EXPLORATORY RESEARCH ON BIM INTEGRATION IN HOUSING REFURBISHMENT IN THE UK

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A whole-house refurbishment is challenging due to the complicated decision making process and inefficient integration of diverse construction information at the early design phase to develop a proper refurbishment solution. Although Building Information Modelling has been introduced to enhance the integration and coordination of construction information, current BIM uptake in the housing sector remains low with 13% due to a lack of practical guide for BIM utilization.
Thus, this research aims at identifying essential and practical BIM input data to determine an affordable refurbishment solution. This research adopts a case study with an energy simulation, and conducts a comparative analysis for reliability check of research outcomes. Consequently, seven major BIM input datasets for the assessment and four major datasets for the design phases are identified to develop an information enriched BIM model, and it is revealed that BIM is feasible to utilise for housing refurbishment when essential datasets are compiled and integrated into a BIM model. The findings of this research contribute to providing essential BIM input datasets that can be practically used for whole-house refurbishment and a better understanding of a BIM environment.

Keywords: BIM, housing refurbishment, whole-house refurbishment

INTRODUCTION

The housing sector alone accounts for 27% of the total UK CO2 emissions (Kelly, 2009), and 87% of those housing responsible for the 27% CO2 emission will still be standing in 2050. Thus, the housing sector has a large potential to reduce CO2 emission by improving energy efficiency of homes to achieve the UK government's CO2 emission reduction target by 2050, and refurbishment is considered a better option than demolish-and-rebuild because of the financial and environmental benefits (Livingstone, 2008; Riley and Cotgrave, 2011). Yet, currently housing refurbishment is partially implemented because low initial costs with a short payback period are mainly considered, although current refurbishment practice is only capable of achieving limited CO2 reduction with 25 to 35% (McMullan, 2007; Thorpe, 2010).

Consequently, there is increasing consensus among researchers that whole-house refurbishment is inevitable to achieve the reduction target (Boardman, 2007; Killip, 2008). 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; Construction Products Association, 2014) because an entire house will be

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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 (Ma *et al*., 2012; 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 to seek a financially and environmentally affordable refurbishment solution by a case study with an energy 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). Rysanek and Choudhary (2013) assert that refurbishment projects should utilise a 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.

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 BIM has been mainly implemented into large-scale new build projects (Arayici *et al*., 2011), and 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, 2015). 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. Thus, this research focuses on identifying essential BIM input data for whole-house refurbishment at the early design phase.

RESESARCH 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 the currently prevalent tool in the UK compatible with AutoCAD platform that is still widely utilised in the UK construction sector (NBS, 2015). The IES VE has been evidenced by a number of researches for energy simulation in refurbishment and has a capability to simulate all possible building energy assumptions compared to other tools (Murray *et al*., 2012; Crawley *et al*., 2008). Since there is no ‘one-size-fits-all’ solution for housing refurbishment in the UK (Jenkins *et al*., 2012), the tool must be capable of coping all possible alternatives and this requirement makes the IES VE relevant for this research. 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 (See Table 2), 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).

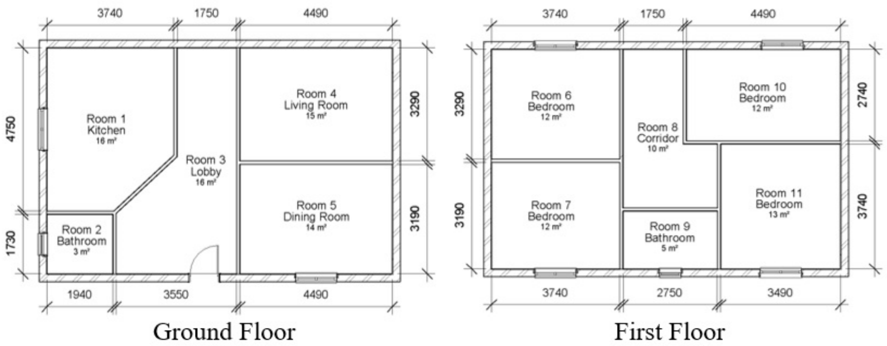

Figure 1. Floor plan for basic BIM model

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
Ceiling	Generic Ceiling	Gypsum Wall Board	12.5
Windows	Double Glazing	Timber Frame	6mm Glazing
Exterior Door	Wooden Door	Wooden Door	44

**Note: The Gross Internal Floor Area (GIFA) was used for the cost estimation.*

RESULTS AND DISCUSSION

Reliability check for BIM Simulation Outcome

The reduction rates for energy demand for heating and energy cost for heating indicate high similarity, while the amounts of CO_2 emission indicate 42% difference as shown in Table 2. 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 CO_2 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 CO_2 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 2: 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.

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 are identified and summarised as seen in Table 3.

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. 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 must be considered for the planning permission. 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.

Table 3: 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) and Storey heights b) Areas of all 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, SAP rating data
	Preparation and Brief	• Customer's Preferences (Park and Kim, 2014): a) Refurbishment Priorities of House Element (Floor, Wall, Roof/Loft, Window, Door, Heating System) b) Decision Making Factors for Selecting Refurbishment Measures (Initial Cost, Disruption, Payback Period, Low Maintenance, CO2 Reduction) c) Refurbishment Materials • 3D House Information Model • Planned Whole-house Refurbishment Solution (Combination of Refurbishment Measures)
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) Thickness and Types of Materials b) U-value for Windows including frames and secondary/tertiary glazing system e) Initial Material and Installation costs • Risk assessment for continuity of insulations

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 3). 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. 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.

REFERENCES

Arayici, Y, Coates, P, Koskela, L, Kagioglou, M, Usher, C and O'Reilly, K (2011) Technology Adoption in the BIM Implementation for Lean Architectural Practice. *Automation in Construction*, **20**(2), 189-195.

Basbagill, J, Flager, F, Lepech, M, and Fischer, M (2013) Application of life-cycle assessment to early stage building design for reduced embodied environmental impacts, Building and Environment, 60, 460–470

Boardman, B (2007) *Home Truths, A Carbon Strategy To Reduce UK Housing Emission By 80% By 2050 ECI Research Report 34*. Oxford: University of Oxford's Environmental Change Institute.

Burton, S (2012) *Handbook of Sustainable Refurbishment-Housing*. Abingdon, Oxon: Earthscan.

Construction Products Association (2014) *An Introduction To Low Carbon Domestic Refurbishment 2nd Edition*. London, UK: Construction Products Association.

Crawleya, D B, Handb, J W, Kummertc, M and Griffith, B T (2008) Contrasting the capabilities of building energy performance simulation programs. *Building and Environment*, **43**(4), 661-673.

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

Doran, D, Douglas, J and Pratley, R (2009) *Refurbishment and Repair in Construction*. Boca Raton, FL: Whittles Publishing.

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

Energy Saving Trust (2009) *CE330 - House Comparison Complete Set*. London, UK: Energy Saving Trust.

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

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

Hamil, S (2010) *What BIM is and How It is Being Used*. London, UK: CIBSE.

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

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

Institute for Sustainability (2011) *Sustainable Retrofit Guides*. London, UK.

Jenkins, D P, Peacock, A D, Banfill, P F G, Kane, D, Ingram, V and Kilpatrick, R (2012) Modelling carbon emissions of UK dwellings: The Tarbase Domestic Model. *Applied Energy*, **93**, 596-605

Kelly, M J (2009) Retrofitting the existing UK building stock. *Building Research & Information*, **37**(2), 196-200.

Killip, G (2008) *Building a greener Britain: Transforming the UK's existing housing stock*. London: Federation of Master Builders.

Kreith, F and Goswami, D Y (2008) *Energy Management and Conservation Handbook*. Boca Raton, Florida, USA, 2008: CRC Press, Taylor & Francis Group.

Livingstone, J (2008) *UK Residential Tower Blocks Demolish Or Refurbish: The Energy Perspective.* MSc Thesis, University of East London, School of Computing and Technology, University Way, London

Ma, Z, Cooper, P, Daly, D and Ledo, L (2012) Existing building retrofits: Methodology and state-of-the-art. *Energy and Buildings*, **55**, 889-902.

McMullan, R (2007) *Environmental Science in Building*. Basingstoke, UK: Palgrave Macmillan.

Menassa, C (2011) Evaluating sustainable retrofits in existing buildings under uncertainty. *Energy and Buildings*, **43**(12), 3576-3583.

Murray, S N, Rocher, B and O'Sullivan, D T J (2012) Static simulation: A sufficient modelling technique for retrofit analysis. *Energy and Buildings*, **47**, 113-121.

NBS (2015) National BIM Report 2015, London, UK.

National Refurbishment Centre (2012) *Refurbishing the Nation: Gathering the Evidence*. Watford: London National Refurbishment Centre.

Neufert, E and Neufert, P (2012) *Neufert Architects' Data*. Oxford, UK: Blackwell Publishing.

Office for National Statistics (2014) *Output in the Construction Industry*. London, UK: Office for National Statistics.

Park, K S and Kim, K P (2014) Essential BIM input data study for housing refurbishment: Homeowners' preferences in the UK. *Buildings*, **4**(3), 467-487

Royal Institute of British Architects (2013) *RIBA Plan of Work 2013*. London, UK: Royal Institute of British Architects.

Riley, M and Cotgrave, A (2008) *Construction Technology 1: House Construction*. London, UK: Palgrave Macmillan.

Riley, M and Cotgrave, A (2011) *Construction Technology 3: The Technology of Refurbishment and Maintenance*. London: Palgrave, MacMillan.

Rysanek, A M and Choudhary, R (2013) Optimum building energy retrofits under technical and economic uncertainty. *Energy and Buildings*, **57**, 324-337

Sebastian, R, Haak, W and Vos, E (2009) BIM application for integrated design and engineering in small-scale housing development: A pilot project in the Netherlands. *In*: *International Symposium on Future Trends in Architectural Management (CIB-W096),* November 2-3, Taiwan. National Cheng Kung University: Taiwan, 161-171.

Thorpe, D (2010) *Sustainable Home Refurbishment*. London, UK: Earthscan.

Thuvander, L, Femenías, P, Mjörnell, K and Meiling, P (2012) Unveiling the process of sustainable renovation. *Sustainability*, **4**(6), 1188-1213.

Utley, J I and Shorrock, L D (2011) *Domestic Energy Fact File 2011.* London, UK: Department of Energy & Climate Change.

Yin, R K (2003) *Case Study Research, Design and Methods, 3rd Edition*. Thousand Oaks, CA: Sage Publications.