Emerald Journal of Facilities Management

Housing Information Modelling for BIM-embedded Housing Refurbishment

Journal:	*Journal of Facilities Management*
Manuscript ID	JFM-09-2016-0037.R1
Manuscript Type:	Research Paper
Keywords:	BIM, Housing Refurbishment, Information Management, Construction Technology, Housing, Process Management

Housing Information Modelling for BIM-embedded Housing Refurbishment

Abstract

Purpose – The aim of this research is to identify BIM input datasets within a BIM-embedded housing refurbishment process and enabling construction professionals to utilize BIM as an information management platform for housing refurbishment projects.

Design/methodology/approach – A hypothetical case study using BIM tools for a housing refurbishment project is adopted to identify BIM input datasets to create a housing information model within a BIM system. Reliability of the research outcome is examined by conducting a comparative analysis between existing and simulated research outcomes.

Findings – This research identifies essential BIM input datasets during the early design phase. The importance of a well-integrated housing information model containing accurate as-built condition, cost and thermal performance information is essential to utilize BIM for housing refurbishment. BIM can be feasible for housing refurbishment when an information enriched housing information model is constructed. Furthermore, the capability of BIM that can enable key project stakeholders to determine the most affordable refurbishment solution among various alternatives is identified since BIM can provide reliable cost estimations and thermal performance of refurbishment alternatives at the early design stage.

Research limitations/implications – The examined refurbishment processes and input datasets are confined to the early design phases since BIM use for housing refurbishment is limited.

Practical implications – This research will contribute to utilize BIM for housing refurbishment by providing essential BIM input datasets and BIM-embedded refurbishment processes.

Originality/value – This research reveals primary housing information datasets and BIM-embedded refurbishment processes at the early design phase.

Keywords: BIM, Housing Refurbishment, Information Management, Construction Technology, Housing, Process Management

Paper type: Research Paper

Introduction

The UK government legislated the Climate Change Act 2008 aiming at 80% CO_2 reduction by 2050 against 1990 CO_2 emission levels. In particular, the UK possesses the oldest housing stock among developed countries with 8.5 million properties over 60-years-old (EST, 2007). It has been estimated that 600,000 houses per each year need to be refurbished from 2012 to achieve the 80% reduction in time (BRE, 2010), and housing accounts for 27% of the total UK CO_2 emissions (Kelly, 2009), and 87% of those housing responsible for the 27% CO_2 emission will still be standing in 2050 (Boardman, 2007). Thus, the housing sector should play a key role in improving energy efficiency, and housing refurbishment is expected to provide substantial contribution to CO_2 reduction since refurbishment is considered a better option than demolish-and-rebuild because of the financial and environmental benefits (Riley and Cotgrave, 2011). Currently, partial refurbishment options with relatively low upfront costs such as cavity wall insulation and loft insulation have been mainly adopted (WWF, 2008). However, the partial refurbishment can achieve only limited CO_2 reduction by 25-35% (McMullan, 2007) and as a result, there is increasing consensus amongst researchers that comprehensive whole-house refurbishments are required to achieve the reduction target in the housing sector (Boardman 2007; Killip 2008). In particular, the UK government has placed emphasis on the importance of a whole-house refurbishment and released the whole-house refurbishment strategy named as the 'Great British Refurbishment' aiming at refurbishing 80% of the housing stock by adopting whole-house refurbishment approach by 2020 (DECC, 2009). The key benefits of adopting the whole-house refurbishment are significant amount of reduction of CO2 emission and energy cost savings through the lifecycle (DECC, 2009; Killip 2008) because an entire house will be refurbished in a systematic way by considering various refurbishment options and building information including housing condition data and energy performance.

However, refurbishment solutions are proposed at the end of design phase in the current refurbishment process when flexibility of refurbishment solutions and opportunities to explore various refurbishment alternatives are significantly limited (Ma et al, 2012; Thuvander et al., 2012). As a result, many researchers point out the absence of an integrated decision-making framework to estimate the financial and environmental impact of a refurbishment solution from the early design stage. Furthermore, they emphasise the importance of proper decision-making and the necessity of using proper information and communications technology (ICT) tools that support construction professionals considering various refurbishment solutions at the early design phase (Froese, 2010; Crawley et al., 2008; Eastman et al, 2011; Hannele et al., 2012). In response to current issues and limitations, many researchers state the potential and importance of Building Information Modelling (BIM) for informed decision making on refurbishment solutions at the early design stages. It is because BIM is capable of enhancing collaboration among stakeholders, and the improvement in integration of project information by exploring and comparing various refurbishment alternatives at the early design stages can lead to better refurbishment solution (Basbagill et al., 2013; HM Government, 2012). Therefore, this research aims at identifying essential input data for housing refurbishment at the early design phase and exploring how to integrate this information into the BIM environment through a BIM-embedded housing refurbishment process to seek a financially and environmentally affordable refurbishment solution by a case study with a BIM simulation.

Challenges in Housing refurbishment

It is essential to cope with diverse information such as effectiveness of refurbishment measures, financial feasibility and environmental impact simultaneously from the early design phase (Killip, 2008), when there are more alternatives to select the most affordable refurbishment solution. Furthermore, a refurbishment project has two major unique characteristics compared to new build housing: a) Higher Risk (Doran et al., 2009; Burton, 2012), and b) Complex Decision Making Process (Menassa, 2011; Thuvander et al., 2012), which requires more considerate planning and data management for a refurbishment solution. Indeed, a holistic approach to refurbishment solutions can achieve 60% of operational cost savings over 30 years by investing only 20% more capital cost in the construction phase (Flanagan and Jewell, 2005). In order to overcome ineffective collaboration and integration of construction information and determine the most affordable refurbishment solution, various researchers proposed refurbishment model or strategy emphasizing the importance of availability of possible refurbishment alternatives and capability of conducting comparative analysis among various refurbishment options. Juan et al. (2009) proposed a generic on-line algorithm-based decision supporting model for selecting refurbishment solutions based on various criteria. Similarly, Jenkins (2012) proposed a step-by-step refurbishment measure adoption strategy named the TARBASE (Technology Assessment for Radically improving the Built Asset baSE) domestic model. Researchers argue that there is no universal refurbishment solution for the UK housing stock, and multiple variants such as fabric, service and renewable energy systems must be combined with considerate CO_2 reduction analysis. Rysanek and Choudhary (2012) and Konstantinoua and Knaack (2013) suggested whole-building simulation model with the list of all the potential refurbishment options that can examine various refurbishment alternatives at the early design phase prior to determining a final refurbishment solution. Both proposed model emphasize the granularity of information regarding refurbishment materials and options that can be examined and tested at the early design stage.

Consequently, Rysanek and Choudhary (2013) assert that refurbishment projects should utilize a capable tool to support informed decision making among various refurbishment alternatives, while considering multiple criteria such as the implication of cost and the environmental impact. According to Schneider and Rode (2010), 50% of possible refurbishment alternatives that can render better outcomes of refurbishment are neglected due to a lack of collaboration among key project stakeholders at the early design stage. Poor decision making at the early design phase results in significant changes in the time and cost of a project which leads to reworks, and the cost for reworks and changes become five times larger as changes occur at later phases (Doran et al., 2009). Indeed, Thuvander et al. (2012) argue the necessity of a decision-making tool that can conduct a brief comparison between potential refurbishment measures to prune unfeasible refurbishment solutions at the early design stage. This suggested tool can enable construction professionals to focus more on feasible refurbishment measures and develop refurbishment solutions further without considering unnecessary measures.

Value of BIM in Housing refurbishment

Through the literature review, it is identified that various researchers commonly emphasize the importance of proper decision-making at the early design phase, and the necessity of using proper tools - whether software is used or not - that can support construction professionals considering various refurbishment solutions (Ellis et al., 2006; Horowitz et al., 2008). Crosbie et al. (2011) pointed out the occurrence of a broken feedback loop after the design phase. In general, a BIM model is not updated by incorporating feedback from any changes made during the construction phase, and researchers argue that the energy performance of a building in the use phase can only be improved by conducting an energy performance simulation based on the actual building operation information. However, the current construction practice cannot manage knowledge gained throughout a project life cycle, and often the lessons learned from previous projects are not used for future projects (Lindner and Wald, 2011). To provide more accurate energy performance simulation results for a BIM model, researchers proposed the IntUBE (Intelligent Use of Buildings' Energy Information) system designed to obtain actual building information throughout a building life cycle, and the restored data will be used to improve building design, energy performance and refurbishment in the future. This system has the capability to restore various information regarding building attributes and actual building performance, allowing design professionals to generate more realistic BIM design alternatives. It enables clients to make informed decisions on design selection at the early design phase. If a BIM model is built based on actual housing attributes retrieved from actual housing conditions and energy performance, a whole-house refurbishment solution will be more realistic and feasible, and customers can make better decisions.

Currently, many researchers argue the potentials of BIM for formulating LCC and LCA simultaneously at the early design stage (Ma et al., 2012; Monteiro and Freire, 2012; Basbagill et al., 2013). Although there have already been various tools to calculate LCC and LCA, BIM has distinct merits in that it can analyse the cost and energy performance of refurbishment measures based on 3D models. Potentially the use of BIM tools can improve the overall information flow throughout a project life cycle and facilitate collaborative efforts among project participants to integrate diverse construction information to make an informed decision at the early design phase (Eastman et al, 2011; Hannele et al., 2012; HM Government, 2012). Particularly, in a BIM environment, a single data source is built into a 3D model based on a parametric design, and project stakeholders are able to exchange instant feedback simultaneously on designs and construction methods without manual re-entry of construction information. Chung et al. (2013) emphasize the importance of pre-developed BIM datasets and libraries that empower design and construction professionals to minimise unnecessary reworks pertained to capturing quality datasets during the design phase. In order to achieve the reconciliation among various stakeholders and integrate abundant building information, an information management and repository platform, which is Common Data Environment (CDE), needs to be essentially established (HM Government, 2015, BSI, 2013). Indeed, the BIM standard PAS 1192 documents explicitly emphasize the importance of establishment of the CDE before actual BIM model creation (BSI, 2015). Chaves et al. (2016) also reveal that BIM can minimize disruption to users during housing refurbishment.

Despite the value of BIM utilization in housing refurbishment, current housing refurbishment practices to estimate the outcome of refurbishment projects rely on simple cost estimation tools and the experience of construction professionals (Kreith, 2008). This is because small and medium sized enterprises are mainly involved in the housing sector, which contribute 92% (250,000 firms) to the total UK construction industry employment (ONS, 2014), and the BIM adoption in SMEs was identified as only 13% as of 2010 (Hamil, 2010). The use of BIM in SMEs is limited because there are no practical guidance, standardised BIM objectives and protocols to utilise BIM, and the investment in BIM systems is not economically feasible (Sebastian et al., 2009; NBS, 2016). However, it is a challenging task to establish an integrated information repository platform for housing refurbishment due to the integrity of a BIM model and availability of BIM objects, which are capable of reflecting the accurate housing conditions (Sigmund, 2016; Dixon and Wilkinson, 2016). Although a BIM system is operated based on a 3D parametric BIM object-based design and management platform, accurate BIM objects and peripheral information that are essential to develop a BIM model congruent to an as-built house are not either readily available or easily retrieved from an existing building. For example, it is challenging to indicate the existing openings for windows because they are usually distorted in its shape as static loads press them over the years. Thus, the CDE establishment can achieve continuous improvement on decision-making processes as all information can be stored in a single repository and retrieved based on single-source data (Froese, 2010; Eastman et al, 2011). Also, the preparation BIM objects for housing refurbishment is a crucial stepping-stone to construct an as-built house model in a BIM system (Kim and Park, 2016). Thus, this research focuses on identifying essential BIM input data for the CDE and a BIM-embedded housing refurbishment process that enable construction professional to make an informed decision on housing refurbishment solution at the early design phase using BIM.

Research Methodology

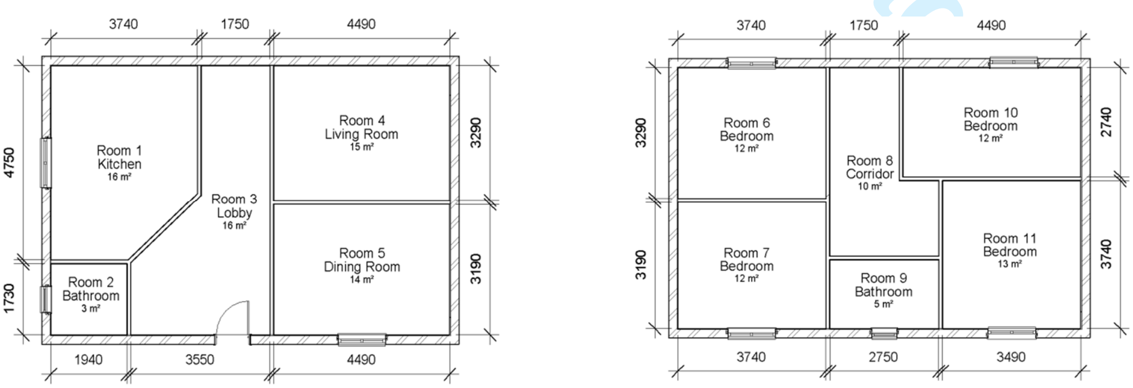
According to Yin (2003), a case study focuses on a contemporary event and answers to 'how' and 'why' questions. As this research explores why whole-house refurbishment should be implemented and how house information dataset can interact and relate in a BIM environment, a case study is adopted to answer the following questions: 'why are different types of data required throughout the process?' and 'how can the required information be integrated and utilised in a BIM system?'. In order to obtain an in depth insights of a particular situation, which is housing refurbishment utilizing BIM as a decision making tool, a case study has been adopted rather than a statistical survey. Furthermore, as this research focuses on practical implication to test if a hypothetical model can actually work in the real world situation, case study is more relevant research strategy compared to grounded theory or experiment. Thus, this research adopted case study as a research strategy.

An actual model simulation with BIM datasets is conducted and a sample house model is examined by utilising relevant BIM tools: Autodesk Revit and Integrated Environmental Solutions Virtual Environment (IES VE). Both tools are the most common and verified tools because Autodesk Revit is currently prevalent tool in the UK compatible with AutoCAD platform that is still widely utilised in the UK construction sector (NBS, 2016). The IES VE has been evidenced by a number of researchers for energy simulation in refurbishment and has a capability to simulate all possible building energy assumptions and transfer a BIM model congruently without geometrical distortion compared to other tools (Jankovic, 2012; Murray et al., 2012; Crawley et al., 2008). Furthermore, IES VE utilize a UK specific construction material dataset named Envest II developed by Building Research Establishment (BRE), a UK based construction professional organization, aiming at conducting a comprehensive assessment of the environmental impact and whole life costs of a building in the UK construction context. Finally, since there is no 'one-size-fits-all' solution for housing refurbishment (Jenkins et al., 2012), the capability of coping all possible refurbishment alternatives is essentially required for a tool, and consequently this requirement makes the IES VE highly relevant for this research.

For a housing type, a solid wall house is determined since it is the most vulnerable to energy efficiency and in needs of refurbishment, which requires immediate attention (National Refurbishment Centre, 2012). In order to develop a basic 3D model for simulation, the average housing condition data published by the UK government was used as the solid wall housing indicates a wide range of variation in its condition such as year built, construction types physical dimensions, extra retrofitted measures and construction materials (Jenkins et al., 2012). This research follows the refurbishment project phases provided by the Institute for Sustainability and the work stage provided by the RIBA (Royal Institute of British Architects). The RIBA has outlined a plan of work (2013) that has been widely adopted in the UK construction industry as a generic construction phase, and recently the Institute for Sustainability, which has a partnership with the Technology Strategy Board (TSB), published 'Low Carbon Domestic Retrofit' guide to provide a sustainable housing refurbishment guide (Institute for Sustainability, 2011). In particular, the TSB is a UK public body operated by the government coordinating 'The Retrofit for the Future' program by advocating the whole-house refurbishment. Thus, the work stages and phases by two professional bodies are adopted for a BIM simulation process. Prior to presenting the identified BIM datasets, this research checked reliability of BIM simulation result by conducting a comparative analysis with the previous research by a UK based professional consultancy on energy efficiency, which is Energy Saving Trust (EST, 2009). The BIM for housing refurbishment has been rarely studied and there is no precedent case study except the one by EST. Moreover, since both studies adopted whole-house refurbishment and used a solid wall house with the same U-values, the case study of EST is used for reliability check to confirm whether the datasets can draw the similar pattern in both research outcomes.

Basic BIM Model: Detached Solid Wall House

The information of a basic BIM model for simulation is provided as shown in Figure 1 and Table 1 (Riley and Cotgrave, 2008, Utley and Shorrock, 2011, Neufert, 2012).



Ground Floor First Floor

Figure 1. Floor Plan for Basic BIM Model

Table 1: Detailed Construction Information

Element	Construction Type	Component	Thickness (mm)	U-value (W/m^{2}k)
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	
Windows	Double Glazing	Double Glazing, Timber Frame	6mm Glazing	2.0
Exterior Door	Wooden Door	Wooden Door	44	3.0

Energy Standards for BIM simulation

Currently, Building Regulation is mandated, and particularly Building Regulation Part L should be considered and complied. The Building Regulation Part L 2010 and 2013 (BR 2010/2013) mandates the minimum energy efficiency standard for housing fabric. In addition to the minimum standard, Building Regulation Part L 2010 and 2013 advise construction professionals to consider further energy efficiency by providing a notional energy efficiency standard aimed at a 25% CO2 reduction. The Fabric Energy Efficiency Standard (FEES) has been recently introduced to the Building Regulation Part L 2013 aimed at achieving zero carbon homes by 2016, which is the most energy efficient standard available at present introduced specifically for zero carbon in existing housing to achieve the required 80% CO_2 reduction. Thus, these energy standards have been adopted for energy simulation in this research since these are the most proper energy standards that need to be considered when a refurbishment solution is planned to improve energy efficiency and carbon performance of an existing house.

Result and discussion

Essential BIM Input Data and Refurbishment Process

This research examines the early refurbishment phases, ‘Assessment’ and ‘Design’ phases, to identify essential BIM input dataset for each work stage. As a result, the essential BIM input datasets and a BIM-embedded housing refurbishment process map are identified and described as seen in Table 2 and Figure 2.

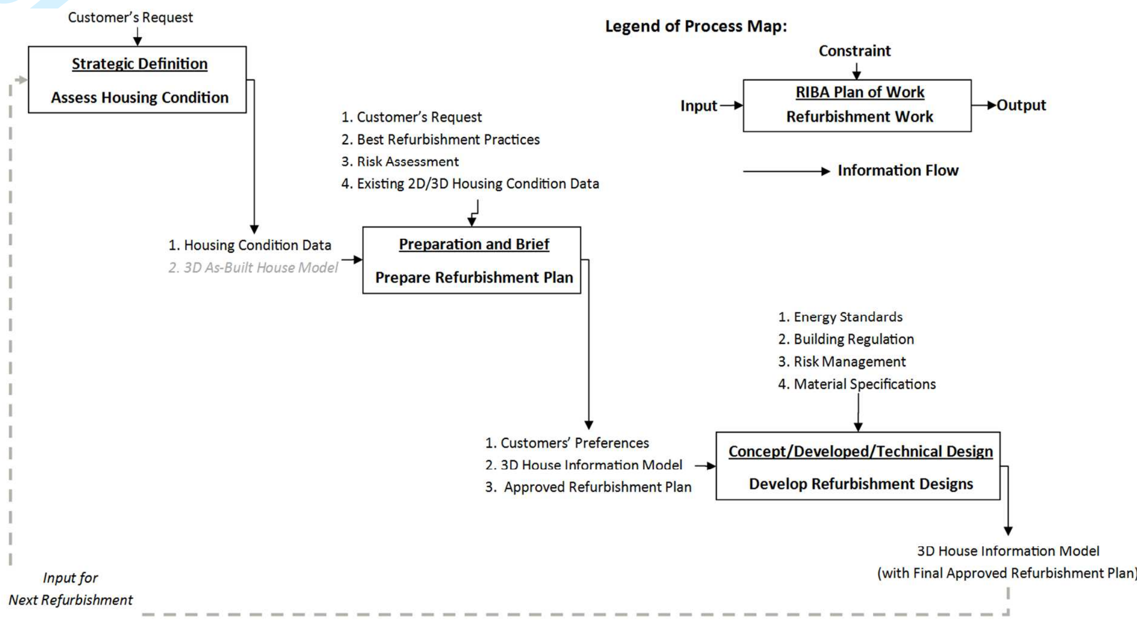


Figure 2. BIM-embedded Housing Refurbishment Process Map

The BIM-embedded processes and input datasets for each work stage have the unique opportunity to provide a substantial contribution to BIM use for housing refurbishment by supporting key project stakeholders to coordinate the right construction information at the right time with the right sequences based on the processes and input dataset. Furthermore, construction professionals can determine the most financially and environmentally refurbishment solution at the early design stage by comparing various refurbishment alternatives.

Table 2: BIM Input Datasets for the Early Design Phase of Housing Refurbishment

Phase	Work Stage	BIM Input Dataset
Assessment	Strategic Definition	• Housing Type and Year Built (As-Built data) • Dimensions: a) Floor areas (Floor Plans) b) Storey heights c) Building fabric elements (wall, roof, floor, window and door) • Detailed Construction Information: a) Construction Types for all fabric elements b) Material Types for External windows and doors c) U-values for all housing elements d) Additional Extension or in-situ construction • Occupancy data, and SAP rating data

	Preparation and Brief	• Customer's Preferences (Park and Kim, 2014): a) Refurbishment Priorities of House Element b) Decision Making Factors for Selecting Refurbishment Options c) Refurbishment Materials • 3D House Information Model • Planned Whole-house Refurbishment Solution (Combination of Refurbishment Options)
Design	Concept Design Developed Design Technical Design	• Building Regulations • Energy Standards: a) Building Regulation 2010/2013 Part La (Minimum) b) Building Regulation 2010/2013 Part La (Notional) c) Fabric Energy Efficiency Standard (Maximum) • Refurbishment Material Specification: a) Attributes of Materials (Thickness and Types) b) U-value for Windows including frames and secondary/tertiary glazing system e) Initial material and Installation costs • Risk assessment for continuity of insulations

At the assessment phase, there are seven major BIM datasets - Housing Type and Year Built; Dimensions; Detailed Construction Information; Occupancy and SAP rating data; Customer's Preferences; 3D House Information Model; Planned Whole-house Refurbishment Solution – are identified as shown in Table 2. More detailed explanation for each dataset will be followed.

Assessment Phase 1 – Strategic Definition Stage

During the assessment phase, occupancy data is required to find out internal temperature and heating timing settings and SAP rating data will be used to set up a current energy use baseline for developing post-refurbishment energy use. Other housing condition data such as geometric and dimensional information or the 3D As-Built House Model (only if 3D laser scanner is utilized) will become the inputs to develop a 3D Housing Information model at the next stage, Preparation and Brief Stage. In the process map, 3D As-Built House Model is grey since 3D laser scanner might/might not be used for housing refurbishment in the current practice.

Assessment Phase 2 – Preparation and Brief Stage

Design professionals and/or BIM professionals who provide a BIM service are responsible for creating a Housing Information Model based on the housing condition data. A 3D Housing Information model contains parametric information that all the information related to building elements are already embedded into the objects. Consequently, all the essential BIM input datasets are embedded in each BIM objects and assembled as one whole Housing Information Model as shown Figure 3.

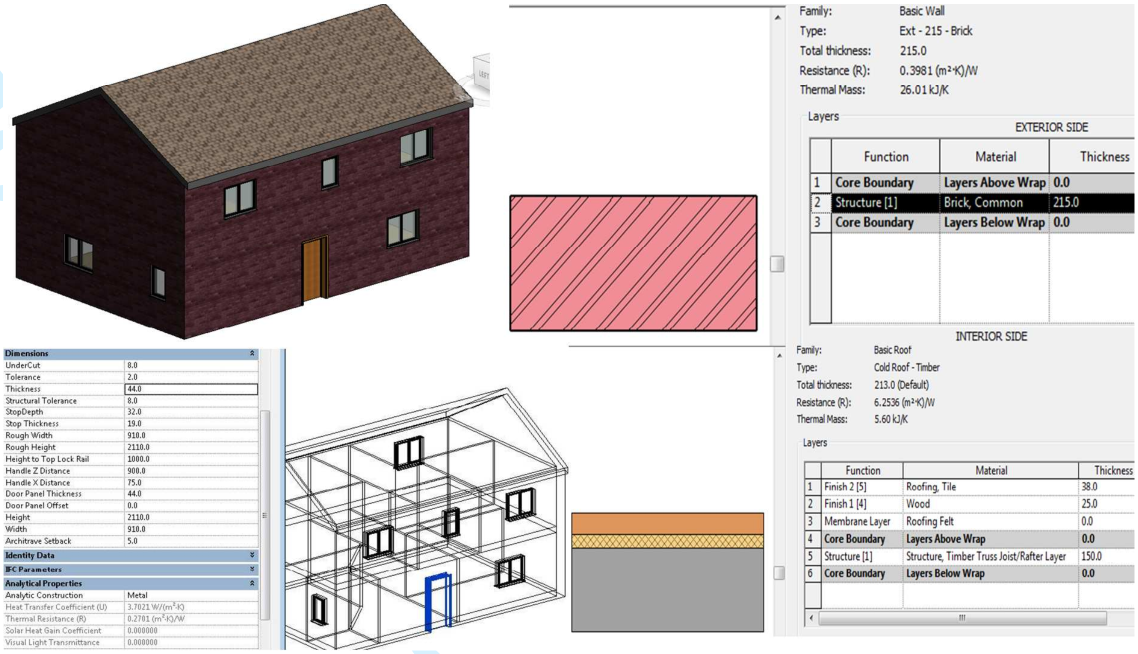


Figure 3. 3D Housing Information Model (top left) and each BIM object information

These provide a snapshot of each housing element with its parametric information such as dimensions, U-values and construction details including as-built data sets of an existing house. The dimensions of elements are automatically changed according to the modification by refurbishment designs and updated through a project life cycle. As a concept of BIM the parametric design principle is applied and relevant information on material quantities, material costs, U-value and embodied CO_2 are instantly updated when they are available without any effort from the quantity surveyor. The material take-off function can simply create a bill of quantities in a customised table as shown in Figure 4. Although a BIM tool can provide an efficient and effective material take-off function, this cannot be achievable without proper BIM datasets that enable a BIM tool to formulate various quantity and cost related information. For example, when a housing model is constructed using basic Revit objects with empty information, the intended information cannot be formulated and the columns in Figure 4 – Material Cost and Total Cost – will be generated empty. Thus, it is essential to establish the CDE with proper BIM datasets to avoid a situation known colloquially as 'garbage in, garbage out'.

Level	Family and Type	Material: Name	Material: Cost	Material: Area	Material: Vol	Total Cost
Ground Floor	Floor: Timber Suspended Floor	Wood Sheathing, Chipboard	£24.56	67 m²	1.47 m³	£1645.14
Ground Floor	Floor: Timber Suspended Floor	Structure, Timber Joist/Rafter Layer	£7.79	67 m²	15.07 m³	£521.81
First Floor	Basic Ceiling: Generic	Gypsum Wall Board	£28.04	65 m²	0.00 m³	£1810.55
First Floor	Basic Ceiling: Generic	Gypsum Wall Board	£28.04	64 m²	0.00 m³	£1807.19
First Floor	Floor: Timber Suspended Floor	Wood Sheathing, Chipboard	£24.56	67 m²	1.47 m³	£1645.14
First Floor	Floor: Timber Suspended Floor	Structure, Timber Joist/Rafter Layer	£7.79	67 m²	15.07 m³	£521.81

Figure 4. Material Take-off Function in BIM

This function meets the needs of effective housing refurbishment since BIM enables construction professionals as well as customers to determine the most affordable housing refurbishment solution at the early design stage by estimating and comparing cost and carbon performance of a refurbished house. Furthermore, the BIM capability of early collaboration based on BIM objects meet the requirements of Level 2 BIM maturity mandated by the UK government from 2016. However, currently it is common that housing condition data is developed through 2D drawings rather than a 3D model (NBS, 2016). As shown in Figure 5, existing CAD files may need to be imported into the BIM software as the 2D or 3D CAD data has no parametric information and so has less capability. For example there would be no instant update information like BIM tools. The imported 2D or 3D CAD data can be converted to a 3D BIM system since the basic information in the drawings can be used to reconstruct a floor plan and dimensions of each space in a house. Housing data imported from 3D CAD is presented in a 3D manner in the BIM system. However all the elements, structures and service systems are presented as one mass without parametric information such as dimensions, thickness and thermal information because they are not object-oriented and cannot be separately converted into a BIM object with parametric information. Consequently, a table of material take-off produced from 3D CAD information is empty due to demerits of using 2D or 3D CAD system.

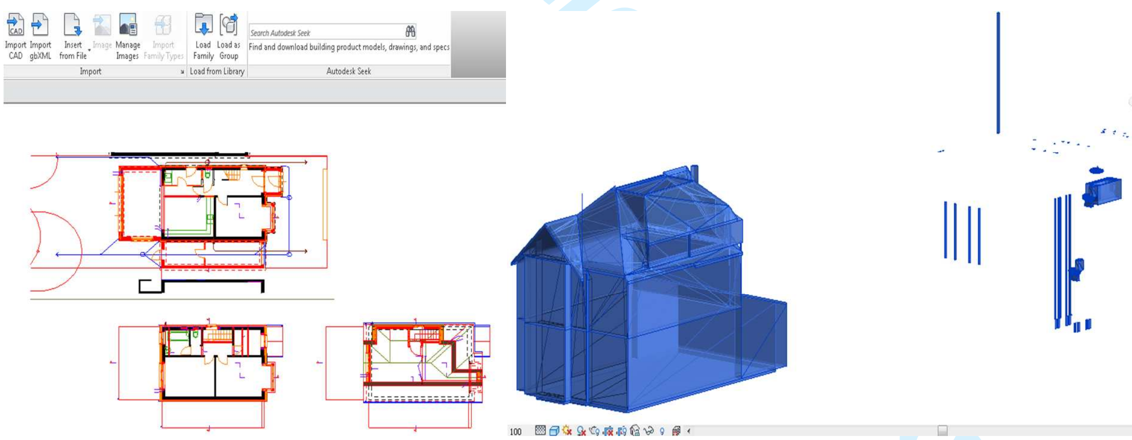


Figure 5. Result of Importing CAD file format into BIM system (Left: 2D CAD, Right: 3D CAD)

At the design phase, there are four major BIM datasets – Building Regulations; Energy Standards; Refurbishment Material Specifications; Risk Assessment for Continuity of Insulations - are identified as shown in Table 2. More detailed explanation for each dataset will be followed.

Design Phase 1– Concept Design Developed, and Technical Design

After the assessment phase, various refurbishment alternatives need to be explored and compared using 3D house information model. When different refurbishment options are examined, the Building Regulations and associated risks with refurbishment options must be considered for the planning permission and risk mitigation. In particular, the risk assessment for continuity of insulations between two different house elements, e.g. Wall and Floor junction, should be considered because the energy efficiency will be lower than planned due to loss of airtightness if continuity of insulations is not secured. In addition, moisture and cold bridging that cause mold growing after refurbishment must be considered. Housing elements such as walls and roofs are vulnerable to moisture after refurbishment because the insulation material can block natural ventilation of the elements. Therefore, construction professionals must carefully plan a combination of refurbishment measures to achieve a planned energy performance of a refurbished house.

Design Phase 2– Developed and Technical Design

Once a refurbishment solution is generated, Housing Information Model needs to be examined by different energy efficiency standards. As this research adopts two BIM tools – Autodesk Revit and IES VE, all the geometric information is transferred from Revit to IES VE to achieve efficiency and eliminate unnecessary reworks and human errors such as mistyping geometrical and thermal performance information. The study found that the International Foundation Class (IFC) format cannot be exchanged between Autodesk Revit and IES VE because the geometric arrangement is broken when IFC data is transferred to IES VE, while Green Building XML (gbXML) format transfer a congruent model in terms of geometric information as shown in Figure 6.

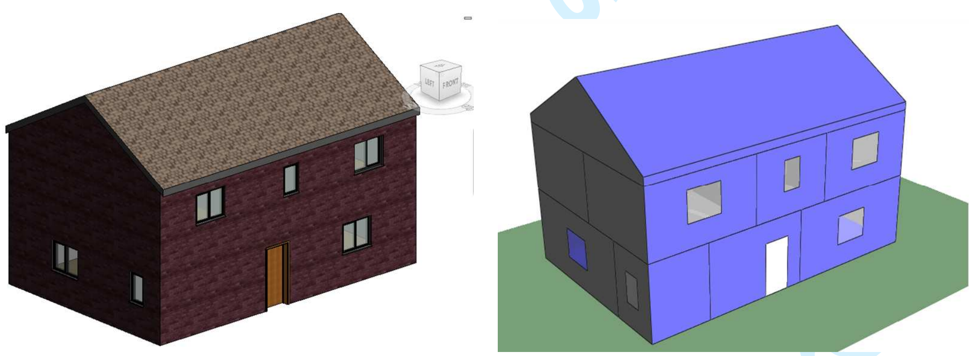


Figure 6. Basic Model Import Result using gbXML format in IES VE (Left: Autodesk Revit, Right: IES VE)

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 has been recognized as a critical technical barrier (Redmond et al., 2012), yet the interoperability issues are still not entirely resolved although the concept of IFC and gbXML data formats within BIM system should exchange necessary data without any conflicts. Furthermore, this finding provides important insight regarding non-graphical information exchange in the Open BIM environment, which is essence of Level 3 BIM maturity promoted by the UK government, since IFC and Construction Operation Building Information Exchange (COBie) should play a key role as a seamless data exchange medium regardless of types of BIM tools. Thus, further studies on the interoperability issues related to IFC, gbXML and COBie are required.

3D Housing Information Model (As-Refurbished Model)

The housing information model used for housing refurbishment will continue to retrieve actual maintenance and operation information throughout a housing life cycle, and eventually the restored data will be utilized when another refurbishment is required in the future. Jung and Joo (2011) also argue the same point regarding a BIM data repository, that practical BIM implementation requires proper BIM data in conjunction with a clear framework. The research emphasized that the importance of data properties embedded in a BIM object or model is essential for a BIM-enabled project. Based on the geometric and non-geometric data in a BIM's objectives, a BIM model can generate knowledge for an entire building in terms of project time, cost and sustainability. As a new build housing project will secure the BIM model from the outset, facility management (FM) will provide the complete BIM model enriched with data and information about as-built housing. As FM utilizes this BIM model throughout the life cycle of a house, this will be the living and growing database for future refurbishment. BIM was not seen as relevant to work on existing buildings until recently when laser point-cloud surveying emerged as a rapid way to capture existing buildings and landforms into digital format. Currently, the importance of Big Data is getting increasing attention, and Construction Industry Council (CIC, 2013) envisages its use, which is captured from the use phase of a building, for future construction and refurbishment projects.

Reliability Check for BIM Simulation Outcome

The expected energy efficiency and carbon performance improvement of a refurbished house depending on energy standards are examined and presented in this section. The reduction rates for energy demand for heating and energy cost for heating indicate high similarity, while the amounts of CO2 emission indicate 42% difference as shown in Table 3. It is mainly because the EST included hot water and secondary heating while this research only included hot water. Furthermore, the EST included building service upgrades such as mechanical ventilation and efficient lightings while this research utilised default building service setting available in BIM tools. It is found out that different heating sources and level of building service upgrades are important measures for energy efficiency and CO2 reduction in housing refurbishment although this research did not include any specific building service upgrades as it is beyond this research scope. Although this research outcome, which is 52% reduction of CO2 emission, does not reflect the building service upgrades and the secondary heating, the research outcome is supported by the previous research results that the maximum of 60% CO2 reduction can be achieved through whole-house refurbishment without building service upgrades (Boardman et al., 2005; Construction Production Association, 2014).

Table 3: Reliability Check for BIM Simulation Outcome

Description	EST House (Floor Area: 104 m2)		Basic Case House (Floor Area: 130 m2)	
	Pre-Refurbishment	Post-Refurbishment	Pre-Refurbishment	Post-Refurbishment
Roof U-value	2.30	0.10	2.30	0.10
Wall U-value	2.10	0.18	2.18	0.18
Floor U-value	0.74	0.15	0.70	0.15
Window U-value	4.80	1.50	4.83	1.54
Door U-value	3.00	1.00	3.03	1.03
Energy Demand for Heating (kWh/yr/m2)	597	73 (89% Reduction)	209.8	40.8 (80% Reduction)
Energy Cost for Heating (£)	1,498	251 (83% Reduction)	1,150	225 (80% Reduction)
CO2 Emission for Heating (kg/yr/m2)	84.9	5.2 (94% Reduction)	84.5	40.6 (52% Reduction)

Thus, the BIM dataset identified through this research have shown its relevance for whole-house refurbishment and the simulation results show the significant energy cost savings and CO2 emission reduction after refurbishment in comparison with the previous research data. Even though the building system upgrades and other heating source like renewable energy are out of scope in this research, they should be taken into account as possible options for energy efficiency, cost savings, CO2 emission reduction throughout housing refurbishment. This research reveals the diminishing returns in reduction of energy cost and CO_2 emission where a significant reduction can no longer be achieved by adopting higher energy standards, and identifies that BIM could provide a more integrated approach to determine the most affordable refurbishment solution among various energy standards.

Conclusions

This research identifies the essential BIM input datasets during the early design phase that enable construction professionals to utilise BIM for improving their current refurbishment practice: seven major input data for the assessment phase and four major input data for the design phase have been identified. The results of this research show that it is important to prepare the CDE with proper BIM datasets and integrate detailed house element information into a BIM model such as accurate as-built condition, cost and thermal performance information for successful BIM use in the housing sector. Currently, a lack of standardized BIM objects and library is identified as a current obstacle to utilize a BIM system for housing refurbishment, and the BIM standard strongly recommend to establish the CDE before fully adopt and utilize a BIM system. Furthermore, a 3D BIM model without reliable information and requirements cannot add more value to the customers and the construction industry. Thus, accurate condition assessment of an existing house is the most important task to construct a reliable BIM house model. Also, the identified essential BIM input datasets should empower construction professionals to adopt and utilize BIM systems effectively. Based on an information enriched BIM model, this research recognises that BIM can be feasible for housing refurbishment to facilitate an informed decision-making for an affordable refurbishment solution at the early design stage. As a result, construction professionals can suggest an affordable housing refurbishment solution to customers more productively without unnecessary future reworks. Furthermore, the findings of this research contribute to shed light on examining potential BIM use for housing refurbishment and providing a better understanding of essential BIM input dataset for whole-house refurbishment. There has been a limitation to examine various combinations of refurbishment options such as building services systems and renewable energy. Since this research is confined to whole-house refurbishment without building services upgrades, generalisation to other whole-house refurbishment cases with different housing types and combination of refurbishment options should be treated with caution. Also, the difference and allowance between simulated and actual results should be monitored and managed in whole-house refurbishment. Future research should focus on exploring further in the BIM datasets for construction and operation phases of refurbishment projects.

Reference

Basbagill, J., Flager, F., Lepech, M., Fischer, M. (2013), "Application of life-cycle assessment to early stage building design for reduced embodied environmental impacts." *Building and Environment,* 2013 (60), pp. 81-92.

Boardman, B., Darby, S., Killip, G., Hinnells, M., Jardine, C. N., Palmer, J., Sinden, G. (2005), "40% House Report", Oxford, Environmental Change Institute.

Boardman, B. (2007). "Home truths, a carbon strategy to reduce UK housing emission by 80% by 2050", Oxford.

BRE (2010), "Sustainable Housing Refurbishment: An update on current guidance and sources of Information", Watford.

Burton, S. (2012), *Handbook of Sustainable Refurbishment – Housing*, Earthscan, Oxon.

Chaves, F.J., Fazenda, T., Formoso, P., Torres, C., Clarissa Notariano, B. (2016), "Building information modelling to cut disruption in housing retrofit", Engineering Sustainability, Proceedings of the Institution of Civil Engineers, pp. 1-12.

CIC, (2013), "Growth through BIM", London.

Crawleya, D.B., Handb, J.W., Kummertc, M., Griffith, B.T. (2008), "Contrasting the capabilities of building energy performance simulation programs." *Building and Environment,* 2008 (43), pp. 661-673.

Crosbie, T., Dawood, N., Dawood, S. (2011), "Improving the energy performance of the built environment: The potential of virtual collaborative life cycle tools", *Automation in Construction*, 20 (2011), pp. 205–216

DECC. (2009), "Heat and Energy Saving Strategy, Consultation", Department of Energy and Climate Change, London.

Dixon, T. and Wilkinson, S. (2016), *Building Resilience in Urban Settlements Through Green Roof Retrofit, in Green Roof Retrofit: Building Urban Resilience*, John Wiley & Sons, Ltd, Chichester.

Doran, D.; Douglas, J.; Pratley, R. (2009), *Refurbishment and Repair in Construction,* Whittles Publishing, Caithness.

Eastman, C., Teicholz, P., Sacks, R., Liston, K. (2011), *BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Architects, Engineers, Contractors, and Fabricators,* John Wiley and Sons, New Jersey.

Ellis, P., Torcellini, P., Crawley, D. (2008), "Energy design plugin: an EnergyPlus plugin for Sketchup", 30 July – 1 August, Berkeley, California, IBPSA-USA SimBuild Conference, pp.1-8.

EST (2007), "Energy-efficient refurbishment of existing housing", Energy Saving Trust, London.

EST (2010). "Fabric first, Focus on fabric and services improvements to increase energy performance in new homes", Energy Saving Trust, London.

Flanagan, R. and Jewell, C. (2005), *Whole Life Appraisal for construction*, Blackwell Publishing Ltd., Oxford.

Froese, M. (2010), "The impact of emerging information technology on project management for Construction" *Automation in Construction*, 19 (5), pp. 531–538

Hamil, S. (2010), "What BIM is and How It is Being Used", CIBSE Report, London.

Hannele, K., Reijo, M., Tarja, M., Sami, P., Jenni, K., Teija, R. (2012). "Expanding uses of building information modeling in life-cycle construction projects", *Work,* 41 (2012), pp. 114-119.

HM Government (2010), "Low Carbon Construction, Innovation & Growth Team Final Report", London.

HM Government (2012), "Building Information Modelling - Industrial strategy: government and industry in partnership", London.

HM Government (2015), "Digital Built Britain: Level 3 Building Information Modelling (BIM) – Strategic Plan", London.

Horowitz, S., Christensen, C., Brandemuehl, M., Krarti, M. (2008), "An enhanced sequential search methodology for identifying cost-optimal building pathways", 30 July – 1 August, Berkeley, California, IBPSA-USA SimBuild Conference, pp. 1-8.

Institute for Sustainability (2011), “Sustainable Retrofit Guides”, Technology Strategy Board, London.
Jankovic, L. (2012), *Designing Zero Carbon Buildings – Using Dynamic Simulation Methods*, Routledge, Abingdon.
Jenkins, D.P., Peacok, A.D., Banfill, P.F.G, Kane, D., Ingram, V., Kilpatrick, R. (2012), “Modelling carbon emissions of UK dwellings - The Tarbase Domestic Model.” *Applied Energy,* 2012 (93), pp. 596-605.
Juan, Y-K., Kim, JH., Roper, K., Castro-Lacouture, D. (2009), “GA-based decision support system for housing condition assessment and refurbishment strategies”, *Automation in Construction*, 18 (2009), pp. 394–401.
Kelly, M.J. (2009), “Retrofitting the existing UK building stock”, *Building Research & Information*, 37 (2), pp. 196-200.
Killip, G. (2008), “Building a Greener Britain”, Federation of Master Builders, UK.
Kim, K.P. and Park, K.S. (2016), "Primary BIM dataset for refurbishing flood risk vulnerable housing in the UK", *Built Environment Project and Asset Management*, 6(4), pp.365 – 378.
Konstantinoua, T., Knaack, U. (2013), “An approach to integrate energy efficiency upgrade into refurbishment design process, applied in two case-study buildings in Northern European climate.” *Energy and Buildings,* 59 (2013), pp. 301-309.
Kreith, F. and Goswami, D.Y. (2008), *Energy Management and Conservation Handbook*, CRC Press, Florida.
Lindner, F. and Wald, A. (2011), “Success factors of knowledge management in temporary organizations”, *International Journal of Project Management*, 29 (7), pp. 877–888.
Ma, Z.; Cooper, P.; Daly, D.; Ledo, L. (2012), “Existing building retrofits: Methodology and state-of-the-art”, *Energy and Buildings*, 2012 (55), pp. 889–902.
McMullan, R. (2007), *Environmental science in building*, Palgrave Macmillan, Basingstoke.
Menassa, C.C., (2011) “Evaluating sustainable retrofits in existing buildings under uncertainty”, *Energy and Buildings,* 2011 (43), pp. 3576–3583.
Monteiro, H. and Freire, F. (2012), “Life cycle assessment of a house with alternative exterior walls: comparison of three impact assessment methods”, *Energy and Buildings*, 47 (2012), pp. 572–583.
Murray, S.N., Rocher, B., O'Sullivan, D.T.J. (2012), “Static Simulation: A sufficient modelling technique for retrofit analysis.” *Energy and Buildings,* 47 (2012), pp. 113-121.
National Refurbishment Centre (2012), “Refurbishing the Nation - Gathering the evidence”, National Refurbishment Centre, Watford.
NBS (2016), “National BIM Report 2016”, London.
Neufert, E. and Neufert, P. (2012), *Neufert Architects’ Data*, Blackwell Publishing, Oxford.
ONS (2014), "Output in the Construction Industry", London.
Park. K. and Kim, K.P. (2014), “Essential BIM Input Data Study for Housing Refurbishment: Homeowners’ Preferences in the UK”, *Buildings*, 4 (3), pp. 467-487
Redmond, A., Hore, A., Alshawi, M., West, R. (2012), “Exploring how information exchanges can be enhanced through Cloud BIM”, *Automation in Construction*, 24 (2012), pp. 175–183.
Reeves, A. (2009). “Achieving deep carbon emission reductions in existing social housing: the case of Peabody”, Ph.D thesis, De Montfort University.
RIBA (2013), “RIBA Plan of Work 2013”, London.
Riley, M. and Cotgrave, A. (2008), *Construction Technology 1: House Construction*, Palgrave Macmillan, London.
Riley, M. and Cotgrave, A. (2011), *Construction Technology 3: The Technology of Refurbishment and Maintenance*, Palgrave MacMillan, London.
Rysanek, A.M., Choudhary, R. (2013), “Optimum building energy retrofits under technical and economic uncertainty.” *Energy and Buildings,* 57 (2013), pp. 324–337.
Sebastian, R., Haak, W., Vos, E. (2009), "BIM Application for Integrated Design and Engineering in Small-Scale Housing Development: A Pilot Project in The Netherlands", 2-4 November, CIB-W096, Taiwan, pp. 161-171.

Scheneider, D., and Rode, P. (2010), “Energy renaissance”, High Performance Building, US.

Sigmund, Z. (2016), "Sustainability in architectural heritage: review of policies and practices." *Organization, Technology and Management in Construction: an International Journal*, 8(1), pp. 1411-1421.

Thuvander, L.; Femenías, P.; Mjörnell, K.; Meiling, P. (2012), “Unveiling the process of sustainable renovation”, *Sustainability,* 2012 (4), pp. 1188–1213.

Utley, J. I. and Shorrock, L. D. (2011), “Domestic energy fact file 2011”, DECC, London.

WWF (2008), “How Low- Achieving optimal carbon savings from the UK’s existing housing stock”, London.

Yin, R.K. (2003), *Case study research, design and methods*, Sage, Thousand Oaks.

Housing Information Modelling for BIM-embedded Housing Refurbishment

Abstract

Purpose – The aim of this research is to identify BIM input datasets within a BIM-embedded housing refurbishment process and enabling construction professionals to utilize BIM as an information management platform for housing refurbishment projects.

Design/methodology/approach – A hypothetical case study using BIM tools for a housing refurbishment project is adopted to identify BIM input datasets to create a housing information model within a BIM system. Reliability of the research outcome is examined by conducting a comparative analysis between existing and simulated research outcomes.

Findings – This research identifies essential BIM input datasets during the early design phase. The importance of a well-integrated housing information model containing accurate as-built condition, cost and thermal performance information is essential to utilize BIM for housing refurbishment. BIM can be feasible for housing refurbishment when an information enriched housing information model is constructed. Furthermore, the capability of BIM that can enable key project stakeholders to determine the most affordable refurbishment solution among various alternatives is identified since BIM can provide reliable cost estimations and thermal performance of refurbishment alternatives at the early design stage.

Research limitations/implications – The examined refurbishment processes and input datasets are confined to the early design phases since BIM use for housing refurbishment is limited.

Practical implications – This research will contribute to utilize BIM for housing refurbishment by providing essential BIM input datasets and BIM-embedded refurbishment processes.

Originality/value – This research reveals primary housing information datasets and BIM-embedded refurbishment processes at the early design phase.

Keywords: BIM, Housing Refurbishment, Information Management, Construction Technology, Housing, Process Management

Paper type: Research Paper

Introduction

The UK government legislated the Climate Change Act 2008 aiming at 80% CO_2 reduction by 2050 against 1990 CO_2 emission levels. In particular, the UK possesses the oldest housing stock among developed countries with 8.5 million properties over 60-years-old (EST, 2007). It has been estimated that 600,000 houses per each year need to be refurbished from 2012 to achieve the 80% reduction in time (BRE, 2010), and housing accounts for 27% of the total UK CO_2 emissions (Kelly, 2009), and 87% of those housing responsible for the 27% CO_2 emission will still be standing in 2050 (Boardman, 2007). Thus, the housing sector should play a key role in improving energy efficiency, and housing refurbishment is expected to provide substantial contribution to CO_2 reduction since refurbishment is considered a better option than demolish-and-rebuild because of the financial and environmental benefits (Riley and Cotgrave, 2011). Currently, partial refurbishment options with relatively low upfront costs such as cavity wall insulation and loft insulation have been mainly adopted (WWF, 2008). However, the partial refurbishment can achieve only limited CO_2 reduction by 25-35% (McMullan, 2007) and as a result, there is increasing consensus amongst researchers that comprehensive whole-house refurbishments are required to achieve the reduction target in the housing sector (Boardman 2007; Killip 2008). In particular, the UK government has placed emphasis on the importance of a whole-house refurbishment and released the whole-house refurbishment strategy named as the 'Great British Refurbishment' aiming at refurbishing 80% of the housing stock by adopting whole-house refurbishment approach by 2020 (DECC, 2009). The key benefits of adopting the whole-house refurbishment are significant amount of reduction of CO2 emission and energy cost savings through the lifecycle (DECC, 2009; Killip 2008) because an entire house will be refurbished in a systematic way by considering various refurbishment options and building information including housing condition data and energy performance.

However, refurbishment solutions are proposed at the end of design phase in the current refurbishment process when flexibility of refurbishment solutions and opportunities to explore various refurbishment alternatives are significantly limited (Ma et al, 2012; Thuvander et al., 2012). As a result, many researchers point out the absence of an integrated decision-making framework to estimate the financial and environmental impact of a refurbishment solution from the early design stage. Furthermore, they emphasise the importance of proper decision-making and the necessity of using proper information and communications technology (ICT) tools that support construction professionals considering various refurbishment solutions at the early design phase (Froese, 2010; Crawley et al., 2008; Eastman et al, 2011; Hannele et al., 2012). In response to current issues and limitations, many researchers state the potential and importance of Building Information Modelling (BIM) for informed decision making on refurbishment solutions at the early design stages. It is because BIM is capable of enhancing collaboration among stakeholders, and the improvement in integration of project information by exploring and comparing various refurbishment alternatives at the early design stages can lead to better refurbishment solution (Basbagill et al., 2013; HM Government, 2012). Therefore, this research aims at identifying essential input data for housing refurbishment at the early design phase and exploring how to integrate this information into the BIM environment through a BIM-embedded housing refurbishment process to seek a financially and environmentally affordable refurbishment solution by a case study with a BIM simulation.

Housing refurbishment and Building information modelling

It is essential to cope with diverse information such as effectiveness of refurbishment measures, financial feasibility and environmental impact simultaneously from the early design phase (Killip, 2008), when there are more alternatives to select the most affordable refurbishment solution. Furthermore, a refurbishment project has two major unique characteristics compared to new build housing: a) Higher Risk (Doran et al., 2009; Burton, 2012), and b) Complex Decision Making Process (Menassa, 2011; Thuvander et al., 2012), which requires more considerate planning and data management for a refurbishment solution. Indeed, a holistic approach to refurbishment solutions can achieve 60% of operational cost savings over 30 years by investing only 20% more capital cost in the construction phase (Flanagan and Jewell, 2005). In order to overcome ineffective collaboration and integration of construction information and determine the most affordable refurbishment solution, various researchers proposed refurbishment model or strategy emphasizing the importance of availability of possible refurbishment alternatives and capability of conducting comparative analysis among various refurbishment options. Juan et al. (2009) proposed a generic on-line algorithm-based decision supporting model for selecting refurbishment solutions based on various criteria. Similarly, Jenkins (2012) proposed a step-by-step refurbishment measure adoption strategy named the TARBASE (Technology Assessment for Radically improving the Built Asset baSE) domestic model. Researchers argue that there is no universal refurbishment solution for the UK housing stock, and multiple variants such as fabric, service and renewable energy systems must be combined with considerate CO_2 reduction analysis. Rysanek and Choudhary (2012) and Konstantinoua and Knaack (2013) suggested whole-building simulation model with the list of all the potential refurbishment options that can examine various refurbishment alternatives at the early design phase prior to determining a final refurbishment solution. Both proposed model emphasize the granularity of information regarding refurbishment materials and options that can be examined and tested at the early design stage.

Consequently, Rysanek and Choudhary (2013) assert that refurbishment projects should utilize a capable tool to support informed decision making among various refurbishment alternatives, while considering multiple criteria such as the implication of cost and the environmental impact. According to Schneider and Rode (2010), 50% of possible refurbishment alternatives that can render better outcomes of refurbishment are neglected due to a lack of collaboration among key project stakeholders at the early design stage. Poor decision making at the early design phase results in significant changes in the time and cost of a project which leads to reworks, and the cost for reworks and changes become five times larger as changes occur at later phases (Doran et al., 2009). Indeed, Thuvander et al. (2012) argue the necessity of a decision-making tool that can conduct a brief comparison between potential refurbishment measures to prune unfeasible refurbishment solutions at the early design stage. This suggested tool can enable construction professionals to focus more on feasible refurbishment measures and develop refurbishment solutions further without considering unnecessary measures. Through the literature review, it is identified that various researchers commonly emphasize the importance of proper decision-making at the early design phase, and the necessity of using proper tools - whether software is used or not - that can support construction professionals considering various refurbishment solutions (Ellis et al., 2006; Horowitz et al., 2008).

Furthermore, Crosbie et al. (2011) pointed out the occurrence of a broken feedback loop after the design phase. In general, a BIM model is not updated by incorporating feedback from any changes made during the construction phase, and researchers argue that the energy performance of a building in the use phase can only be improved by conducting an energy performance simulation based on the actual building operation information. However, the current construction practice cannot manage knowledge gained throughout a project life cycle, and often the lessons learned from previous projects are not used for future projects (Lindner and Wald, 2011). To provide more accurate energy performance simulation results for a BIM model, researchers proposed the IntUBE (Intelligent Use of Buildings' Energy Information) system designed to obtain actual building information throughout a building life cycle, and the restored data will be used to improve building design, energy performance and refurbishment in the future. This system has the capability to restore various information regarding building attributes and actual building performance, allowing design professionals to generate more realistic BIM design alternatives. It enables clients to make informed decisions on design selection at the early design phase. If a BIM model is built based on actual housing attributes retrieved from actual housing conditions and energy performance, a whole-house refurbishment solution will be more realistic and feasible, and customers can make better decisions. Currently, many researchers argue the potentials of BIM for formulating LCC and LCA simultaneously at the early design stage (Ma et al., 2012; Monteiro and Freire, 2012; Basbagill et al., 2013). Although there have already been various tools to calculate LCC and LCA, BIM has distinct merits in that it can analyse the cost and energy performance of refurbishment measures based on 3D models. Potentially the use of BIM tools can improve the overall information flow throughout a project life cycle and facilitate collaborative efforts among project participants to integrate diverse construction information to make an informed decision at the early design phase (Eastman et al, 2011; Hannele et al., 2012; HM Government, 2012). Particularly, in a BIM environment, a single data source is built into a 3D model based on a parametric design, and project stakeholders are able to exchange instant feedback simultaneously on designs and construction methods without manual re-entry of construction information. Thus, this capability can achieve continuous improvement on decision-making processes as all information can be stored in a single repository and retrieved based on single-source data (Froese, 2010; Eastman et al, 2011).

Despite the benefits of a BIM tool, current housing refurbishment practices to estimate the outcome of refurbishment projects rely on simple cost estimation tools and the experience of construction professionals (Kreith, 2008). This is because small and medium sized enterprises are mainly involved in the housing sector, which contribute 92% (250,000 firms) to the total UK construction industry employment (ONS, 2014), and the BIM adoption in SMEs was identified as only 13% as of 2010 (Hamil, 2010). The use of BIM in SMEs is limited because there are no practical guidance and standardised BIM protocols to utilise BIM, and the investment in BIM systems is not economically feasible (Sebastian et al., 2009; NBS, 2016). Although BIM standards such as PAS 1192 series have been developed and they provide a high level of 3D building model definition, they focus on a new build construction and there is no specific guidance about required data for each work stage. Moreover, the CIC (2013) established Regional BIM Hubs for enabling SMEs to get advice from local networks, and yet fruitful outcomes regarding BIM adoption in the housing sector have not been made. Thus, this research focuses on identifying essential BIM input data and a BIM-embedded housing refurbishment process that enable construction professional to make an informed decision on housing refurbishment solution at the early design phase using BIM.

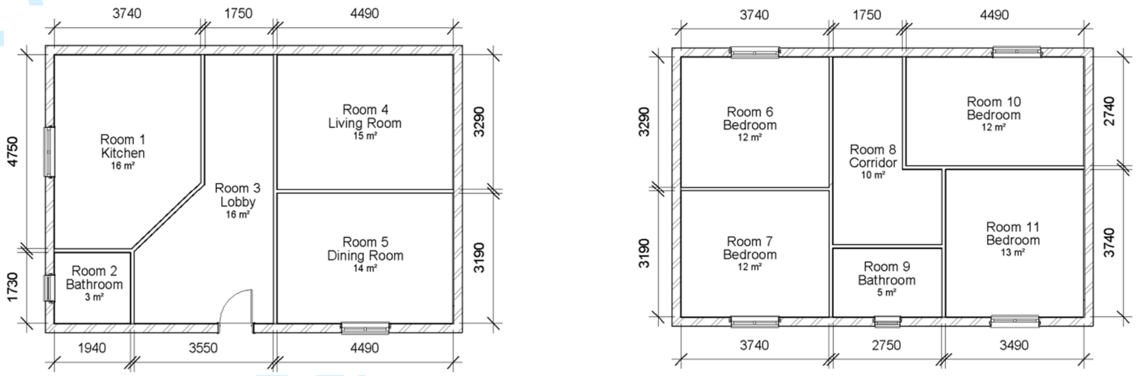
Research Methodology

According to Yin (2003), a case study focuses on a contemporary event and answers to 'how' and 'why' questions. As this research explores why whole-house refurbishment should be implemented and how house information dataset can interact and relate in a BIM environment, a case study is adopted to answer the following questions: 'why are different types of data required throughout the process?' and 'how can the required information be integrated and utilised in a BIM system?' An actual model simulation with BIM datasets is conducted and a sample house model is examined by utilising relevant BIM tools: Autodesk Revit and IES VE. Both tools are the most common and verified tools because Autodesk Revit is currently prevalent tool in the UK compatible with AutoCAD platform that is still widely utilised in the UK construction sector (NBS, 2016). 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 and transfer a BIM model congruently without geometrical distortion compared to other tools (Jankovic, 2012; Murray et al., 2012; Crawley et al., 2008). Furthermore, IES VE utilize a UK specific construction material dataset named Envest II developed by Building Research Establishment (BRE), a UK based construction professional organization, aiming at conducting a comprehensive assessment of the environmental impact and whole life costs of a building in the UK construction context. Finally, since there is no 'one-size-fits-all' solution for housing refurbishment (Jenkins et al., 2012), the capability of coping all possible refurbishment alternatives is essentially required for a tool, and consequently this requirement makes the IES VE highly relevant for this research.

For a housing type, a solid wall house is determined since it is the most vulnerable to energy efficiency and in needs of refurbishment, which requires immediate attention (National Refurbishment Centre, 2012). In order to develop a basic 3D model for simulation, the average housing condition data published by the UK government was used as the solid wall housing indicates a wide range of variation in its condition such as year built, construction types physical dimensions, extra retrofitted measures and construction materials (Jenkins et al., 2012). This research follows the refurbishment project phases provided by the Institute for Sustainability and the work stage provided by the RIBA (Royal Institute of British Architects). The RIBA has outlined a plan of work (2013) that has been widely adopted in the UK construction industry as a generic construction phase, and recently the Institute for Sustainability, which has a partnership with the Technology Strategy Board (TSB), published 'Low Carbon Domestic Retrofit' guide to provide a sustainable housing refurbishment guide (Institute for Sustainability, 2011). In particular, the TSB is a UK public body operated by the government coordinating 'The Retrofit for the Future' program by advocating the whole-house refurbishment. Thus, the work stages and phases by two professional bodies are adopted for a BIM simulation process. Prior to presenting the identified BIM datasets, this research checked reliability of BIM simulation result by conducting a comparative analysis with the previous research by a UK based professional consultancy on energy efficiency, which is Energy Saving Trust (EST, 2009). The BIM for housing refurbishment has been rarely studied and there is no precedent case study except the one by EST. Moreover, since both studies adopted whole-house refurbishment and used a solid wall house with the same U-values, the case study of EST is used for reliability check to confirm whether the datasets can draw the similar pattern in both research outcomes.

Basic BIM Model: Detached Solid Wall House

The information of a basic BIM model for simulation is provided as shown in Figure 1 and Table 1 (Riley and Cotgrave, 2008, Utley and Shorrock, 2011, Neufert, 2012).



Ground Floor First Floor

Figure 1. Floor Plan for Basic BIM Model

Table 1: Detailed Construction Information

Element	Construction Type	Components	Thickness (mm)
Roof	Pitched Roof with Timber Joist and Rafter	Roofing Tile	25
		Wood (Batten)	25
		Roofing Felt	5
		Timber Structure	140
External Wall	Solid Brickwork Masonry Wall (Single Leaf)	Dense Gypsum Plaster	13
		Solid Brickwork	220
Floors	Suspended Timber Floor	Timber Joist Structure	225
		Chipboard	25
		Carpet	10
Windows	Double Glazing	Timber Frame	6mm Glazing
Exterior Door	Wooden Door	Wooden Door	44

Energy Standards for BIM simulation

Currently, Building Regulation is mandated, and particularly Building Regulation Part L should be considered and complied. The Building Regulation Part L 2010 and 2013 (BR 2010/2013) mandates the minimum energy efficiency standard for housing fabric. In addition to the minimum standard, Building Regulation Part L 2010 and 2013 advise construction professionals to consider further energy efficiency by providing a notional energy efficiency standard aimed at a 25% CO2 reduction. The Fabric Energy Efficiency Standard (FEES) has been recently introduced to the Building Regulation Part L 2013 aimed at achieving zero carbon homes by 2016, which is the most energy efficient standard available at present introduced specifically for zero carbon in existing housing to achieve the required 80% CO_2 reduction. Thus, these energy standards are the most proper energy standards that need to be considered when a refurbishment solution is planned to improve energy efficiency and carbon performance of an existing house. Thus, these standards have been adopted for energy simulation in this research.

Result and discussion

Essential BIM Input Data and Refurbishment Process

This research examines the early refurbishment phases, 'Assessment' and 'Design' phases, to identify essential BIM input dataset for each work stage. As a result, the essential BIM input datasets and a BIM-embedded housing refurbishment process map are identified and described as seen in Table 2 and Figure 2.

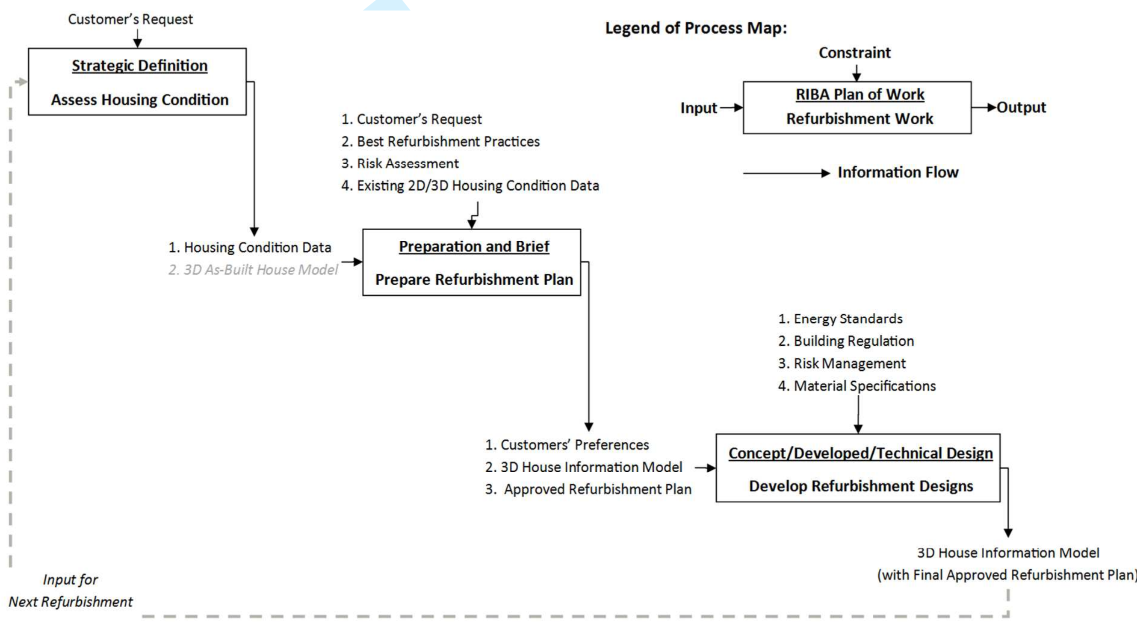


Figure 2. BIM-embedded Housing Refurbishment Process Map

The BIM-embedded processes and input datasets for each work stage have the unique opportunity to provide a substantial contribution to BIM use for housing refurbishment by supporting key project stakeholders to coordinate the right construction information at the right time with the right sequences based on the processes and input dataset. Furthermore, construction professionals can determine the most financially and environmentally refurbishment solution at the early design stage by comparing various refurbishment alternatives.

Table 2: BIM Input Datasets for the Early Design Phase of Housing Refurbishment

<table>
<tr><th>Phase</th><th>Work Stage</th><th>BIM Input Dataset</th></tr>
<tr><td rowspan="2">Assessment</td><td>Strategic Definition</td><td>• Housing Type and Year Built (As-Built data)
• Dimensions:
a) Floor areas (Floor Plans)
b) Storey heights
c) Building fabric elements (wall, roof, floor, window and door)
• Detailed Construction Information:
a) Construction Types for all fabric elements
b) Material Types for External windows and doors
c) U-values for all housing elements
d) Additional Extension or in-situ construction
• Occupancy data, and SAP rating data</td></tr>
<tr><td>Preparation and Brief</td><td>• Customer's Preferences (Park and Kim, 2014):
a) Refurbishment Priorities of House Element
b) Decision Making Factors for Selecting Refurbishment Options
c) Refurbishment Materials
• 3D House Information Model
• Planned Whole-house Refurbishment Solution
(Combination of Refurbishment Options)</td></tr>
<tr><td rowspan="3">Design</td><td>Concept Design</td><td rowspan="3">• Building Regulations
• Energy Standards:
a) Building Regulation 2010/2013 Part La (Minimum)
b) Building Regulation 2010/2013 Part La (Notional)
c) Fabric Energy Efficiency Standard (Maximum)
• Refurbishment Material Specification:
a) Attributes of Materials (Thickness and Types)
b) U-value for Windows including frames and secondary/tertiary glazing system
e) Initial material and Installation costs
• Risk assessment for continuity of insulations</td></tr>
<tr><td>Developed Design</td></tr>
<tr><td>Technical Design</td></tr>
</table>

Assessment Phase 1 – Strategic Definition Stage

During the assessment phase, occupancy data is required to find out internal temperature and heating timing settings and SAP rating data will be used to set up a current energy use baseline for developing post-refurbishment energy use. Other housing condition data such as geometric and dimensional information or the 3D As-Built House Model (only if 3D laser scanner is utilized) will become the inputs to develop a 3D Housing Information model at the next stage, Preparation and Brief Stage. In the process map, 3D As-Built House Model is grey since 3D laser scanner might/might not be used for housing refurbishment in the current practice.

Assessment Phase 2 – Preparation and Brief Stage

Design professionals and/or BIM professionals who provide a BIM service are responsible for creating a Housing Information Model based on the housing condition data. A 3D Housing

Information model contains parametric information that all the information related to building elements are already embedded into the objects. Consequently, all the essential BIM input datasets are embedded in each BIM objects and assembled as one whole Housing Information Model as shown Figure 3.

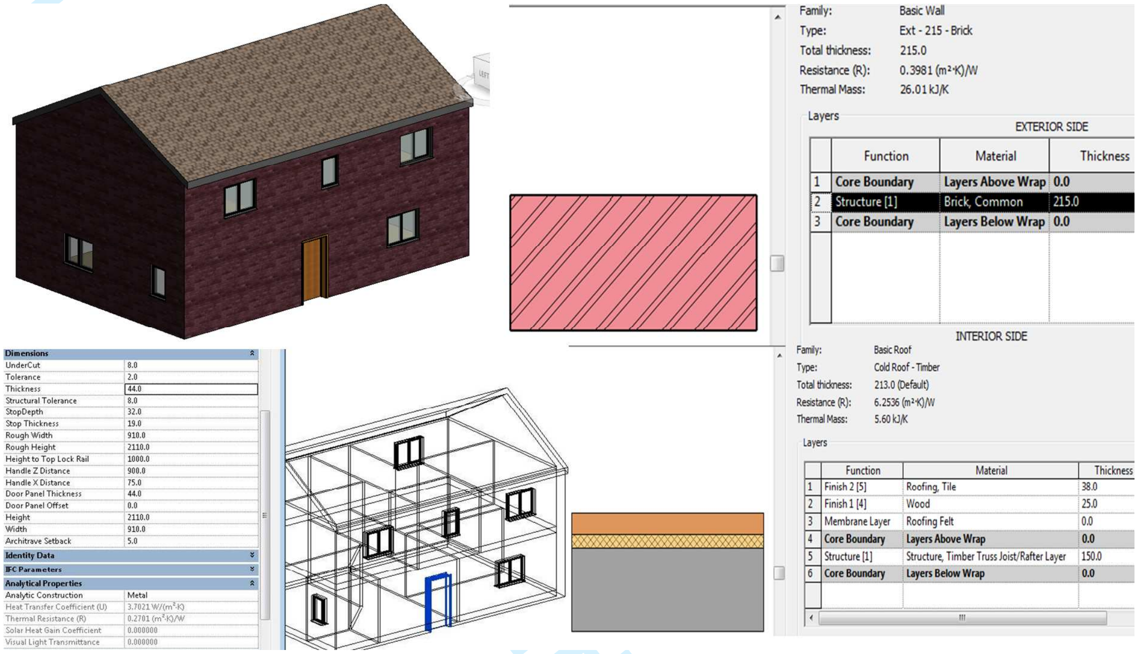


Figure 3. 3D Housing Information Model (top left) and each BIM object information

These provide a snapshot of each housing element with its parametric information such as dimensions, U-values and construction details including as-built data sets of an existing house. The dimensions of elements are automatically changed according to the modification by refurbishment designs and updated through a project life cycle. As a concept of BIM the parametric design principle is applied and relevant information on material quantities, material costs, U-value and embodied CO_2 are instantly updated when they are available without any effort from the quantity surveyor. The material take-off function can simply create a bill of quantities in a customised table as shown in Figure 4.

Level	Family and Type	Material: Name	Material: Cost	Material: Area	Material: Vol	Total Cost
Ground Floor	Floor: Timber Suspended Floor	Wood Sheathing, Chipboard	£24.56	67 m²	1.47 m³	£1645.14
Ground Floor	Floor: Timber Suspended Floor	Structure, Timber Joist/Rafter Layer	£7.79	67 m²	15.07 m³	£521.81
First Floor	Basic Ceiling: Generic	Gypsum Wall Board	£28.04	65 m²	0.00 m³	£1810.55
First Floor	Basic Ceiling: Generic	Gypsum Wall Board	£28.04	64 m²	0.00 m³	£1807.19
First Floor	Floor: Timber Suspended Floor	Wood Sheathing, Chipboard	£24.56	67 m²	1.47 m³	£1645.14
First Floor	Floor: Timber Suspended Floor	Structure, Timber Joist/Rafter Layer	£7.79	67 m²	15.07 m³	£521.81

Figure 4. Material Take-off Function in BIM

This function meets the needs of effective housing refurbishment since BIM enables construction professionals as well as customers to determine the most affordable housing refurbishment solution at the early design stage by estimating and comparing cost and carbon performance of a refurbished house. Furthermore, the BIM capability of early collaboration based on BIM objects meet the requirements of Level 2 BIM maturity mandated by the UK government from 2016. However, currently it is common that housing condition data is developed through 2D drawings rather than a 3D model (NBS, 2016). As shown in Figure 5, existing CAD files may need to be imported into the BIM software as the 2D or 3D CAD data has no parametric information and so has less capability. For example there would be no instant update information like BIM tools. The imported 2D or 3D CAD data can be converted to a 3D BIM system since the basic information in the drawings can be used to reconstruct a floor plan and dimensions of each space in a house. Housing data imported from 3D CAD is presented in a 3D manner in the BIM system. However all the elements, structures and service systems are presented as one mass without parametric information such as dimensions, thickness and thermal information because they are not object-oriented and cannot be separately converted into a BIM object with parametric information. Consequently, a table of material take-off produced from 3D CAD information is empty due to demerits of using 2D or 3D CAD system.

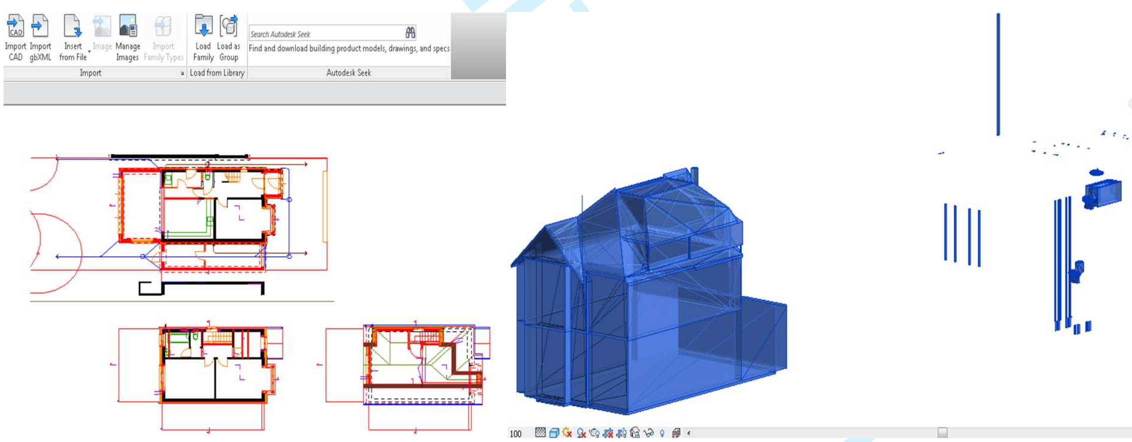


Figure 5. Result of Importing CAD file format into BIM system (Left: 2D CAD, Right: 3D CAD)

Design Phase 1– Concept Design Developed, and Technical Design

After the assessment phase, various refurbishment alternatives need to be explored and compared using 3D house information model. When different refurbishment options are examined, the Building Regulations and associated risks with refurbishment options must be considered for the planning permission and risk mitigation. In particular, the risk assessment for continuity of insulations between two different house elements, e.g. Wall and Floor junction, should be considered because the energy efficiency will be lower than planned due to loss of airtightness if continuity of insulations is not secured. In addition, moisture and cold bridging that cause mold growing after refurbishment must be considered. Housing elements such as walls and roofs are vulnerable to moisture after refurbishment because the insulation material can block natural ventilation of the elements. Therefore, construction professionals must carefully plan a combination of refurbishment measures to achieve a planned energy performance of a refurbished house.

Design Phase 2– Developed and Technical Design

Once a refurbishment solution is generated, Housing Information Model needs to be examined by different energy efficiency standards. As this research adopts two BIM tools – Autodesk Revit and IES VE, all the geometric information is transferred from Revit to IES VE to achieve efficiency and eliminate unnecessary reworks and human errors such as mistyping geometrical and thermal performance information. The study found that the International Foundation Class (IFC) format cannot be exchanged between Autodesk Revit and IES VE because the geometric arrangement is broken when IFC data is transferred to IES VE, while Green Building XML (gbXML) format transfer a congruent model in terms of geometric information as shown in Figure 6.

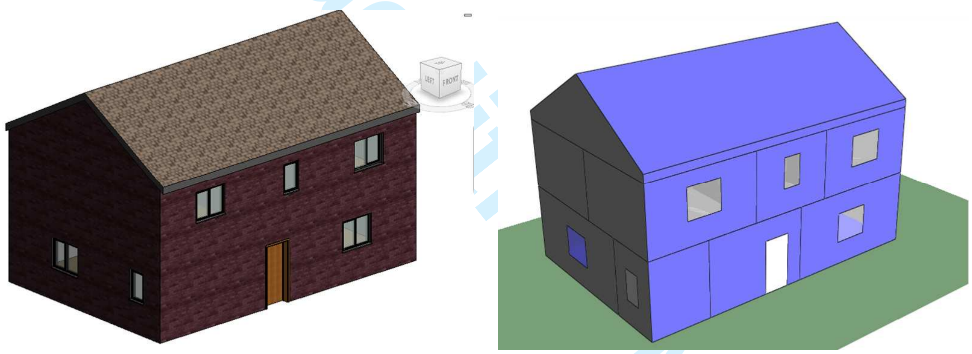


Figure 6. Basic Model Import Result using gbXML format in IES VE (Left: Autodesk Revit, Right: IES VE)

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 has been recognized as a critical technical barrier (Redmond et al, 2012), yet the interoperability issues are still not entirely resolved although the concept of IFC and gbXML data formats within BIM system should exchange necessary data without any conflicts. Furthermore, this finding provides important insight regarding non-graphical information exchange in the Open BIM environment, which is essence of Level 3 BIM maturity promoted by the UK government, since IFC and Construction Operation Building Information Exchange (COBie) should play a key role as a seamless data exchange medium regardless of types of BIM tools. Thus, further researches on the interoperability issues related to IFC, gbXML and COBie are required.

3D Housing Information Model (As-Refurbished Model)

The housing information model used for housing refurbishment will continue to retrieve actual maintenance and operation information throughout a housing life cycle, and eventually the restored data will be utilized when another refurbishment is required in the future. Jung and Joo (2011) also argue the same point regarding a BIM data repository, that practical BIM implementation requires proper BIM data in conjunction with a clear framework. Researchers emphasized that the importance of data properties embedded in a BIM object or model is essential for a BIM-enabled project. Based on the geometric and non-geometric data in a BIM's objectives, a BIM model can generate knowledge for an entire building in terms of project time, cost and sustainability. Researchers pointed out that once BIM is widely adopted in the construction industry, knowledge and lessons learned from construction projects will be restored as a historical database, and will be fully utilized for new build and retrofit projects. As a new build housing project will secure the BIM model from the outset, facility management (FM) will provide the complete BIM model enriched with data and information about as-built housing. As FM utilizes this BIM model throughout the life cycle of a house, this will be the living and growing database for future refurbishment. BIM was not seen as relevant to work on existing buildings until recently when laser point-cloud surveying emerged as a rapid way to capture existing buildings and landforms into digital format. Currently, the importance of Big Data is getting increasing attention, and Construction Industry Council (CIC, 2013) envisages its use, which is captured from the use phase of a building, for future construction and refurbishment projects.

Reliability Check for BIM Simulation Outcome

The expected energy efficiency and carbon performance improvement of a refurbished house depending on energy standards are examined and presented in this section. The reduction rates for energy demand for heating and energy cost for heating indicate high similarity, while the amounts of CO2 emission indicate 42% difference as shown in Table 3. It is mainly because the EST included hot water and secondary heating while this research only included hot water. Furthermore, the EST included building service upgrades such as mechanical ventilation and efficient lightings while this research utilised default building service setting available in BIM tools. It is found out that different heating sources and level of building service upgrades are important measures for energy efficiency and CO2 reduction in housing refurbishment although this research did not include any specific building service upgrades as it is beyond this research scope. Although this research outcome, which is 52% reduction of CO2 emission, does not reflect the building service upgrades and the secondary heating, the research outcome is supported by the previous research results that the maximum of

60% CO_2 reduction can be achieved through whole-house refurbishment without building service upgrades (Boardman et al., 2005; Construction Production Association, 2014).

Table 3: Reliability Check for BIM Simulation Outcome

Description	EST House (Floor Area: 104 m2)		Basic Case House (Floor Area: 130 m2)	
	Pre-Refurbishment	Post-Refurbishment	Pre-Refurbishment	Post-Refurbishment
Roof U-value	2.30	0.10	2.30	0.10
Wall U-value	2.10	0.18	2.18	0.18
Floor U-value	0.74	0.15	0.70	0.15
Window U-value	4.80	1.50	4.83	1.54
Door U-value	3.00	1.00	3.03	1.03
Energy Demand for Heating (kWh/yr/m2)	597	73 (89% Reduction)	209.8	40.8 (80% Reduction)
Energy Cost for Heating (£)	1,498	251 (83% Reduction)	1,150	225 (80% Reduction)
CO2 Emission for Heating (kg/yr/m2)	84.9	5.2 (94% Reduction)	84.5	40.6 (52% Reduction)

Thus, the BIM dataset identified through this research have shown its relevance for whole-house refurbishment and the simulation results show the significant energy cost savings and CO_2 emission reduction after refurbishment in comparison with the previous research data. Even though the building system upgrades and other heating source like renewable energy are out of scope in this research, they should be taken into account as possible options for energy efficiency, cost savings, CO_2 emission reduction throughout housing refurbishment. This research reveals the diminishing returns in reduction of energy cost and CO_2 emission where a significant reduction can no longer be achieved by adopting higher energy standards, and identifies that BIM could provide a more integrated approach to determine the most affordable refurbishment solution among various energy standards.

Conclusions

This research identifies the essential BIM input datasets during the early design phase that enable construction professionals to utilise BIM for improving their current refurbishment practice: seven major input data for the assessment phase and four major input data for the design phase have been identified (See Table 2). The results of this research show that it is important to prepare and integrate detailed house element information into a BIM model such as accurate as-built condition, cost and thermal performance information for successful BIM use in the housing sector. A 3D BIM model without reliable information and requirements cannot add more value to the customers and the construction industry. Thus, accurate condition assessment of an existing house is the most important task to construct a reliable BIM house model. Based on an information enriched BIM model, this research recognises that BIM can be feasible for housing refurbishment to facilitate an informed decision-making for an affordable refurbishment solution at the early design stage. As a result, construction professionals can suggest an affordable housing refurbishment solution to customers more productively without unnecessary future reworks. Furthermore, the findings of this research contribute to shed light on examining potential BIM use for housing refurbishment and providing a better understanding of essential BIM input dataset for whole-house refurbishment. There has been a limitation to examine various combinations of refurbishment options such as building services systems and renewable energy. Since this research is confined to whole-house refurbishment without building services upgrades, generalisation to other whole-house refurbishment cases with different housing types and combination of refurbishment options should be treated with caution. Also, the difference and allowance between simulated and actual results should be monitored and managed in whole-house refurbishment. Future research should focus on exploring further in the BIM datasets for construction and operation phases of refurbishment projects.

Reference

Basbagill, J., Flager, F., Lepech, M., Fischer, M. (2013), "Application of life-cycle assessment to early stage building design for reduced embodied environmental impacts." *Building and Environment,* 2013 (60), pp. 81-92.
Boardman, B., Darby, S., Killip, G., Hinnells, M., Jardine, C. N., Palmer, J., Sinden, G., (2005), "40% House Report", Oxford, Environmental Change Institute.
Boardman, B. (2007). "Home truths, a carbon strategy to reduce UK housing emission by 80% by 2050", Oxford.
BRE (2010), "Sustainable Housing Refurbishment: An update on current guidance and sources of Information", Watford.
Burton, S. (2012), *Handbook of Sustainable Refurbishment – Housing*, Earthscan, Oxon.
CIC, (2013), "Growth through BIM", London.
Crawleya, D.B., Handb, J.W., Kummertc, M., Griffith, B.T. (2008), "Contrasting the capabilities of building energy performance simulation programs." *Building and Environment,* 2008 (43), pp. 661-673.
Crosbie, T., Dawood, N., Dawood, S. (2011), "Improving the energy performance of the built environment: The potential of virtual collaborative life cycle tools", *Automation in Construction*, 20 (2011), pp. 205–216
DECC. (2009), "Heat and Energy Saving Strategy, Consultation", Department of Energy and Climate Change, London.
Doran, D.; Douglas, J.; Pratley, R. (2009), *Refurbishment and Repair in Construction,* Whittles Publishing, Caithness.
Eastman, C., Teicholz, P., Sacks, R., Liston, K. (2011), *BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Architects, Engineers, Contractors, and Fabricators,* John Wiley and Sons, New Jersey.
Ellis, P., Torcellini, P., Crawley, D. (2008), "Energy design plugin: an EnergyPlus plugin for Sketchup", 30 July – 1 August, Berkeley, California, IBPSA-USA SimBuild Conference, pp.1-8.
EST (2007), "Energy-efficient refurbishment of existing housing", Energy Saving Trust, London.
EST (2010). "Fabric first, Focus on fabric and services improvements to increase energy performance in new homes", Energy Saving Trust, London.
Flanagan, R. and Jewell, C. (2005), *Whole Life Appraisal for construction*, Blackwell Publishing Ltd., Oxford.
Froese, M. (2010), "The impact of emerging information technology on project management for Construction" *Automation in Construction*, 19 (5), pp. 531–538
Hamil, S. (2010), "What BIM is and How It is Being Used", CIBSE Report, London.
Hannele, K., Reijo, M., Tarja, M., Sami, P., Jenni, K., Teija, R. (2012). "Expanding uses of building information modeling in life-cycle construction projects", *Work,* 41 (2012), pp. 114-119.
HM Government (2010), "Low Carbon Construction, Innovation & Growth Team Final Report", London.
HM Government (2012), "Building Information Modelling - Industrial strategy: government and industry in partnership", London.
Horowitz, S., Christensen, C., Brandemuehl, M., Krarti, M. (2008), "An enhanced sequential search methodology for identifying cost-optimal building pathways", 30 July – 1 August, Berkeley, California, IBPSA-USA SimBuild Conference, pp. 1-8.
Institute for Sustainability (2011), "Sustainable Retrofit Guides", Technology Strategy Board, London.
Jankovic, L. (2012), *Designing Zero Carbon Buildings – Using Dynamic Simulation Methods*, Routledge, Abingdon.
Jenkins, D.P., Peacock, A.D., Banfill, P.F.G, Kane, D., Ingram, V., Kilpatrick, R. (2012), "Modelling carbon emissions of UK dwellings - The Tarbase Domestic Model." *Applied Energy,* 2012 (93), pp. 596-605.
Juan, Y-K., Kim, JH., Roper, K., Castro-Lacouture, D. (2009), "GA-based decision support system for

housing condition assessment and refurbishment strategies”, *Automation Construction*, 18 (2009), pp. 394–401.
Kelly, M.J. (2009), “Retrofitting the existing UK building stock”, *Building Research & Information*, 37 (2), pp. 196-200.
Killip, G. (2008), “Building a Greener Britain”, Federation of Master Builders, UK.
Konstantinoua, T., Knaack, U. (2013), “An approach to integrate energy efficiency upgrade into refurbishment design process, applied in two case-study buildings in Northern European climate.” *Energy and Buildings,* 59 (2013), pp. 301-309.
Kreith, F. and Goswami, D.Y. (2008), *Energy Management and Conservation Handbook*, CRC Press, Florida.
Lindner, F. and Wald, A. (2011), “Success factors of knowledge management in temporary organizations”, *International Journal of Project Management*, 29 (7), pp. 877–888.
Ma, Z.; Cooper, P.; Daly, D.; Ledo, L. (2012), “Existing building retrofits: Methodology and state-of-the-art”, *Energy and Buildings*, 2012 (55), pp. 889–902.
McMullan, R. (2007), *Environmental science in building*, Palgrave Macmillan, Basingstoke.
Menassa, C.C., (2011) “Evaluating sustainable retrofits in existing buildings under uncertainty”, *Energy and Buildings,* 2011 (43), pp. 3576–3583.
Monteiro, H. and Freire, F. (2012), “Life cycle assessment of a house with alternative exterior walls: comparison of three impact assessment methods”, *Energy and Buildings*, 47 (2012), pp. 572–583.
Murray, S.N., Rocher, B., O'Sullivan, D.T.J. (2012), “Static Simulation: A sufficient modelling technique for retrofit analysis.” *Energy and Buildings,* 47 (2012), pp. 113-121.
National Refurbishment Centre (2012), “Refurbishing the Nation - Gathering the evidence”, National Refurbishment Centre, Watford.
NBS (2016), “National BIM Report 2016”, London.
Neufert, E. and Neufert, P. (2012), *Neufert Architects’ Data*, Blackwell Publishing, Oxford.
ONS (2014), "Output in the Construction Industry", London.
Park. K. and Kim, K.P. (2014), “Essential BIM Input Data Study for Housing Refurbishment: Homeowners’ Preferences in the UK”, *Buildings*, 4 (3), pp. 467-487
Redmond, A., Hore, A., Alshawi, M., West, R. (2012), “Exploring how information exchanges can be enhanced through Cloud BIM”, *Automation in Construction*, 24 (2012), pp. 175–183.
Reeves, A. (2009). “Achieving deep carbon emission reductions in existing social housing: the case of Peabody”, Ph.D thesis, De Montfort University.
RIBA (2013), “RIBA Plan of Work 2013”, London.
Riley, M. and Cotgrave, A. (2008), *Construction Technology 1: House Construction*, Palgrave Macmillan, London.
Riley, M. and Cotgrave, A. (2011), *Construction Technology 3: The Technology of Refurbishment and Maintenance*, Palgrave MacMillan, London.
Rysanek, A.M., Choudhary, R. (2013), “Optimum building energy retrofits under technical and economic uncertainty.” *Energy and Buildings,* 57 (2013), pp. 324–337.
Sebastian, R., Haak, W., Vos, E. (2009), "BIM Application for Integrated Design and Engineering in Small-Scale Housing Development: A Pilot Project in The Netherlands", 2-4 November, CIB-W096, Taiwan, pp. 161-171.
Scheneider, D., and Rode, P. (2010), “Energy renaissance”, High Performance Building, US.
Thuvander, L.; Femenías, P.; Mjörnell, K.; Meiling, P. (2012), “Unveiling the process of sustainable renovation”, *Sustainability,* 2012 (4), pp. 1188–1213.
Utley, J. I. and Shorrock, L. D. (2011), “Domestic energy fact file 2011”, Department Energy and Climate Change, London.
WWF (2008), “How Low- Achieving optimal carbon savings from the UK’s existing housing stock”, London.
Yin, R.K. (2003), *Case study research, design and methods*, Sage, Thousand Oaks.

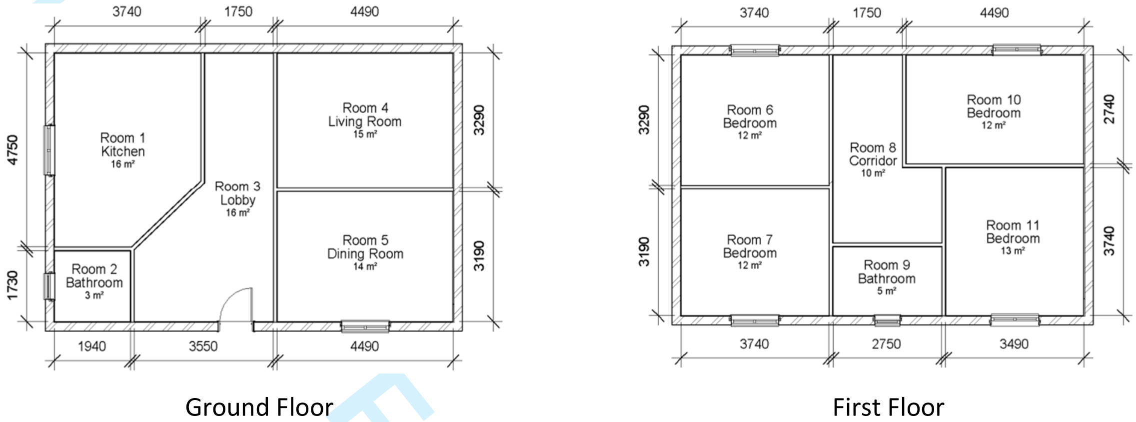


Figure 1. Floor Plan for Basic BIM Model

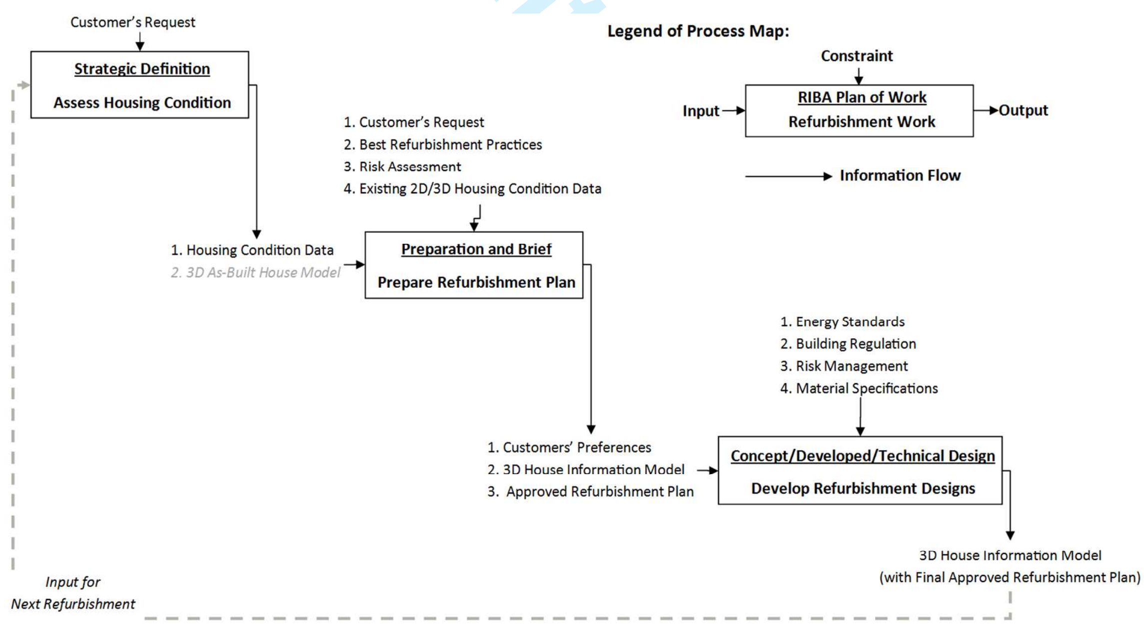


Figure 2. BIM-embedded Housing Refurbishment Process Map

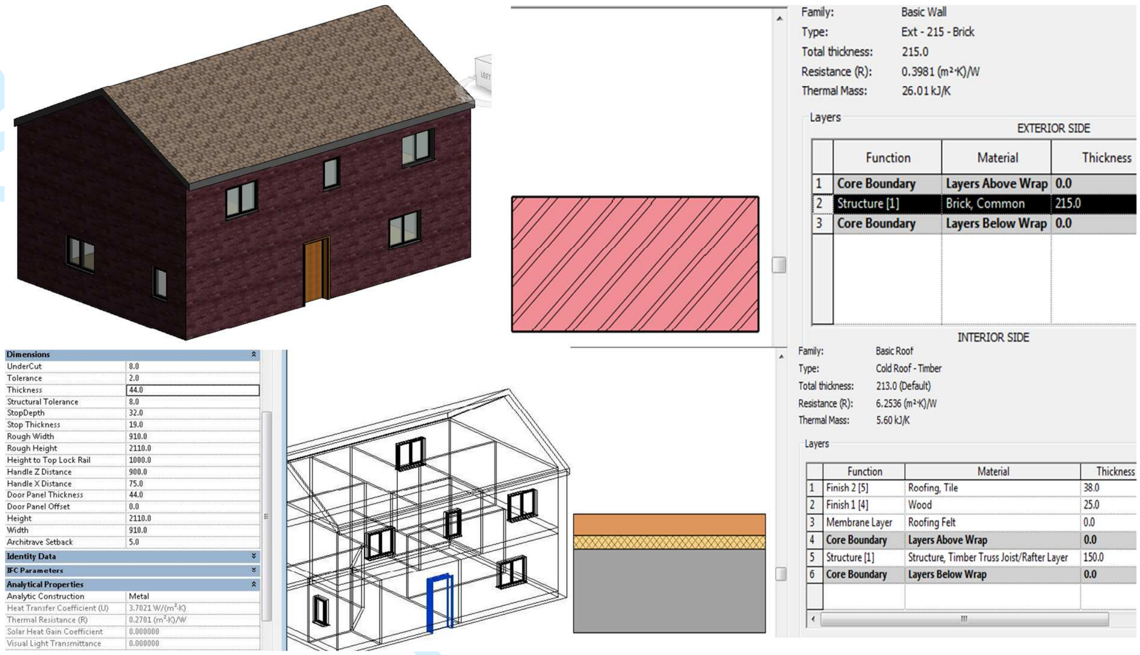


Figure 3. 3D Housing Information Model (top left) and each BIM object information

Level	Family and Type	Material: Name	Material: Cost	Material: Area	Material: Vol	Total Cost
Ground Floor	Floor: Timber Suspended Floor	Wood Sheathing, Chipboard	£24.56	67 m²	1.47 m³	£1645.14
Ground Floor	Floor: Timber Suspended Floor	Structure, Timber Joist/Rafter Layer	£7.79	67 m²	15.07 m³	£521.81
First Floor	Basic Ceiling: Generic	Gypsum Wall Board	£28.04	65 m²	0.00 m³	£1810.55
First Floor	Basic Ceiling: Generic	Gypsum Wall Board	£28.04	64 m²	0.00 m³	£1807.19
First Floor	Floor: Timber Suspended Floor	Wood Sheathing, Chipboard	£24.56	67 m²	1.47 m³	£1645.14
First Floor	Floor: Timber Suspended Floor	Structure, Timber Joist/Rafter Layer	£7.79	67 m²	15.07 m³	£521.81

Figure 4. Material Take-off Function in BIM

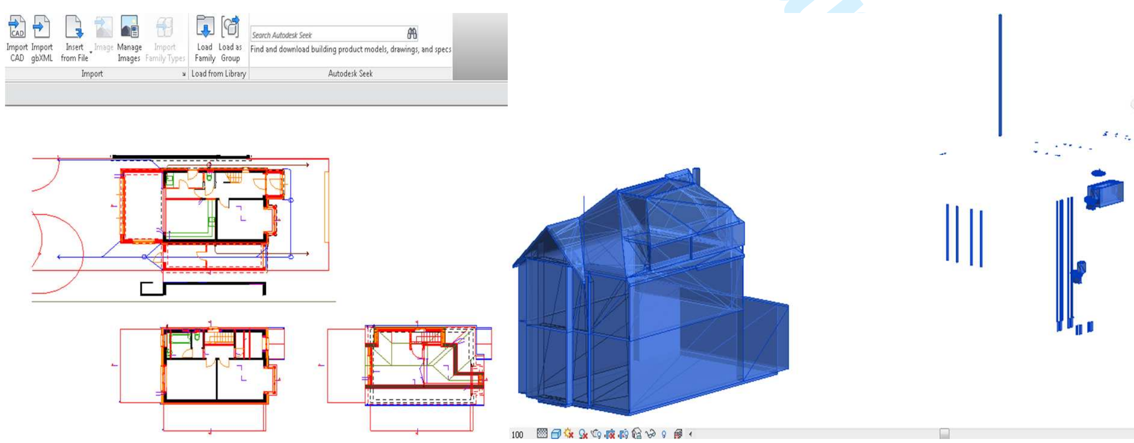


Figure 5. Result of Importing CAD file format into BIM system (Left: 2D CAD, Right: 3D CAD)

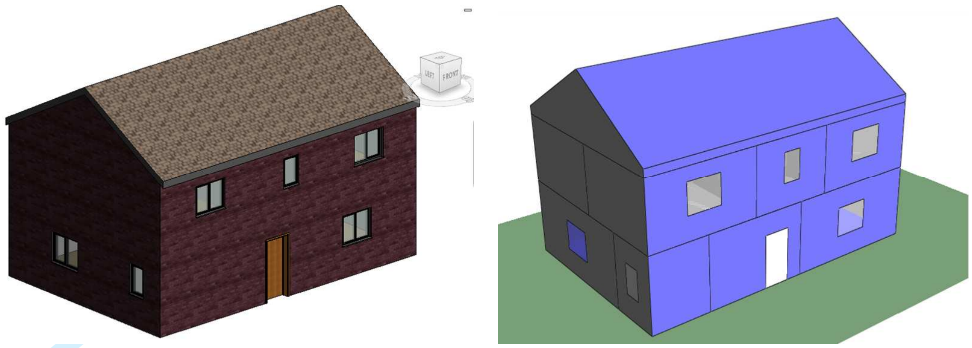


Figure 6. Basic Model Import Result using gbXML format in IES VE (Left: Autodesk Revit, Right: IES VE)

Table 1: Detailed Construction Information

Element	Construction Type	Components	Thickness (mm)
Roof	Pitched Roof with Timber Joist and Rafter	Roofing Tile	25
		Wood (Batten)	25
		Roofing Felt	5
		Timber Structure	140
External Wall	Solid Brickwork Masonry Wall (Single Leaf)	Dense Gypsum Plaster	13
		Solid Brickwork	220
Floors	Suspended Timber Floor	Timber Joist Structure	225
		Chipboard	25
		Carpet	10
Windows	Double Glazing	Timber Frame	6mm Glazing
Exterior Door	Wooden Door	Wooden Door	44

Table 2: BIM Input Datasets for the Early Design Phase of Housing Refurbishment

Phase	Work Stage	BIM Input Dataset
Assessment	Strategic Definition	• Housing Type and Year Built (As-Built data) • Dimensions: a) Floor areas (Floor Plans) b) Storey heights c) Building fabric elements (wall, roof, floor, window and door) • Detailed Construction Information: a) Construction Types for all fabric elements b) Material Types for External windows and doors c) U-values for all housing elements d) Additional Extension or in-situ construction • Occupancy data, and SAP rating data
	Preparation and Brief	• Customer's Preferences (Park and Kim, 2014): a) Refurbishment Priorities of House Element b) Decision Making Factors for Selecting Refurbishment Options c) Refurbishment Materials • 3D House Information Model • Planned Whole-house Refurbishment Solution (Combination of Refurbishment Options)
Design	Concept Design Developed Design Technical Design	• Building Regulations • Energy Standards: a) Building Regulation 2010/2013 Part La (Minimum) b) Building Regulation 2010/2013 Part La (Notional) c) Fabric Energy Efficiency Standard (Maximum) • Refurbishment Material Specification: a) Attributes of Materials (Thickness and Types) b) U-value for Windows including frames and secondary/tertiary glazing system e) Initial material and Installation costs • Risk assessment for continuity of insulations

Table 3: Reliability Check for BIM Simulation Outcome

Description	EST House (Floor Area: 104 m2)		Basic Case House (Floor Area: 130 m2)	
	Pre-Refurbishment	Post-Refurbishment	Pre-Refurbishment	Post-Refurbishment
Roof U-value	2.30	0.10	2.30	0.10
Wall U-value	2.10	0.18	2.18	0.18
Floor U-value	0.74	0.15	0.70	0.15
Window U-value	4.80	1.50	4.83	1.54
Door U-value	3.00	1.00	3.03	1.03
Energy Demand for Heating (kWh/yr/m2)	597	73 (89% Reduction)	209.8	40.8 (80% Reduction)
Energy Cost for Heating (£)	1,498	251 (83% Reduction)	1,150	225 (80% Reduction)
CO2 Emission for Heating (kg/yr/m2)	84.9	5.2 (94% Reduction)	84.5	40.6 (52% Reduction)