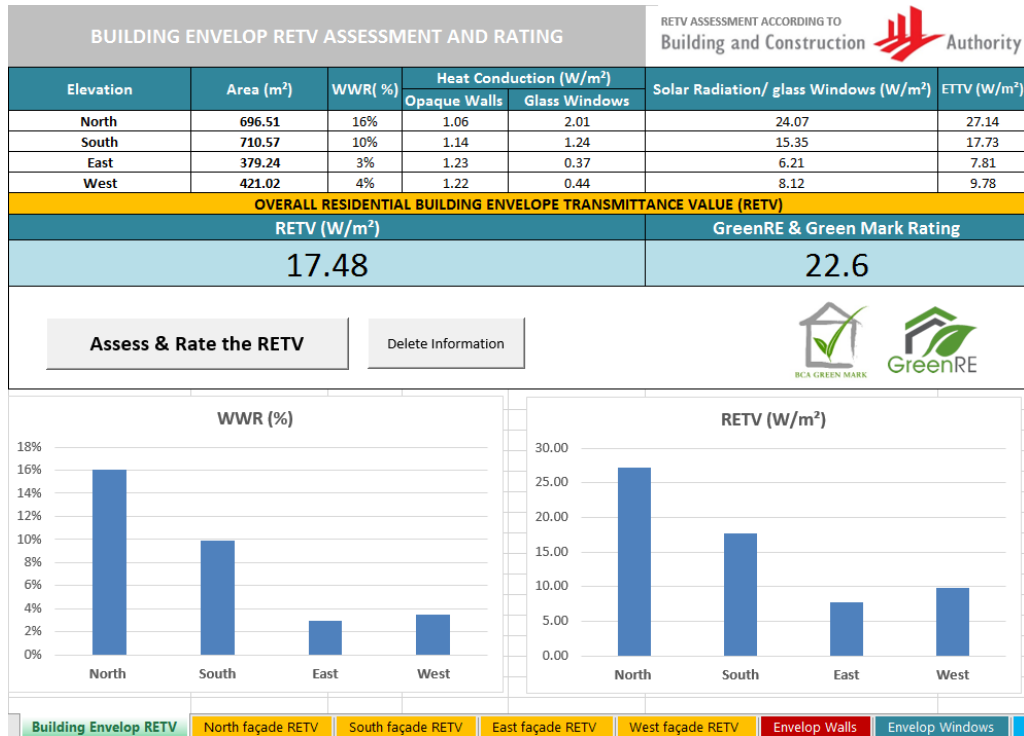


Figure 5: Main template for building ETTV assessment and rating results

building. Then, the user has to assign building elements; walls, windows, floors and roofs using ‘model by face’ functionality. It is worthy to say that user have to check that all the normal vectors of the assigned walls are oriented to the exterior, so façade orientation can be detected correctly.

In order to evaluate the ETTV of the design, user first need to run two main Dynamo scripts as follows: (1) Auto wall orientation detection, (2) Auto window orientation detection. By running these two Dynamo definitions, all required data related to walls and windows is exported to an Excel template for ETTV assessment and rating, see Fig. 5. The data contains information about wall/windows area, ID, orientation, thermal proprieties...etc. Once the data is exported to Excel, ETTV is assessed according to Green Mark and GreenRE requirement (for residential buildings). At this level, designers are able to modify design configuration, study the impact on whole building ETTV performance and do comparative analysis. To validate the tool, the ETTV of the north façade was calculated manually and compared with the tool’s ETTV results. The manual calculations are performed by hand, hence all the information related to walls and windows are obtained by observing the model or by checking the elements proprieties. For example, windows in the north façade are counted one by one and its dimension is referred from the prosperity panel of the window. Then the total area of the windows is divided by the total gross area of the wall in order to get the window-to-wall ratio. During this hand-based calculation it was very clear that ETTV manual documentation process is a very tedious and time consuming task especially when building envelop configuration is complex.

6. Conclusion

This study shows the importance and the potential of integrating BIM and VPL for building envelope ETTV assessment and rating with several constraints. Within the scope of this study, ETTV requirement

was evaluated and matched up with BIM and VPL functionalities. Then, a BIM-VPL based model for ETTV’s data management and extraction is developed. Using this tool designer are able to create several design option of the conceptual design, compare the ETTV performance together with the earned credit point, then make decision. Further, building orientation can be changed easily using Revit, hence designer are able to compare different orientation option performance then select the optimum one in the conceptual stage.

At this level of development this tool is considered as a Passive Decision Support System (Passive-DSS) because design decision making is based on manual comparison of different design option performance. However, further development can be implemented in the tool to become an Active-DSS by integrating multi-objective optimization algorithm such as Optimo which is a package developed by Asl et al. (2011) for Visual scripting environment. Moreover, extra work can be done to send back the data of the optimum design option automatically to the BIM model.

Building component such as curtain wall or tilt walls cannot be handled by the tool in this level of development. Moreover, the effective shading coefficient of external shading devices SC2 was not taken into consideration. However, it is an important step to automate its calculation using the same workflow particularly in tropical climate like in Malaysia or Singapore where shading is essential for the reduction of heat gains. Cost estimation an analysis of each design option can be also done by integrating a database that contains cost information of building component. The author also argues that the provision of ETTV’s required documents for submission can be automated using a similar workflow based on BIM and VPL.

During, the development of this tool, it has been noticed that using Visual Programming to handle the BIM data can lead the user to automate time labor tasks by developing custom programs. Besides, the

same program can be developed in many ways depending on what Node/workflow the user implement. Finally, the proposed ETTV tools (scripts and workflow) can be further developed as a user-friendly plug-in for Revit using Revit API (application programming interface).

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