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Exploring Capabilities of BIM Tools for Housing Refurbishment in the UK

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ABSTRACT: Currently whole-house refurbishment for substantial energy efficiency improvement of existing housing stock is needed to achieve the targeted 80% CO2 emission reduction. As whole-house refurbishment requires a larger capital investment for lower CO2 emission, the simultaneous use of Life Cycle Costing (LCC) and Life Cycle Assessment (LCA) methodologies are recommended to generate affordable refurbishment solutions. However, two methodologies are difficult to use due to a lack of proper LCC and LCA datasets. As a response to the current problems, many researchers explore potentials in Building Information Modelling (BIM) to improve current construction practice. As a result, a BIM tool - IES IMPACT (Integrated Material Profile And Costing Tool) - has been introduced to the UK construction industry for simultaneous calculation of LCC and LCA. Thus, this research aims at examining the capability and limitation of the IES VE/IMPACT as a BIM tool for whole-house refurbishment. This research reveals that the IES VE/IMPACT is feasible for whole-house refurbishment by providing LCC and LCA information simultaneously for informed decision on refurbishment solution selection. This research shed lights on the current problems lying on the data exchange between two different BIM tools. It is revealed that additional efforts from construction professionals and industry are required to make reliable BIM objects library with LCC and LCA datasets.

KEYWORDS: BIM, Housing Refurbishment, Life Cycle Cost, Life Cycle Assessment

1. Introduction

The UK government legislated in the Climate Change Act 2008 for an 80% CO_2 reduction by 2050 against 1990 levels and it is very challenging because it could not be achieved without improving energy efficiency across all sectors of the UK economy. The similar efforts to reduce CO_2 emission have been made in South Korea as the government mandates 90% energy consumption reduction against 2009, and zero energy building from 2025 (MOLIT, 2014). UK Government mandates more efficient use of energy in all economic sectors, and in particular more attention should be drawn to the housing sector as it a major contributor to a large amount of energy consumption and CO_2 emissions (Bell and Lowe, 2000). The UK has the oldest housing stock among the developed countries as 8.5 million properties are over 60 years old (National Refurbishment Centre, 2012), and currently, 45% of total CO_2 emission in the UK is generated from the existing buildings, and particularly, existing housing stock alone accounts for 27% (Kelly, 2009). Particularly, 10% of total income of average family in South Korea is spent on energy and fuel for heating and hot water which is large amount of expenditure. Thus, it is important to improve energy efficiency and reduce carbon emission by 2025. Indeed, there is a great opportunity lying on the existing housing stock to achieve the targeted CO_2 reduction as the whole-house refurbishment can achieve significant energy savings and CO_2 reduction since all the refurbishment works will be carried on at once and many researchers agree that comprehensive whole-house refurbishment for substantial energy efficiency improvement of existing housing stock needs to be adopted to achieve the reduction target (Itard and Meijer, 2008; Summerson, 2011; Boardman, 2007; Killip, 2008; Reeves, 2009). However, the whole-house refurbishment requires a larger capital investment in the construction phase to achieve lower operational energy cost and CO_2 emission in the use phase and there is a lack of skilled personnel who can manage the trade-off

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relationship between the capital investment and energy efficiency improvement for providing affordable refurbishment solution although it is essential to maximise value for money (Menassa, 2011; Konstantinoua and Knaack, 2013; Thuvander et al., 2012). To challenge this, the UK government and researchers recommend the Life Cycle Costing (LCC) and Life Cycle Assessment (LCA) methodologies should be integrated to generate affordable refurbishment solutions and convince home occupants of high capital investment since the investment will often be compensated from reduced energy bill over a building life cycle (Bowsell and Walker, 2004; BSI, 2008; Hacker et al, 2008; HM government, 2010). For example, when the LCC is considerately planned, 60% of operational cost savings can be achieved over 30 years by investing 20% more capital cost in the construction phase (Flanagan and Jewell, 2005) and the better performance of a low carbon house can be examined in comparison with a traditional house.

2. LCC and LCA Studies in the Housing Sector

LCC and LCA methodologies are not easy to use for construction projects because proper LCC and LCA datasets for construction materials and building are not fully available at the early design phase. It is challenging to identify and retrieve the necessary data from various project stakeholders due to the fragmented nature of the construction industry (Monteiro and Freire, 2012; Finnveden et al. 2009; Flanagan and Jewell, 2005). Establishing necessary dataset for LCC and LCA is critical as informed decisions on refurbishment solutions cannot be made without them (Bribian et al., 2009). As a response to the current problems such as restricted information, construction data conflicts and unnecessary reworks due to shortage of skilled construction professionals in the housing sector, many researchers are exploring adaptable information and communication technologies (ICT) such as Building Information Modelling to improve current practice of refurbishments and generate an affordable refurbishment solution based on LCC and LCA (Basbagill et al., 2013; Grilo and Jardim-Goncalves, 2010; BSI, 2010; Redmond et al., 2012). As a result, a BIM tool named as IES VE/IMPACT (Virtual Environment/Integrated Material Profile And Costing Tool) has been developed by the Building Research Establishment (BRE), a UK government established construction organization, to calculate LCC and LCA simultaneously based on the Envest which use the specific database developed for LCC and LCA calculation in the UK construction environment. Furthermore, the use of IES VE/IMPACT is encouraged by the BREEAM (BRE Environmental Assessment Method) manual since the use of IES VE/IMPACT can provide a proper decision making criteria on whole-house refurbishment solution based on the LCC and LCA. Therefore, this research examined the capability and limitations of the IES VE/IMPACT as a tool for formulating LCC and LCA and explored feasibility of the tool for whole-house refurbishment.

3. Research Methodology

This research adopts a hypothetical case study for building simulation using BIM tool to formulate LCC and LCA of housing refurbishment alternatives. The followings are the main simulation tools: a) Autodesk Revit 2016 for basic housing model development; b) IES VE/IMPACT for formulating LCC and LCA. Autodesk Revit was selected for this research because it is one of the most widely used BIM tools for architectural design, and it is comparable with AutoCAD platform which is the most prevalent tool in the construction industry (NBS, 2014). The IES VE/IMPACT was selected due to its capability of simultaneous formulation of LCC and LCA, and particularly the database for LCC and LCA calculation is specifically developed for the UK construction environment in terms of materials and climate. Furthermore, The IES VE has been evidenced by a number of researches for energy simulation in refurbishment and has a capability to simulate all possible building energy assumptions compared to other tools (Crawley et al., 2008). Since there is no 'one-size-fits-all' solution for housing refurbishment in the UK (Jenkins et al., 2012), the tool must be capable of coping all possible alternatives and this requirement makes the IES VE relevant for this research. The following data sources have been used in conjunction with BIM tools:

- LCC and LCA - IES IMPACT dataset (BRE, 2013)
- Cost for Materials and Labour
  - SMM7 Estimating Price Book 2013 (BCIS, 2012)
- Embodied CO_2 for Materials-University of Bath

(Hammond and Jones, 2011)

- Embodied CO_2 for Construction Works–Black Book (Franklin and Andrews, 2010)

In order to generate more reliable information for LCC and LCA, data sources provided by highly-rated construction organizations have been used as inputs at the beginning to avoid a situation known colloquially as 'garbage in, garbage out'. In order to avoid biased information of BIM objects provided by third parties, the data published by well-known construction organizations are adopted. This research requires no control over behavioural events, and focuses on contemporary event which is energy vulnerable housing refurbishment using BIM in the UK to identify interactions and relationships between building information datasets asking how and why (Yin, 2003). Thus, a case study is the most relevant strategy for this research compare to other strategies such as surveys, grounded theory and action research.

3.1 Scope of Simulation

For the BIM simulation, this research first determined a detached solid wall house as a basic simulation model because this is the most energy inefficient housing type requiring immediate attention and in needs of refurbishment (National Refurbishment Centre, 2012; Kim, 2014). Once the case housing type is decided, the average housing condition data published by the UK government was used to build up a case building model in a BIM system hypothetically because the condition of solid wall housing indicates a wide range of variation in its characteristic such as year built, construction types physical dimensions, extra retrofitted measures and construction materials, which cannot be generalized. After establishment of a basic model, this research narrowed the scope of whole-house refurbishment down to the whole-house fabric refurbishment, as the fabric approach should be the first stepping stone to improve a whole-house and various researchers and construction professional organizations have argued that the whole-house fabric should be improved first rather than upgrade services or renewable energy systems (Rosa, 2012; Gupta and Chandiwala, 2010; National Refurbishment Centre, 2012; EST, 2010; Institute for sustainability, 2011, Zero Carbon Hub,

Table 1. Best refurbishment practices for whole-house fabric refurbishment

Element	Construction Type	Best Refurbishment Measure
Roof	Pitched Roof	Rafter or Loft insulation
Wall	Solid Wall	External or Internal Wall Insulation
Floor	Suspended Timber Floor	a. Underfloor Insulation (Insulation between joists) b. Surface Insulation (Insulation over the floor board)
Window	Single Glazing	Double or Triple Glazing

2012). The current refurbishment best practices for whole-house refurbishment applied for solid wall housing were identified as shown in Table 1, in order to implement refurbishment measures in a BIM simulation.

For the BIM simulation, the Fibre Glass and Expanded Polystyrene (EPS) were selected for the housing refurbishment materials because home occupants consider the initial cost as first priority when they select refurbishment measure (Park and Kim, 2014) and these materials belong to the relatively low cost range compared to other materials with high initial material cost such as Vacuum Insulated Panel and Polyurethane/Polyisocyanurate. Furthermore, only information regarding these two insulation materials is commonly available in both data sources – SMM7 and Autodesk Revit 2016 – that are widely accepted as a standardized cost.

3.2 Basic Information for House Model

The general information about the detached solid wall house in the UK is provided in Tables 2 to 4, and Figures 1 and 2 (Utley and Shorrock, 2011; Brinkley, 2008; Neufert, 2012; Riley and Cotgrave, 2008). The Gross Internal Floor Area (GIFA) was used for the calculation of LCC and LCA

Table 2. General information about a house for simulation

Information	Detached House
Number of Bedrooms	4 Bedrooms
Construction Type	Solid Brick Wall
Ventilation	Natural Ventilation
Heating (using water)	Radiator
Main Energy Source	Natural Gas
Household size (Number of people)	Single Family (2.3)
Indoor Temperature	19–23°C
Usable Floor Area	130 m^2
Ceiling Heights (Ground and First Floor)	2.7 m

Table 3. Room and space information

Information	Room	Detached House	Area (m^2)
Ground Floor	Room 1	Kitchen	16
	Room 2	Bathroom	3
	Room 3	Lobby	16
	Room 4	Living Room	15
	Room 5	Dining Room	14
First Floor	Room 6	Bedroom	12
	Room 7	Bedroom	12
	Room 8	Corridor	10
	Room 9	Bathroom	5
	Room 10	Bedroom	12
	Room 11	Bedroom	13
Total Usable Floor Area			130

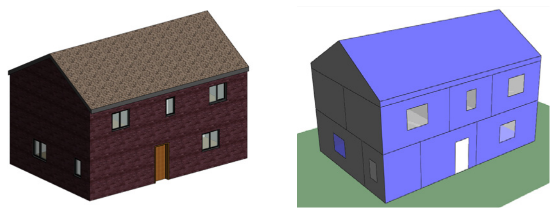


Figure 1. BIM house model
(Left: Autodesk revit, Right: IES VE/IMPACT)

and energy performance simulation.

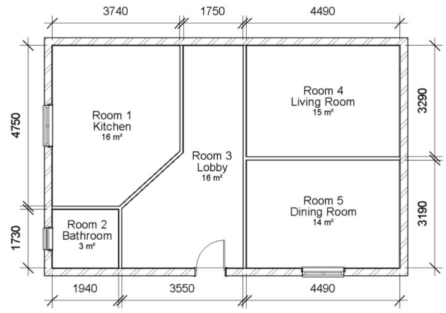
The basic house models developed by Revit and IES VE/IMPACT are visualized as shown in Figures 1. The basic model was transferred from the Autodesk Revit.

The information regarding air permeability and thermal bridging has been inherited from IES VE/IMPACT because this information cannot be generalised as a typical in-formation since various housing condition exist.

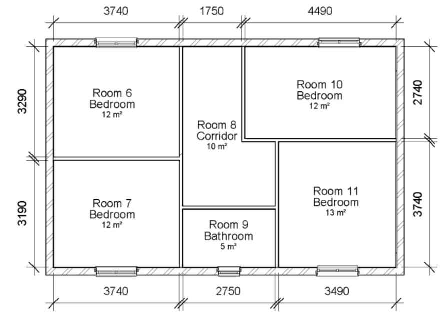
The energy simulation was conducted based on the default weather dataset of IES VE/IMPACT, which is London, and the differences in energy demand based on the location -Edinburgh, Manchester, London – from Northern area to Southern area are not significant (Mohammadpourkarbasi and Sharples, 2013).

3.3 Energy Performance Standard

Building Regulation Part L 2010, Building Regulation Part L 2013 and the Fabric Energy Efficiency Standard (FEES) will be adopted for energy simulations. The Building Regulation Part L 2010 and 2013 (BR 2010/2013) mandates the minimum energy efficiency standard for housing fabric as shown in Table 6. The FEES has been recently introduced



Ground floor (mm)



First floor (mm)

Figure 2. Floor plan for a typical detached house

Table 4. Construction information

Element	Construction Type	Component	Thickness (mm)	U-value (W/m^2k)
Roof	Pitched Roof with Timber Joist and Rafter	Roofing Tile	25	0.8
		Wood (Batten)	25	
		Roofing Felt	5	
		Timber Structure	140	
External Wall	Solid Brickwork Masonry Wall (Single Leaf)	Dense Gypsum Plaster Finish (External)	13	2.1
		Solid Brickwork	220	
Party Wall	Timber Stud Partition Wall	Gypsum Wall Board	12.5	0
		Air Infiltration Barrier	7.5	
		Gypsum Wall Board	12.5	
Floors	Suspended Timber Floor	Timber Joist Structure	225	0.7
		Chipboard	25	
		Carpet	10	
Ceiling	Generic Ceiling	Gypsum Wall Board	12.5	N/A
Windows	Double Glazing	Double Glazing, TimberFrame	6mm Glazing	2.0
Exterior Door	Wooden Door	Wooden Door	44	3.0

Note: U-Value and Thickness has referred to RdSAP 2009 (BRE, 2011)

to the Building Regulation Part L 2013 aimed at achieving zero carbon homes by 2016, which provides the maximum energy efficiency level. These energy efficiency standards

Table 5. Energy efficiency standards

Housing Element	Energy Standard (U-value)	
	BR 2010/2013 (Minimum)	FEES (Maximum)
Wall	0.3	0.15
Floor	0.25	0.13
Roof	0.2	0.13
Window	2.0	1.2
Door	2.0	1.0

have been adopted because there is no energy efficiency standard for housing refurbishment and these are the most reliable standards at present.

3.4 Data Analysis for LCC and LCA

This research has adopted a 60-year life cycle study because it was assumed that the life span for LCC and LCA studies was 60 years (ISO, 2008). The embodied CO_2 calculation adopted the cradle to site study (ISO, 2006). This research has excluded the categories including client definable costs and administrative and overheads cost in order to secure reliability of data analysis because these costs are estimated separately depending on clients' request (ISO, 2008) and there is no published standardised data available. More detail assumption about construction cost based on the NRM – Risk contingency and other costs are not included since this energy simulation is conducted under the fully controlled environment based on a hypothetical case study. The LCA study adopts a Cradle to Grave approach with the exclusion of the recycle, reuse and/or disposal stage as this contributes minimal percentages of CO_2 impact throughout the entire life cycle of a house (Rosa, 2012).

4. Research Resuls

4.1 Basic Model Transfer between BIM tools

The study found that the IFC format cannot be exchanged between Autodesk Revit and IES VE/IMPACT. The geometric arrangement is broken when IFC data is transferred to IES VE/IMPACT, while gbXML format transfer an intact model in terms of geometric information (See Fig. 1). All the geometric information is not presented in the same way although the IFC data format is supposed to be a communication channel between different BIM tools. Interoperability between different BIM tools is a critical technical barrier, yet the interoperability

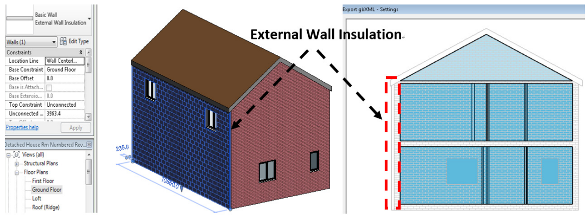


Figure 3. Construction information in revit (gbXML format)

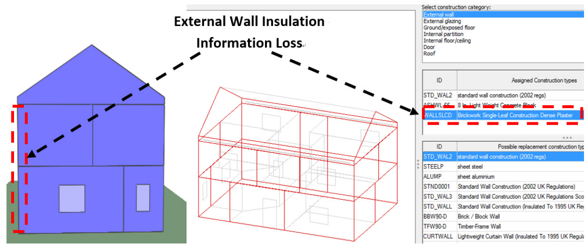


Figure 4. Construction information loss in IES VE/IMPACT

issues are still not resolved although the concept of IFC and gbXML data formats within BIM system should exchange necessary data without any conflicts. Thus, the gbXML file format is recommended for data exchange between BIM tools and IES VE/IMPACT. Although, the gbXML format transfers geometric information without distortion of a model, other refurbishment information such as insulation materials is not transferred. The missing information about the insulation materials needs to be manually entered and reviewed in IES VE/IMPACT. As a demonstration purpose, external wall insulation was used for testing data loss as shown in Figure 3 and 4.

4.2 Incomplete Dataset for LCC and LCA

The life cycle costs and CO_2 information of BIM objects should be created in a standardised format in both BIM tools -Autodesk Revit and IES VE/IMPACT. However, the Revit has its own generic material database provided by third parties, and IES VE/IMPACT also has its own dataset and data format based on the green guide to specification developed by the BRE. As a result, LCC and LCA for the construction phase, i.e. LCC for construction costs and LCA for embodied CO_2 cannot be currently calculated from the generic construction material database imported from Revit as shown in Figure 5.

LCC and LCA information can only be calculated when the materials provided by IES VE/IMPACT database are

ID2	ID3	Element	CM	Code	Rate	Quantity	Lifecycle total £
2.2.1		Upper floors (UF)		121			
		8 In. Light Weight Concrete Floor Deck [ASHIF5]	A	6	0.00	142	0.00
2.3.1		Roof structure		122			
		4 In. Light Weight Concrete [ASHRF28]	A	6	0.00	82	0.00

ID2	ID3	Element	Code	Quant	Units	Product	Constrn	Use (B1-7)	EoL (C1-4)	Ecopts	kgCO2
2.2		Upper floors (UF)	121		m²	0	0	0	0	0	0
		[ASHIF5] 8 In. Light Weight Concr...	6	142.0	m²	0	0	0	0	0	0
2.4		Stairs and ramps (STR)	139		m²	0	0	0	0	0	0
2.1		Frame	135		m²	0	0	0	0	0	0
2.3		Roof (ROO)	122		m²	0	0	0	0	0	0
		[ASHRF28] 4 In. Light Weight Con...	6	82.0	m²	0	0	0	0	0	0

Figure 5. LCC and LCA outcomes of revit construction material database (Up: LCC, Down: LCA)

ID2	ID3	Element	CM	Code	Rate	Quantity	Lifecycle total £
2.2.1		Upper floors (UF)		121			
		8 In. Light Weight Concrete Floor Deck [ASHIF5]	A	6	0.00	142	0.00
2.3.1		Roof structure		122			
		Timber trussed rafters and joists with insulation; roofing underlay; counterbat...	A	6	130.00	82	16,203.20

ID2	ID3	Element	Code	Quant	Units	Product	Constrn	Use (B1-7)	EoL (C1-4)	Ecopts	kgCO2
2.2		Upper floors (UF)	121		m²	0	0	0	0	0	0
		[ASHIF5] 8 In. Light Weight Concr...	6	142.0	m²	0	0	0	0	0	0
2.4		Stairs and ramps (STR)	139		m²	0	0	0	0	0	0
2.1		Frame	135		m²	0	0	0	0	0	0
2.3		Roof (ROO)	122		m²	0	0	0	0	0	0
		[GGOP624] Timber trussed rafter...	6	82.0	m²	21	0.68	20	6.7	47	7000

Figure 6. LCC and LCA outcomes of IES VE/IMPACT con–struction material database (Up: LCC, Down: LCA)

Family	Family and Type	Material: Name	Material: Cost (Material Cost + Labor Cost)	Material: Embodied CO2 (Cost)	Material: Area	Material: Volume	Construction Embodied CO2	Total Cost	Total Embodied CO2
		SMM7 Pitched roof members including ceiling joist. Revit does not include celing joist and Carbon book also does not include							
Floor	Floor: Roof Ceiling Joist	Structure, Timber Joist/Rafter Layer 100x150		0.71	67	6.7	4.058	£ -	276.643
Basic Roof	Basic Roof: Cold Roof - Timber	Wood Strutt 50x150	£ 6.61	0.71	90	2.26	2.184	£ 594.90	198.1646
Basic Roof	Basic Roof: Cold Roof - Timber	Structure, Timber Truss Joist/Rafter Layer	£ 12.49	0.71	90	13.56	4.058	£ 1,124.10	374.8476
Basic Roof	Basic Roof: Cold Roof - Timber	Roofing, Tile 65mm lap 100mm gauge	£ 58.40	0.45	90	3.43	37.56	£ 5,256.00	3381.9435
Basic Roof	Basic Roof: Cold Roof - Timber	Roofing Felt	£ 6.83	0.41	90	0	5.22	£ 614.70	469.8
					429	25.95		£ 7,589.70	4701.3987
Basic Wall	Basic Wall: Ext - 215 - Brick	Brick, Common cement mortar 1:3	£ 87.59	0.23	54	11.43	98.017	£ 4,729.86	5295.5469
Basic Wall	Basic Wall: Ext - 215 - Brick	Plaster	£ 10.77	0.12	54	1.08	3.29	£ 581.58	177.7896
Basic Wall	Basic Wall: Ext - 215 - Brick	Brick, Common	£ 87.59	0.23	42	9.11	98.017	£ 3,678.78	4118.8093
Basic Wall	Basic Wall: Ext - 215 - Brick	Plaster	£ 10.77	0.12	42	0.85	3.29	£ 452.34	138.282
Basic Wall	Basic Wall: Ext - 215 - Brick	Brick, Common	£ 87.59	0.23	49	10.34	98.017	£ 4,291.91	4805.2112
Basic Wall	Basic Wall: Ext - 215 - Brick	Plaster	£ 10.77	0.12	49	0.98	3.29	£ 527.73	161.3276
Basic Wall	Basic Wall: Ext - 215 - Brick	Brick, Common	£ 87.59	0.23	39	8.43	98.017	£ 3,416.01	3824.6019
Basic Wall	Basic Wall: Ext - 215 - Brick	Plaster	£ 10.77	0.12	39	0.78	3.29	£ 420.03	128.4036
					184	42.98		£ 18,098.24	18649.9721

Figure 7. LCC and LCA calculation for construction phase

used as shown in Figure 6. Loft insulation was taken as an example to demonstrate this. Thus, in order to resolve the current issues of datasets and formulate LCC and LCA information, manual calculation using MS Excel in conjunction with the various data sources is required (See Research Methodology). As a result, the LCC and LCA information can be calculated as shown in Figure 7.

LCC and LCA information for operation and maintenance phase for 60 years are calculated by MS Excel as well (Appendix 1). Although there are issues regarding interoperability and dataset, IES VE/IMPACT is capable of calculating the total amount of CO_2 emission and energy costs (Electricity and Gas) once proper construction materials are chosen. Finally, the LCC and LCA information for whole–house fabric refurbishment have been formulated as shown in Table 6.

Table 6. Life cycle study result with fibre glass and EPS

Detached Solid Wall House			Basic Model	Energy Standard	
				BR 2010/2013 (Minimum)	FEES (Maximum)
Energy Demand (KWh/yr/m^2)			209.8	52.5	39.3
CO_2 Emission (kg/yr/m^2)			84.5	43.4	41
Energy Demand (MWh/yr)			38.4	9.6	7.2
CO_2 Emission (kg/yr)			10,985	5,635.5	5,328.3
Energy Cost (£/yr)			1,150	295	224.75
Life Cycle Cost (£)	Construction Cost	Fibre Glass	41,371.35	7,065.57	10,425.47
		EPS		12,004.63	19,917.36
	Operation & Maintenance Cost	Fibre Glass	205,359.48	144,414.43	145,938.91
		EPS		148,325.25	153,668.72
	Total Cost	Fibre Glass	246,730.83	151,480.0	156,364.38
		EPS		160,329.88	173,586.08
Life Cycle Assessment (kg)	Embodied CO_2 (Cradle to Site)	Fibre Glass	34,994.9	12,197.25	23,140.86
		EPS		13,505.52	25,689.4
	Total CO_2 (Cradle to Grave)	Fibre Glass	45,979.9	17,832.75	28,469.16
		EPS		19,141.02	31,017.7

Based on the outcomes of energy simulation, it is confirmed that about 50% CO_2 emission reduction is achievable through whole–house fabric refurbishment regardless of insulation materials, and there is very slight difference between two energy standards – 49% for minimum and 51% for maximum energy standards. The research outcome is supported by the previous research results that the maximum of 50% to 60% CO2 reduction can be achieved through whole–house refurbishment with airtightness upgrades (Boardman, 2007; Construction Production Association, 2014). Since maximum 10% CO_2 reduction can be achieved through airtightness only, which is calculated by BIM tools without any modifications in this research while the existing research includes maximum airtightness, this research outcomes can be considered reliable. Energy cost saving can be achieved about 80% when the maximum energy standard is adopted, and 74% energy cost saving is achievable for the minimum energy standard adoption. Based on the LCC and LCA outcomes, the fibre glass is the most affordable construction materials for whole–house refurbishment compared to the EPS.

5. Limitations of the Research

There are various types of refurbishment materials available. However, this research was able to examine only limited types of refurbishment materials such as fibre glass and EPS due to the limited standardised material datasets for LCC and LCA calculations. In order to conduct more in-depth comparative analysis of LCC and LCA depending on more different types of refurbishment materials, more BIM objects or library with reliable LCC and LCA datasets are required. In addition, possible combination of whole-house refurbishment alternatives including mechanical and building service systems need to be examined in conjunction with whole-house fabric refurbishment. Furthermore, actual housing information for the BIM simulation is limited, and as a result, hypothetical housing information based on the UK government data was used instead. It would be much beneficial and accurate for homeowners, occupiers and construction professionals to explore refurbishment solutions with realistic case study with an existing house.

6. Conclusion

The purpose of this study is to seek the way in which informed decision is made based on the LCC and LCA results through a case study adopting IES VE/IMPACT, and to explore capabilities and limitations of IES VE/IMPACT utilization as a BIM tool for a whole-house refurbishment project. As a result, this research reveals that the IES VE/IMPACT is a feasible BIM tool for whole-house refurbishment by providing LCC and LCA information simultaneously for informed decision on refurbishment solution selection. More importantly, this research reveals limitations and barriers in utilising BIM tools for housing refurbishment. In particular, the seamless information exchange between two different BIM tools – Autodesk Revit and IES VE/IMPACT – is not yet achievable. For geometric data exchange, the gbXML format is recommended for IESVE/IMPACT rather than IFC format. In addition, it is revealed that cost and thermal performance data is not transferred from Autodesk Revit to IES VE/IMPACT. In order to develop a house model with accurate information of LCC and LCA, inefficient process such as reviewing transferred model and re-entering construction information is inevitable. Furthermore, LCC and LCA information for types of refurbishment different materials are not readily available in the IES VE/IMPCAT. In order to calculate accurate LCC and LCA information, manual information feeding and calculation of LCC and LCA using MS Excel in conjunction with IES VE/IMPACT is required. Finally, the differences of LCC and LCA depending on refurbishment materials are identified. Therefore, it is found out that additional efforts from construction professionals and industry are required to standardise common BIM objects library with LCC and LCA. Without reliable dataset about construction materials in terms of cost and CO_2 performance of housing elements, the application of BIM concept cannot add more value to the customers and the construction industry. Thus, the preparation of detailed BIM objects with required dataset such as accurate as-built condition and cost information is revealed as a critical step for utilization of successful BIM tools for housing refurbishment. This research is expected to provide an opportunity for construction professionals and industry to enhance understanding of BIM-enabled environment and IES VE/IMPACT for housing refurbishment in the UK context. Although this research is confined to the UK housing sector, the implication of use of BIM tools for housing refurbishment should provide valuable insights and lessons learned for Korean construction professionals to attempt to use proper BIM tools for their practice. Future research should focus on exploring further in the BIM dataset for practical implementation of a BIM system on housing refurbishment with a realistic case study.

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