Exploring Capabilities of BIM Tools for Housing Refurbishment in the UK

Kim, Ki Pyung 1) · Park, Kenneth S 2)

Received May 19, 2016; Received June 26, 2016 / Accepted September 29, 2016

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

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

1. Introduction

The UK government legislated in the Climate Change Act 2008 for an 80% CO2 reduction by 2050 against 1990 levels and it is very challenging because it could not be achieved without improving energy efficiency across all sectors of the UK economy. The similar efforts to reduce CO2 emission have been made in South Korea as the government mandates 90% energy consumption reduction against 2009, and zero energy building from 2025 (MOLIT, 2014). UK Government mandates more efficient use of energy in all economic sectors, and in particular more attention should be drawn to the housing sector as it a major contributor to a large amount of energy consumption and CO2 emissions (Bell and Lowe, 2000). The UK has the oldest housing stock among the developed countries as 8.5 million properties are over 60 years old (National Refurbishment Centre, 2012), and currently, 45% of total CO2 emission in the UK is generated from the existing buildings, and particularly, existing housing stock alone accounts for 27% (Kelly, 2009). Particularly, 10% of total income of average family in South Korea is spent on energy and fuel for heating and hot water which is large amount of expenditure. Thus, it is important to improve energy efficiency and reduce carbon emission by 2025. Indeed, there is a great opportunity lying on the existing housing stock to achieve the targeted CO2 reduction as the whole-house refurbishment can achieve significant energy savings and CO2 reduction since all the refurbishment works will be carried on at once and many researchers agree that comprehensive whole-house refurbishment for substantial energy efficiency improvement of existing housing stock needs to be adopted to achieve the reduction target (Itard and Meijer, 2008; Summerson, 2011; Boardman, 2007; Killip, 2008; Reeves, 2009). However, the whole-house refurbishment requires a larger capital investment in the construction phase to achieve lower operational energy cost and CO2 emission in the use phase and there is a lack of skilled personnel who can manage the trade-off.
relationship between the capital investment and energy efficiency improvement for providing affordable refurbishment solution although it is essential to maximise value for money (Menassa, 2011; Konstantinoua and Knaack, 2013; Thuvander et al., 2012). To challenge this, the UK government and researchers recommend the Life Cycle Costing (LCC) and Life Cycle Assessment (LCA) methodologies should be integrated to generate affordable refurbishment solutions and convince home occupants of high capital investment since the investment will often be compensated from reduced energy bill over a building life cycle (Bowsell and Walker, 2004; BSI, 2008; Hacker et al, 2008; HM government, 2010). For example, when the LCC is considerably planned, 60% of operational cost savings can be achieved over 30 years by investing 20% more capital cost in the construction phase (Flanagan and Jewell, 2005) and the better performance of a low carbon house can be examined in comparison with a traditional house.

2. LCC and LCA Studies in the Housing Sector

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

3. Research Methodology

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

- LCC and LCA – IES IMPACT dataset (BRE, 2013)
- Cost for Materials and Labour – SMM7 Estimating Price Book 2013 (BCIS, 2012)
- Embodied CO₂ for Materials–University of Bath
In order to generate more reliable information for LCC and LCA, data sources provided by highly-rated construction organizations have been used as inputs at the beginning to avoid a situation known colloquially as ‘garbage in, garbage out’. In order to avoid biased information of BIM objects provided by third parties, the data published by well-known construction organizations are adopted. This research requires no control over behavioural events, and focuses on contemporary event which is energy vulnerable housing refurbishment using BIM in the UK to identify interactions and relationships between building information datasets asking how and why (Yin, 2003). Thus, a case study is the most relevant strategy for this research compare to other strategies such as surveys, grounded theory and action research.

3.1 Scope of Simulation

For the BIM simulation, this research first determined a detached solid wall house as a basic simulation model because this is the most energy inefficient housing type requiring immediate attention and in needs of refurbishment (National Refurbishment Centre, 2012; Kim, 2014). Once the case housing type is decided, the average housing condition data published by the UK government was used to build up a case building model in a BIM system hypothetically because the condition of solid wall housing indicates a wide range of variation in its characteristic such as year built, construction types physical dimensions, extra retrofitted measures and construction materials, which cannot be generalized. After establishment of a basic model, this research narrowed the scope of whole-house refurbishment down to the whole-house fabric refurbishment, as the fabric approach should be the first stepping stone to improve a whole-house and various researchers and construction professional organizations have argued that the whole-house fabric should be improved first rather than upgrade services or renewable energy systems (Rosa, 2012; Gupta and Chandiwala, 2010: National Refurbishment Centre, 2012; EST, 2010: Institute for sustainability, 2011, Zero Carbon Hub, 2012). The current refurbishment best practices for whole-house refurbishment applied for solid wall housing were identified as shown in Table 1, in order to implement refurbishment measures in a BIM simulation.

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

3.2 Basic Information for House Model

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

| Table 1. Best refurbishment practices for whole-house fabric refurbishment |
|---------------------------------|-----------------|-----------------|
| **Element** | **Construction Type** | **Best Refurbishment Measure** |
| Roof | Pitched Roof | Rafter or Loft Insulation |
| Wall | Solid Wall | External or Internal Wall Insulation |
| Floor | Suspended Timber Floor | a. Underfloor Insulation (Insulation between joists) |
| | | b. Surface Insulation (Insulation over the floor board) |
| Window | Single Glazing | Double or Triple Glazing |

| Table 2. General information about a house for simulation |
|---------------------------------|-----------------|-----------------|
| **Information** | **Detached House** |
| Number of Bedrooms | 4 Bedrooms |
| Construction Type | Solid Brick Wall |
| Ventilation | Natural Ventilation |
| Heating (using water) | Radiator |
| Main Energy Source | Natural Gas |
| Household size (Number of people) | Single Family (2,3) |
| Indoor Temperature | 19–23°C |
| Usable Floor Area | 130 m² |
| Ceiling Heights (Ground and First Floor) | 2.7 m |
Table 3. Room and space information

| Information | Room      | Detached House | Area (m²) |
|-------------|-----------|----------------|-----------|
| Ground Floor| Room 1    | Kitchen        | 16        |
|             | Room 2    | Bathroom       | 3         |
|             | Room 3    | Lobby          | 16        |
|             | Room 4    | Living Room    | 15        |
|             | Room 5    | Dining Room    | 14        |
|             | Room 6    | Bedroom        | 12        |
|             | Room 7    | Bedroom        | 12        |
|             | Room 8    | Corridor       | 10        |
|             | Room 9    | Bathroom       | 5         |
|             | Room 10   | Bedroom        | 12        |
|             | Room 11   | Bedroom        | 13        |
|             | Total Usable Floor Area | 130    |

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

Figure 2. Floor plan for a typical detached house

Table 4. Construction information

| Element                  | Construction Type                                | Component                  | Thickness (mm) | U-value (W/m²K) |
|--------------------------|--------------------------------------------------|----------------------------|----------------|-----------------|
| 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             |
| Party Wall               | Timber Stud Partition Wall                      | Gypsum Wall Board         | 12.5           |                 |
|                          |                                                  | Air Infiltration Barrier  | 7.5            |                 |
| Floors                   | Suspended Timber Floor                           | Timber Joist Structure    | 225            | 0.7             |
|                          |                                                  | Chipboard                 | 25             |                 |
|                          |                                                  | Carpet                     | 10             |                 |
| Ceiling                  | Generic Ceiling                                 | Gypsum Wall Board         | 12.5           | N/A             |
| Windows                  | Double Glazing                                  | Double Glazing, TimberFrame | 6mm Glazing   | 2.0             |
| Exterior Door            | Wooden Door                                     | Wooden Door                | 44             | 3.0             |

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

3.3 Energy Performance Standard

Building Regulation Part L 2010, Building Regulation Part L 2013 and the Fabric Energy Efficiency Standard (FEES) will be adopted for energy simulations. The Building Regulation Part L 2010 and 2013 (BR 2010/2013) mandates the minimum energy efficiency standard for housing fabric as shown in Table 6. The FEES has been recently introduced to the Building Regulation Part L 2013 aimed at achieving zero carbon homes by 2016, which provides the maximum energy efficiency level. These energy efficiency standards
Table 5. Energy efficiency standards

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

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

3.4 Data Analysis for LCC and LCA

This research has adopted a 60-year life cycle study because it was assumed that the life span for LCC and LCA studies was 60 years (ISO, 2008). The embodied CO$_2$ calculation adopted the cradle to site study (ISO, 2006). This research has excluded the categories including client definable costs and administrative and overheads cost in order to secure reliability of data analysis because these costs are estimated separately depending on clients’ request (ISO, 2008) and there is no published standardised data available. More detail assumption about construction cost based on the NRM – Risk contingency and other costs are not included since this energy simulation is conducted under the fully controlled environment based on a hypothetical case study. The LCA study adopts a Cradle to Grave approach with the exclusion of the recycle, reuse and/or disposal stage as this contributes minimal percentages of CO$_2$ impact throughout the entire life cycle of a house (Rosa, 2012).

4. Research Results

4.1 Basic Model Transfer between BIM tools

The study found that the IFC format cannot be exchanged between Autodesk Revit and IES VE/IMPACT. The geometric arrangement is broken when IFC data is transferred to IES VE/IMPACT, while gbXML format transfer an intact model in terms of geometric information (See Fig. 1). All the geometric information is not presented in the same way although the IFC data format is supposed to be a communication channel between different BIM tools. Interoperability between different BIM tools is a critical technical barrier, yet the interoperability issues are still not resolved although the concept of IFC and gbXML data formats within BIM system should exchange necessary data without any conflicts. Thus, the gbXML file format is recommended for data exchange between BIM tools and IES VE/IMPACT. Although, the gbXML format transfers geometric information without distortion of a model, other refurbishment information such as insulation materials is not transferred. The missing information about the insulation materials needs to be manually entered and reviewed in IES VE/IMPACT. As a demonstration purpose, external wall insulation was used for testing data loss as shown in Figure 3 and 4.

4.2 Incomplete Dataset for LCC and LCA

The life cycle costs and CO$_2$ information of BIM objects should be created in a standardised format in both BIM tools –Autodesk Revit and IES VE/IMPACT. However, the Revit has its own generic material database provided by third parties, and IES VE/IMPACT also has its own dataset and data format based on the green guide to specification developed by the BRE. As a result, LCC and LCA for the construction phase, i.e. LCC for construction costs and LCA for embodied CO$_2$ cannot be currently calculated from the generic construction material database imported from Revit as shown in Figure 5.

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

LCC and LCA information for operation and maintenance phase for 60 years are calculated by MS Excel as well (Appendix 1). Although there are issues regarding interoperability and dataset, IES VE/IMPACT is capable of calculating the total amount of CO₂ emission and energy costs (Electricity and Gas) once proper construction materials are chosen. Finally, the LCC and LCA information for whole-house fabric refurbishment have been formulated as shown in Table 6.

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

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

6. Conclusion

The purpose of this study is to seek the way in which informed decision is made based on the LCC and LCA results through a case study adopting IES VE/IMPACT, and to explore capabilities and limitations of IES VE/IMPACT utilization as a BIM tool for a whole-house refurbishment project. As a result, this research reveals that the IES VE/IMPACT is a feasible BIM tool for whole-house refurbishment by providing LCC and LCA information simultaneously for informed decision on refurbishment solution selection. More importantly, this research reveals limitations and barriers in utilising BIM tools for housing refurbishment. In particular, the seamless information exchange between two different BIM tools — Autodesk Revit and IES VE/IMPACT — is not yet achievable. For geometric data exchange, the gbXML format is recommended for IESVE/IMPACT rather than IFC format, in addition, it is revealed that cost and thermal performance data is not transferred from Autodesk Revit to IES VE/IMPACT. In order to develop a house model with accurate information of LCC and LCA, inefficient process such as reviewing transferred model and re-entering construction information is inevitable. Furthermore, LCC and LCA information for types of refurbishment different materials are not readily available in the IES VE/IMPACT. In order to calculate accurate LCC and LCA information, manual information feeding and calculation of LCC and LCA using MS Excel in conjunction with IES VE/IMPACT is required. Finally, the differences of LCC and LCA depending on refurbishment materials are identified. Therefore, it is found out that additional efforts from construction professionals and industry are required to standardise common BIM objects library with LCC and LCA. Without reliable dataset about construction materials in terms of cost and CO₂ performance of housing elements, the application of BIM concept cannot add more value to the customers and the construction industry. Thus, the preparation of detailed BIM objects with required dataset such as accurate as-built condition and cost information is revealed as a critical step for utilization of successful BIM tools for housing refurbishment. This research is expected to provide an opportunity for construction professionals and industry to enhance understanding of BIM-enabled environment and IES VE/IMPACT for housing refurbishment in the UK context. Although this research is confined to the UK housing sector, the implication of use of BIM tools for housing refurbishment should provide valuable insights and lessons learned for Korean construction professionals to attempt to use proper BIM tools for their practice. Future research should focus on exploring further in the BIM dataset for practical implementation of a BIM system on housing refurbishment with a realistic case study.

References

Adalberth, K., Almgren, A. and Petersen, E, H. (2001). Life cycle assessment of four multi?family buildings, International Journal of Low Energy and Sustainable Buildings, 2001(2), pp. 1-21.

Asif, M., Muneer, T., Kelley, R. (2007). Life cycle assessment: A case study of a dwelling home in Scotland, Building and Environment, 2007(42), pp. 1391-1394.

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.
BCIS (2012). SMM7 Estimating Price Book 2013, Building Cost Information Service, UK.
Bell, M. and Lowe, R. (2000). Energy efficient modernisation of housing: A UK Case study, Energy and Buildings, 32 (3), pp.267–280.
Blengini, G. A., Di Carlo, T. (2010). The changing role of life cycle phases, subsystems and materials in the LCA of low energy buildings, Energy and Buildings, 2010(42), pp, 860–880.
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.
Boswell, P. and Walker, L. (2004). Procurement and Process Design, FIDIC and Lorna Walker Consulting Ltd., Geneva/ London.
BRE (2011), RdSAP 2009, The Government’s Standard Assessment Procedure for Energy Rating of Dwellings 2009 edition incorporating RdSAP 2009, BRE, Watford, UK.
BRE (2013), Green Guide Specification, Watford, UK.
Bribian, I.Z., Uson, A.A., Scarpellini, S. (2009), Life cycle assessment in buildings: state–of the–art and simplified LCA methodology as a complement for building certification, Building and Environment, 44(12), pp, 2510–2520.
Brinkley, M. (2008), The Housebuilder’s Bible (7th Edition), Ovolo Publishing, Cambridge, UK.
BSI (2010), Constructing the Business Case: Building Information Modelling; British Standards Institution and Building SMART UK: London/Surrey, UK, 2010.
BSI (2008), Standardised method of life cycle costing for construction procurement, A supplement to BS ISO 15686–5, Buildings and constructed assets, Service life planning, Life cycle costing, London.
Construction Products Association (2014). An introduction to low carbon domestic refurbishment, London, UK.
Crawleya, D.B., Hando, J.W., Kummerle, M., Griffith, B.T. (2008), Contrasting the capabilities of building energy performance simulation programs, Building and Environment, 2008(43), pp, 661–673.
EST (2010), Fabric first, Focus on fabric and services improvements to increase energy performance in new homes, CE320, Energy Saving Trust; London,
Finnveden, G.A., Hauschild, M., Ekvall, T., Guiney, J., Heijungs, R., Hellweg, S., Koehler,A., Pennington, D., and Suh, S. (2009), Recent developments in Life Cycle Assessment, Journal of Environmental Management, 91(1), pp, 1–21.
Flanagan, R. and Jewell, C. (2005), Whole Life Appraisal for construction, Blackwell Publishing Ltd., Garsington Road, Oxford.
Franklin and Andrews (2010), UK Building Blackbook: The Cost and CarbonGuide Hutchins: 2011.
Grilo, A.; Jardim–Goncalves, R. (2010). Value proposition on interoperability of BIM and collaborative working environments, Automation in Construction, 2010(19), pp, 522–530.
Gupta, R. and Chandiwala, S. (2010), Understanding occupants: feedback techniques for large–scale low–carbon domestic refurbishments, Building Research & Information, 38(5), pp, 530–548.
Hacker, J., De Saulles, T. P., Minson, A. J., Holmes, M. J. (2008), Embodied and operational carbon dioxide emissions from housing: A case study on the effects of thermal mass and climate change, Energy and Buildings, 40 (2008), pp, 375–384.
Hammond, G. P., Jones, C. I. (2008). Embodied energy and carbon in construction materials, Proceedings of Institution of Civil Engineers: Energy, 161(2008), pp, 87–98.
HM Government (2010). Low Carbon Construction, Innovation & Growth Team Final Report, London, UK.
Institute for Sustainability (2011), Sustainable Retrofit Guides, Technology Strategy Board, London, UK.
Itard, L., and Meijer, F. (2008). Towards a Sustainable Northern European Housing Stock: figures, facts and future, Research Institute OTB, Delft University of Technology.
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.
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: transforming the UK’s existing housing stock, London, Federation of Master Builders.
Kim, K.P. (2014), Conceptual Building Information Modelling framework for whole-house refurbishment based on LCC and LCA, PhD Thesis, Aston University, pp. 25–37.

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.

Martinaitis, V., Kazakevicius, E., Vitkauskašb, A. (2007), A two-factor method for appraising building renovation and energy efficiency improvement projects, Energy Policy, 35(2007), pp. 192–201.

Mohammadpourkarbasi, H. and Sharples, S. (2013), The Eco-Refurbishment of a 19th Century Terraced House: Energy and Cost Performance for Current and Future UK Climates, Buildings, 2013(3), pp. 220–244.

MOLIT (2014), Ministry of Land, Infrastructure and Transport, Experience of Energy Savings in Daily Life – Demand oriented Building Energy Performance Improvement Strategy, Gyeonggi, South Korea.

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, London.

NBS (2014), National BIM Report 2014, http://www.thenbs.com/pdts/NBS?National?BIM?Report?2014.pdf (May. 17, 2016).

Neufert, E. and Neufert, P. (2012), Neufert Architects’ Data, Blackwell Publishing, Oxford, UK.

Ortiz, O., Bonnet, C., Bruno, J.C., Castells, F. (2009), Sustainability based on LCM of residential dwellings: a case study in Catalonia, Spain, Building and Environment, 44(2009), pp. 584–594.

Park, K.S. and Kim, K.P. (2014), Essential BIM Input Data Study for Housing Refurbishment: Homeowners’ Preferences in the UK, Buildings, 2014(4), pp. 467–487.

Peuportier, B. L. P. (2001), Life cycle assessment applied to the comparative evaluation of single family houses in the French context, Energy and Buildings, 33(2001), pp. 443–450.

Redmond, A.; Hore, A.; Alshawi, M.; West, R. (2012), Exploring how information exchanges can be enhanced through Cloud BIM, Automation in Construction, 2012(24), 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.

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

Rosa, M., Franca, C., Azapagic, A. (2012), Environmental impacts of the UK residential sector: Life cycle assessment of houses, Building and Environment, 54(2012), pp. 86–99.

Summerson, G.M. (2011), Lessons learnt from piloting BREEAM Domestic Refurbishment, Watford, London.

Thuvander, L., Fememoa, P., Mjornell, K., Melling, P. (2012), Unveiling the Process of Sustainable Renovation, Sustainability, 4(6), p. 1188–1213.

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

Wang, W., Zmeureanu, R., Rivad, H. (2005), Applying multi-objective genetic algorithms in green building design optimization, Building and Environment, 40(15), pp. 12–25.

Yin, R.K. (2003), Case study research, design and methods 3rd ed., Sage, Thousand Oaks, CA.