Buildings **2014**, *4*, 467-487; doi:10.3390/buildings4030467

OPEN ACCESS

buildings

ISSN 2075-5309

www.mdpi.com/journal/buildings/

Article

Essential BIM Input Data Study for Housing Refurbishment: Homeowners' Preferences in the UK

Kenneth Sungho Park and Ki Pyung Kim *

School of Engineering and Applied Science, Aston University, Aston Triangle,
Birmingham B4 7ET, UK; E-Mail: s.h.park@aston.ac.uk

***** Author to whom correspondence should be addressed; E-Mail: kimkp@aston.ac.uk;
Tel.: +44-121-204-5172.

Received: 13 March 2014; in revised form: 25 July 2014 / Accepted: 4 September 2014 / Published: 11 September 2014

Abstract: Construction customers are persistently seeking to achieve sustainability and maximize value as sustainability has become a major consideration in the construction industry. In particular, it is essential to refurbish a whole house to achieve the sustainability agenda of 80% CO_2 reduction by 2050 as the housing sector accounts for 28% of the total UK CO_2 emission. However, whole house refurbishment seems to be challenging due to the highly fragmented nature of construction practice, which makes the integration of diverse information throughout the project lifecycle difficult. Consequently, Building Information Modeling (BIM) is becoming increasingly difficult to ignore in order to manage construction projects in a collaborative manner, although the current uptake of the housing sector is low at 25%. This research aims to investigate homeowners' decision making factors for housing refurbishment projects and to provide a valuable dataset as an essential input to BIM for such projects. One-hundred and twelve homeowners and 39 construction professionals involved in UK housing refurbishment were surveyed. It was revealed that homeowners value initial cost more while construction professionals value thermal performance. The results supported that homeowners and professionals both considered the first priority to be roof refurbishment. This research revealed that BIM requires a proper BIM dataset and objects for housing refurbishment.

Keywords: building Information modeling; housing refurbishment; homeowner's preference

---

1. Introduction

In the construction industry, it is a central issue for construction customers to maximize value, lower cost and achieve sustainability. Customers' recent design requirements have become more irregular and bespoke, which are difficult to be presented in a two-dimensional manner. Furthermore, sustainable approaches to a construction project such as high energy performance and low environmental impacts are increasingly becoming one of the major considerations in the construction industry. As a result, relevant construction information has become more specialized and larger in its volume, and it has become crucial to manage and integrate the massive amount of information amongst project stakeholders throughout a project life cycle. However, current construction practice has limited capability to manage a construction project in a collaborative and integrated manner. This is because construction projects are managed in a fragmented way based on 2D drawings during both design and construction phases. Due to the highly fragmented nature of the construction practice, data conflicts of design and unnecessary reworks and waste are commonly caused. Reworks due to poor detailed drawings and miscommunication cost about £1 billion annum in the UK [1]. In a situation where changes occurred in a design, labor-intensive works are mandated to integrate all the changes into various separate design documents and to generate updated design documents and information accordingly.

2. Sustainability of the Housing Sector in the UK

As the UK government is aiming at an 80% CO_2 reduction by 2050, sustainability in the UK construction sector has become the most overarching issue. Currently, 45% of the total UK CO_2 emission is generated from the existing buildings, and particularly the current existing housing stock accounts for 27% CO_2 [2]. Furthermore, 87% of the housing stock, which is responsible for current 27% CO_2 emission, will still stand in 2050 [3]. Thus, the housing sector will play a key role in achieving the CO_2 reduction target [4,5], although the targeted reduction could be achieved if energy efficiency across all sectors of the UK economy is improved. The UK government has initiated a series of incentive schemes for improving energy efficiency in the housing sector that mainly focuses on low upfront costs and a short payback period [4,6,7]. However, these measures are capable of achieving a limited CO_2 reduction of 25% to 35% [8,9]; consequently, many researchers recommend that a whole-house refurbishment—consideration of possible refurbishment measures from fabric to services—should be adopted to achieve the reduction target in time [3,10–12]. Despite all the efforts, the uptake of housing refurbishment amongst homeowners remains low. This is because there are the three major barriers when carrying out the whole-house refurbishments: little research on homeowners' requirements, high initial cost for whole house refurbishment and the fragmented practice of the construction sector. Sebastian *et al.* [13] revealed that 10%–25% loss of efficiency occurs in a construction project due to unplanned redesigns and ad-hoc modifications with a lack of communications during the construction phase. Eventually, this inefficiency results in delays in the schedule, compromised quality of a building and a higher price for the clients.

As a response to these problems in the construction sector, Building Information Modeling (BIM) has been introduced to manage the complexity of construction projects, achieve sustainability and integrate stakeholders' requirements and technical inputs/outputs. BIM has been recognized as a facilitating tool to improve the fragmented practice and productivity in the construction industry, and to lower the high construction project costs [14]. There are various research works and commercial reports that reveal various benefits of BIM adoption in the non-domestic sector. However, a limited amount of literature and studies is has been dedicated to BIM utilization for the housing sector despite the benefits of BIM as previously mentioned. In particular, homeowners' preferences and decision making factors for a housing refurbishment project have rarely been researched, although this is the most important and essential input for BIM utilization in housing refurbishment projects. Hence, this research aims at identifying homeowners' requirements for housing refurbishment, and revealing a possible outcome when homeowners' requirements are visualized and customized in BIM. Finally, the outcome of this research will provide a useful input dataset for a BIM enabled housing refurbishment project.

2.1. Homeowners' Preferences in Housing Refurbishment

High initial cost is one of the most significant barriers when adopting a whole house refurbishment. However, recent studies reveal positive possibility to extend the budget for refurbishment from homeowners as they are willing to allocate additional budget for energy efficiency improvement from £2000 to £10,000 [15,16]. According to this survey, homeowners have shown positive possibility to extend the budget for refurbishment. Nevertheless, they are not confident about the services proposed by construction professionals because the refurbishment solutions suggested by them are not always fully understood by homeowners. This situation is mainly caused by the unfriendly behavior towards customers in the construction industry [17,18], because construction professionals usually design and plan a refurbishment project based on their preferences and priorities, and eventually the unbalanced information and miscommunication between them misleads homeowners into believing that the construction professional may be providing unnecessary services [16,19]. Therefore, in order to provide a realistic and affordable solution to homeowners, it is essential to understand which elements of house homeowners prefer to refurbish the most, and what decision-making factors are considered when selecting refurbishment measures compared to construction professionals' preferences. The majority of homeowners are interested in what kinds of refurbishment solutions provide the best outcomes in energy efficiency [20]. In spite of the importance of homeowners' requirements, this subject has rarely been researched.

Lomas [21] asserts that construction professionals should research and integrate technical and socio-technical factors which refer to occupants' intentions and preferences in order to select the appropriate refurbishment measures. Mills and Schleich [22] revealed that a refurbishment solution fitting some people might not be applicable to others. This research revealed that the identification of homeowners' needs is significantly important from the outset of a project, and one-fits-all solution cannot be technically achievable [23,24]. Nair *et al.* [25,26] carried out extensive research on the relationship between energy efficiency improvement and the decision making factors for homeowners. It has identified that the experience of past investments in housing refurbishment has a strong influence on adopting refurbishment measures regardless of the level of income. More homeowners would invest in whole house refurbishment after having positive experiences of energy performance improvement such as thermal comfort and the energy savings [27,28]. Additionally, Banfill *et al.* [29] emphasize the importance of customer-oriented design, because homeowners indicated a tendency to accept proposed refurbishment measures more positively, and to recognize the potential benefits when they get clear explanation and understanding about refurbishment technologies. Therefore, the uptake of whole-house refurbishment should remain low unless homeowners' preferences are fully understood and the technical solutions are clearly visualized.

2.2. Process of Housing Refurbishment Project

It is difficult not only for homeowners to secure enough budget for housing refurbishment due to the current economic situation, but also for construction professionals to provide an accurate estimate for a refurbishment project because of the limited information at the early design stage. Killip [30] addressed that whole-house refurbishment is not necessarily undertaken at once, but possible refurbishment solutions for the future should not be compromised, and future refurbishment should be taken into consideration from the outset of a project. For example, the researcher considers potential future solar energy system installation when roof refurbishment is carried out, and installs necessary electric components in the roof. In addition, the Energy Saving Trust [16] proposed a trigger point approach for whole-house refurbishment that take a room-by-room approach. This approach requires an understanding of the refurbishment trigger-points and processes of regular home improvements based on home occupants' standpoints. When homeowners consider kitchen improvement or extension of a house, it is the trigger point to carry out energy improvement refurbishment such as wall and/or floor insulation [16]. The most important consideration of this step-by-step approach is not to compromise future potential refurbishment opportunities that ultimately provide a foundation for the whole-house refurbishment.

However, the current practice could be challenging to achieve seamless information flow between previous and future refurbishment works due to the highly fragmented nature of the construction practice. In particular, housing refurbishment projects are unique compared with new build housing in three major characteristics [20,31–34]:

(a) Higher Risk (than New Build);
(b) Complex Decision Making Process;
(c) Complicated Stakeholder Coordination.

Thus, housing refurbishment requires integrated decision making processes since a homeowner's decision for designs and materials influence the final results of housing refurbishment in terms of energy efficiency and CO_2 reduction. Moreover, construction professionals who are capable of providing trade-off information between energy efficiency and sustainability are involved at the end of the design phase [32,33,35], when it is challenging to change a design. Thus, the design for refurbishment projects should not be simply carried out by a single construction professional, but it should be undertaken by the integration of diverse construction information and collaboration amongst project stakeholders [20,36]. Researchers assert that decision making should be made based on the clients' priorities, and then a design team can adjust refurbishment measures accordingly in order to reduce redesign and reworks. Since current refurbishment processes limit the involvement of customers at the early design stage, the processes need to be updated to produce satisfactory refurbishment outcomes based on occupants' perspectives. Therefore, in order for construction professionals to propose affordable and customer-oriented refurbishment solutions, refurbishment project processes should secure homeowners' early involvement from the briefing/early design stage [37].

3. BIM in the Housing Sector

3.1. Benefits of BIM Adoption

An integrated project management information system is necessitated to resolve the current fragmented communication and restricted information, and minimize data conflicts and unnecessary reworks. As a response to this, many researchers are exploring various information and communication technologies (ICT) and BIM is recognized as a new ICT to integrate a great deal of information and documents to improve productivity in the construction industry. It is apparent that BIM has become a central issue in the UK construction industry and will be mandatory for public sector projects by 2016 [38]. There are three major benefits commonly addressed in the literature [39–43]:

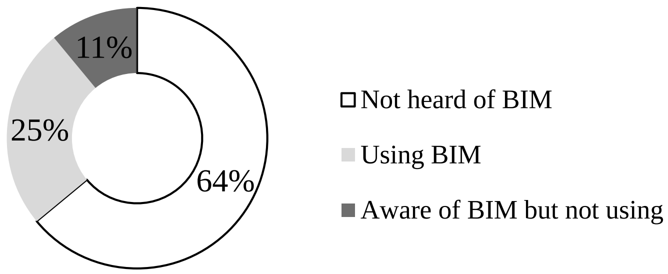
(a) Design Optimization;
(b) Efficiency Improvement (Effective Project Information Management);
(c) Sustainability Enhancement.

Bryde *et al.* [44] researched the benefits of BIM in 20 project cases, and the following benefits were identified: Cost reduction or control, Time reduction or control, Communication improvement, Coordination improvement and Quality increase or control. In particular, many researchers addressed the potentials of BIM for formulating financial and environmental implications simultaneously at the early design stage [33,39]. Since BIM has the unique merits that it can perform a comparative analysis between possible refurbishment alternatives in 3D, design and construction professionals can make an informed decision about refurbishment measures at the early design stages [39].

According to a UK government report [40], the current measured benefit of BIM is about 38% reduction of total construction project cost, and 19% to 40% cost reduction is expected from the design stage alone. Her Majesty's Government [38] particularly pointed out that BIM has the potential to be used for refurbishment projects and BRE Trust [45] has consistently shown that the high initial cost could be minimized and the fragmented practice can be improved if BIM is adopted in housing refurbishment projects from the outset. However, the current status of BIM penetration in the UK housing sector is surprisingly limited as shown in Figure 1 [19]. The NHBC foundation [19] found that major house builders in the UK consider that BIM adoption for housing projects is not relevant to current construction practices and the survey results provide a snapshot about the poor state of BIM penetration in the housing sector, although this survey mainly focused on the new build housing projects.

There were academic efforts to implement BIM in the housing sector, although the studies have been mainly carried out in new building housing projects. Sebastian *et al.* [13] applied BIM for small scale housing development projects. This research found that BIM facilitates proactive early collaboration amongst project participants and supports the earlier engagement of constructors in the design phase so more accurate informed decision can be made for cost estimation and selection of construction materials. However, BIM is not fully implemented due to data exchanges between different software systems, and current legal contract issues [13]. Chung *et al.* [46] implemented BIM for a 34 story domestic buildings and revealed that BIM can render various benefits such as 3D BIM for constructability and sustainability check, better risk management by virtual schedule planning for construction works and equipment operation.

Figure 1. Building Information Modeling (BIM) adoption in the UK housing industry.



Previous studies have shown that the potential BIM use for housing refurbishment has been rarely researched [47,48]. In spite of the various advantages of BIM, few researchers have explored the possibility of adopting BIM for housing refurbishment projects. Construction Industry Council [17] has reported that house builders are most likely to take advantage of BIM for their projects since the project processes have been well developed. In particular, BIM can attract customers using parametric object-based visualization that can provide the opportunity for them to customize homes based on their preferences [49]. Given the qualitative and quantitative benefits of BIM, it is proven that the construction industry should take advantage of implementing BIM. According to BIM survey [50], the current BIM adoption rate in the UK construction sector is 39%.

3.2. Barriers of BIM Adoption

Many researchers have attempted to identify various barriers when adopting BIM and these barriers may fall into three categories: Business and Legal, Technical and Organizational problem as shown in Table 1. The three major categories of barriers are inherited from the highly fragmented nature of the construction industry [51,52]. Interestingly, BIM adoption in the construction industry implies the current cultural changes, and requires more integrated and collaborated practices throughout a project lifecycle [38]. To encourage practitioners for BIM implementation, Building Services Research and Information Association [53] released the Soft Landing guideline for architects and constructors to collaborate through a process to provide valuable feedback to project teams and improve building performance. This guideline explicitly addresses the importance of early involvement of key project stakeholders from the design phase to minimize the waste and improve productivity. Currently small and medium size local house builders who are mainly involved in housing refurbishment projects are unlikely to have a BIM system like major companies. However, since the house building principles will be broadly similar, the uptake of BIM amongst local builders will increase quickly once they find BIM necessary and useful. Furthermore, as the BIM uptake for new build projects increases, the uptake for housing refurbishment projects should increase as the BIM data used for new build projects can be utilized for refurbishments, and this data will be enriched throughout operation and maintenance phase. The application of BIM varies from an individual house to a multi-story apartment, and the result proves that BIM has potentials to improve efficiency in the housing sector [18]. In order to utilize BIM effectively as well as efficiently, this research explored the homeowners' requirements for housing refurbishment as an initial BIM input dataset.

Table 1. Barriers to BIM adoption.

Barrier Categories	Description	References
Business and Legal Problem	- Lack of standards - Ambiguity in data ownership and legal risks - Lack of clarity on roles and responsibilities - Lack of clients/market demands - High investment cost and low incentives - Return on Investment	[51,54,55]
Technical Problem	- Lack of standards - Interoperability - BIM Library/Dataset	[51,55,56]
Organizational Problem	- Lack of initiative and training - Resistance to changing current practices - Lack of knowledge/data library	[42,51,54]

4. Results and Discussion

4.1. Questionnaire Survey Response Rate and Respondents' Profile

4.1.1. Homeowners

The 300 targeted homeowners were asked to answer the questionnaire via online and face to face questionnaire survey, and a total of 112 homeowners responded (62 respondents who have no interest in housing refurbishment are excluded). The response rate of the questionnaire survey was 37%.

According to the survey result (Table 2), 77% (87 respondents) indicated that their homes were built before 1945 when solid wall construction was prevalent and the Building Regulations Part L was practiced in the housing sector. Thus, this result identified that homeowners dwelling on old housing stock have more interest in housing refurbishment for energy performance improvement than relatively new and high energy standard housing. The 62 respondents who are not included indicated that they have no interest in housing refurbishment since they live in good energy performance housing built after 1980s.

Regardless of the locations and year built the survey results have shown very similar priorities on preferable refurbishment elements, measure and materials; for example, roof and window are 1st and 2nd priorities to refurbish although the weighted averages on an element of roof for Northern and Southern Regions are slightly higher with 4.1 and 4.2 respectively. Eighty-seven respondents living in a house built before 1945 totally agreed with the priorities in Table 3, while 19 homeowners out of 25 living in a house built after 1945 responded differently as "window" is the first priority and "roof" is the second.

Table 2. Homeowners' profile.

Item	Category	Number of Respondents	%
Location	Northern Region	17	15%
	Midlands	66	59%
	Southern Region	29	26%
	Total	112	100%
Age	20 s	9	8%
	30 s	34	30%
	40 s	32	29%
	50 s	28	25%
	60+	9	8%
	Total	112	100%
Occupants	Singles	19	17%
	Young Couples	16	14%
	Families with young children	44	39%
	Families with older (16+) children	13	12%
	Empty Nesters, whose children had moved on	20	18%
	Total	112	100%
Housing Type	Terraced	38	34%
	Semi-Detached	49	44%
	Detached	21	19%
	Don't Know	4	4%
	Total	112	100%
Year Built	Pre 1919	53	47%
	1919–1944	34	30%
	1945–1964	9	8%
	1965–1980	3	3%
	1981–1990	6	5%
	Post 1990	6	5%
	Don't Know	1	1%
	Total	112	100%

Notes: Source: Northern Region—North East, North West, Yorkshire and Humberside; Midlands—East Midlands, West Midlands; Southern Region—East of London, London, South East, South West.

Table 3. Comparative analysis of refurbishment priorities between homeowners and construction professionals.

Priorities	Homeowners		Construction Professionals	
	Elements	Weighted Average	Elements	Weighted Average
1st	Roof	4.0	Roof	4.9
2nd	Window	3.8	Wall (External)	4.0
3rd	Wall (Internal)	2.9	Window	3.6
4th	Wall (External)	2.6	Wall (Internal)	2.6
5th	Floor	2.3	Floor	1.8

4.1.2. Construction Professionals

The 100 targeted construction professionals were asked to answer the questionnaire via online questionnaire survey, and a total of 39 professionals responded. The response rate of the questionnaire survey was 39%. The average years of experience is 18 years, and over 50% of respondents have more than 21 years of experience in housing refurbishment projects as shown in Table 4.

Table 4. Construction professionals' profile.

Years of Experience	Number of Respondents	%
Less than 5 years	5	13%
5–10 years	6	15%
11–15 years	4	10%
16–20 years	4	10%
21–25 years	3	8%
26+ years	17	44%
Total	39	100%

AT	MB	BS	CO	PP	QS	PM	SC	LA	PrM	Total
7	7	6	5	5	3	2	2	1	1	39

Notes: AT: Architect; MB: Master Builder; BS: Building Surveyor; CO: Contractors; PP: Private Practice; QS: Quantity Surveyor; PM: Project Management; SC: Special Contractor; LA: Local Authority; PrM: Property Management.

4.2. Results of Questionnaire Survey

The Cronbach's Alpha test indicated that the survey results are reliable enough to use as a dataset for statistical analysis with 0.7 for refurbishment measures and 0.8 for refurbishment materials as shown in Tables 5 and 6. The priorities amongst elements of a house did not adopt the Cronbach's Alpha test since the survey result was indicated as a ranking order (ordinal) data, not as a Likert Scale. Weighted average was used to compare the survey result between homeowners and construction professionals.

Table 5. Importance about decision making factor for refurbishment measures (Cronbach's Alpha = 0.7).

Decision Making Factors	Homeowners		Construction Professionals	
	Level of Importance	Weighted Average	Level of Importance	Weighted Average
Initial Cost	1st	4.1	3rd	4.4
Thermal Performance	2nd	4.0	1st	4.6
Low Maintenance	2nd	4.0	4th	3.8
Payback Period	4th	3.8	2nd	4.4
Disruption	5th	3.3	5th	3.6
CO_2 Reduction	6th	2.8	6th	3.4

Table 6. Importance about decision making factor for refurbishment materials (Cronbach's Alpha = 0.8).

Decision Making Factors	Homeowners		Construction Professionals	
	Level of Importance	Weighted Average	Level of Importance	Weighted Average
Aesthetic (Finished look)	1st	4.4	3rd	4.1
Health and Safety	2nd	4.3	4th	4.2
Low Maintenance (Durability)	3rd	4.2	2nd	4.3
Initial Cost	4th	4.1	6th	4.1
Thermal Performance	5th	4.1	1st	4.5
Manufacturers' Reputation	6th	3.7	7th	3.5
Life Cycle Cost	7th	3.7	5th	4.1
Recycled Materials	8th	3.1	8th	3.2

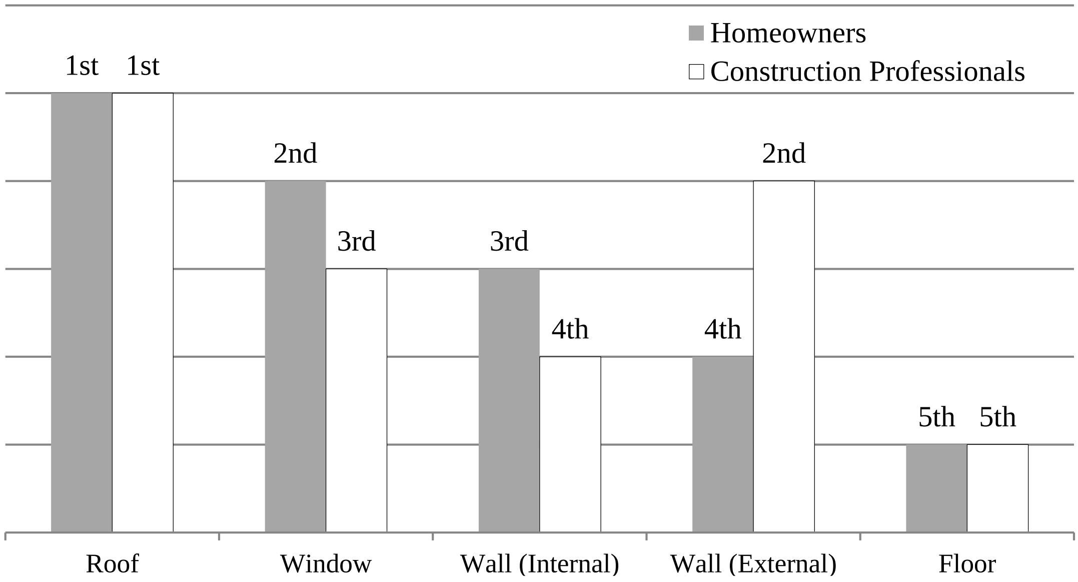
4.2.1. Refurbishment Priorities amongst Elements of House

Respondents were asked to indicate the refurbishment priorities for the elements of a house. The priorities between the two groups are compared using weights from 5 for 1st priority to 0 for 5th priority. The elements listed in Table 3 has been adopted from RDSAP 2005 as a default fabric of a typical house [57].

Homeowners and construction professionals indicated the same priorities on the Roof and Floor refurbishment as shown in Table 3. Both groups addressed that the roof refurbishment usually means loft insulation with top-up insulation material on the ceiling joist. Homeowners prefer this measure since it is financially affordable and does not disrupt them much due to quick installation, while construction professionals prefer this measure because there is high chance to receive government incentives and the duration for installation is short. The priorities for window and wall were identified differently between homeowners and construction professionals as shown in Figure 2. The external wall refurbishment particularly indicated the largest difference in priorities. Homeowners do not prefer the external wall insulation as it is expensive and the external appearance of their houses will be altered. In contrast, construction professionals prefer the external wall insulation to internal insulation because it is effective measure for energy efficiency improvement, and causes fewer risks related with moss and fungal growth. As a result, construction professionals indicated the internal insulation as 4th priority, and internal insulation can be very disruptive to homeowners rather than external insulation.

Similarly, homeowners do not prefer internal insulation (3rd priority) as they may need to vacate their home until the insulation is completed. Homeowners commented that they prefer to change windows because of the government funding support and easy installation, and most homeowners believe that the window is the largest heat loss element in their homes. This implied that there is a lack of knowledge about housing energy performance amongst homeowners. Overall, these results provide important insights that there are conflicts of priorities between homeowners and construction professionals, and these results echoed with the current construction professionals oriented design practice which renders low customer satisfaction in the housing sector.

Figure 2. Refurbishment priorities for elements of a house.

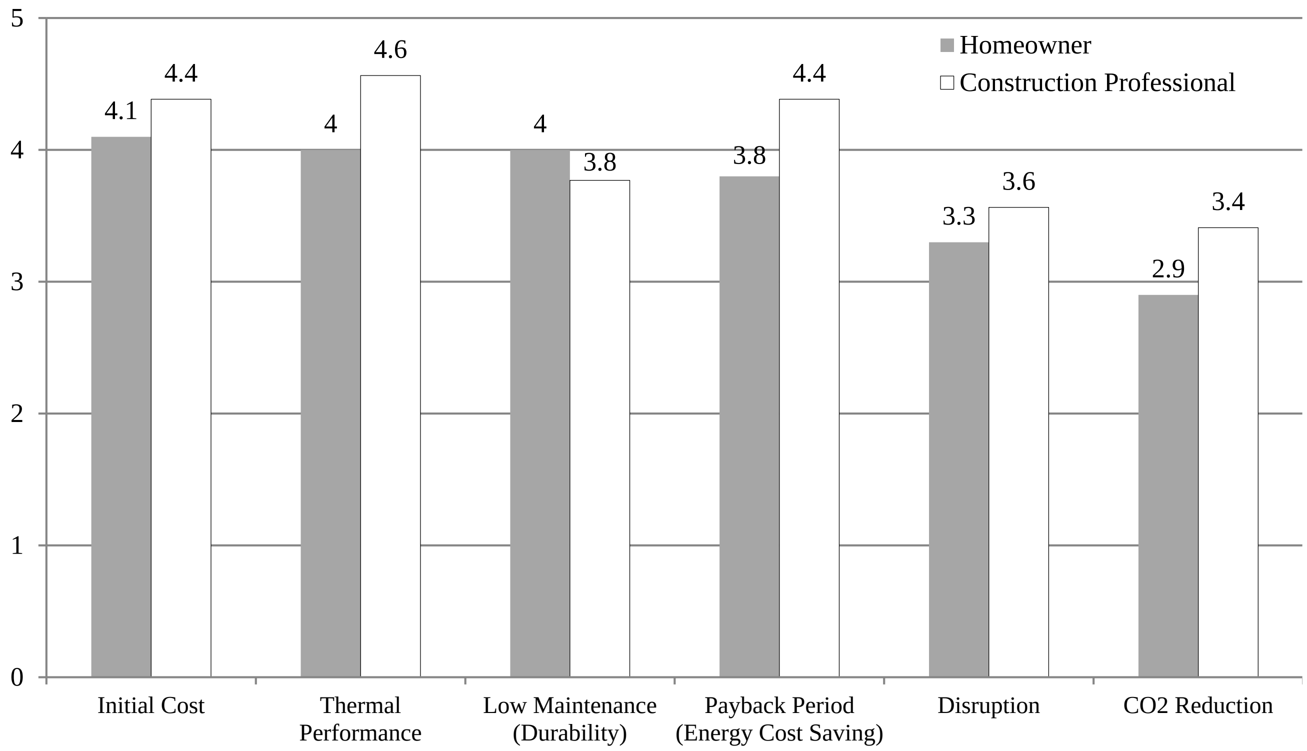


4.2.2. Importance of Refurbishment Measures

Respondents were asked to indicate the importance of decision making factors about refurbishment measures in the Likert Scale from "Very Important" to "Not Considered". The priorities between the two groups are compared using weights from 5 for "Very Important" to 0 for "Not Considered". The factors listed in Table 5 has been adopted from the government report and literature that researched customers' preferences and factors for housing refurbishment [19,25,26].

Surprisingly, both homeowners and construction professionals indicated the lowest importance on CO_2 reduction when they selected a refurbishment measure, whereas both groups indicated high importance of initial cost for refurbishment measures as shown in Table 5. Overall, two groups have shown similar preferences on the decision making factors of initial cost, thermal performance, low maintenance and payback period as shown in Figure 3. The most interesting result from this question is that homeowners care relatively little about disruption caused by refurbishment although many researchers assert that the disruption is one of the most significant barriers that prevents homeowners from doing housing refurbishment [16,19,27,31,32]. Many homeowners commented that the initial cost is the most important since refurbishment cannot be carried out if the cost is over budget for them. They also commented that the disruption can be tolerated once they determine to refurbish their homes, and the benefits from refurbishment are clearly understood. Therefore, it is important to convince homeowners with affordable and proper refurbishment solutions by adequately visualizing processes and providing relevant and necessary information for their better understanding of the benefits of housing refurbishment.

Figure 3. Decision making factor for refurbishment measure (Likert scale from 5—"Very Important" to 1—"Not Considered").

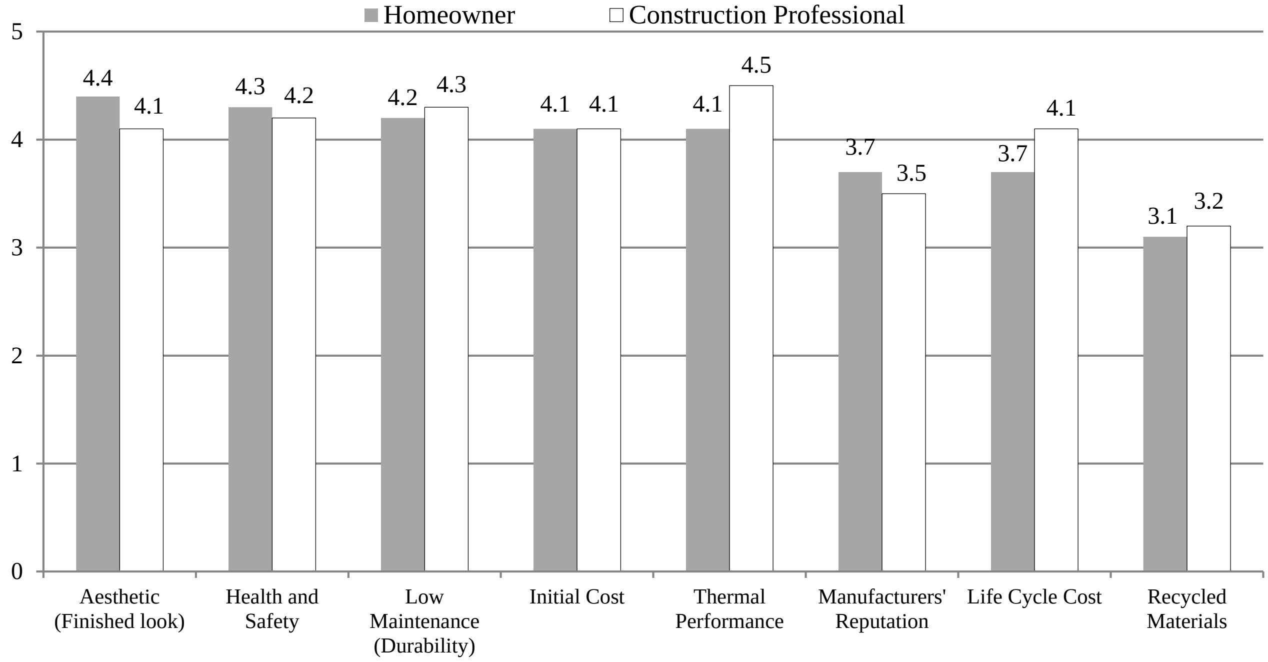


4.2.3. Importance of Refurbishment Materials

Respondents were asked to indicate the importance of decision making factors about refurbishment materials in the Likert Scale from "Very Important" to "Not Considered". The priorities between the two groups are compared using weights from 5 for "Very Important" to 0 for "Not Considered". The factors listed in Table 6 has been adopted from the government report and literature that researched customers' preferences and factors for housing refurbishment [19,25,26].

As shown in Table 6, the manufacturer's reputation and recycled materials are the lowest important factors for both groups, and the majority of homeowners commented that they are not aware of manufacturers, and they are more interested in the finishing of refurbishment materials such as colors, shapes and designs. As a consequence, the aesthetic was identified as the most important decision making factor when they select refurbishment materials while the most important factor for construction professionals is the thermal performance of refurbishment materials as shown in Figure 4. This result is echoed with the previous results of survey questions about the priority of elements and the importance of refurbishment measures. These results show that the construction professionals consistently indicated that their priorities of housing refurbishment are on thermal performance and effectiveness of refurbishment outcomes, whereas homeowners indicated that their priorities are on the initial cost and their own interests such as the Aesthetic.

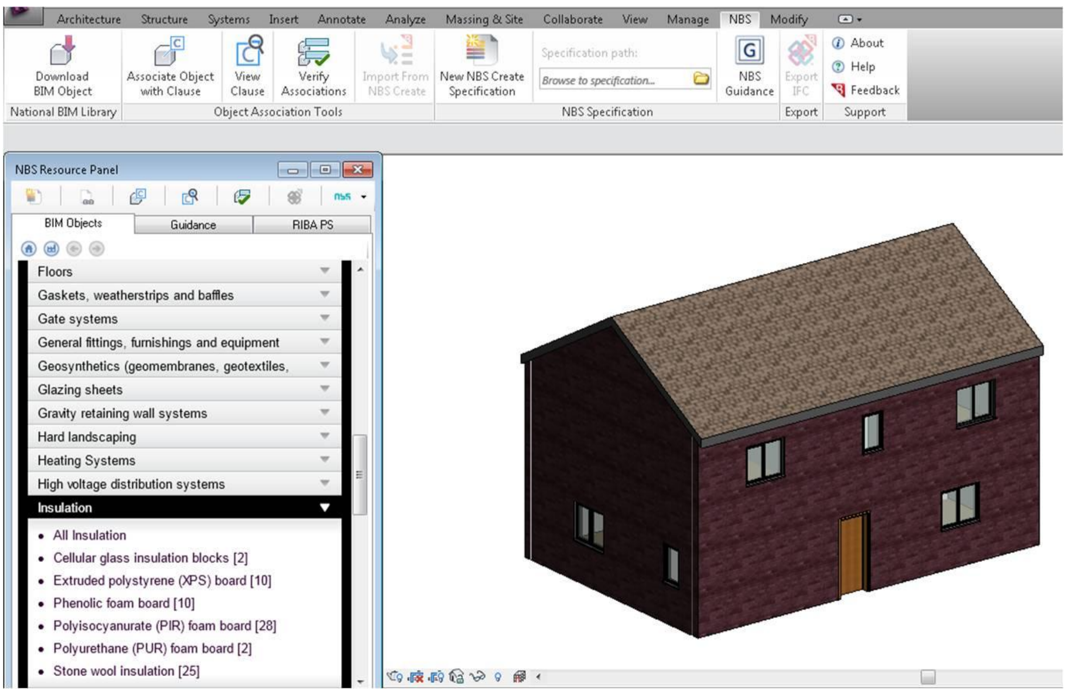
Figure 4. Decision making factor for refurbishment materials (Likert scale from 5—"Very Important" to 0—"Not Considered").



4.3. Application of BIM for Homeowners' Preferences

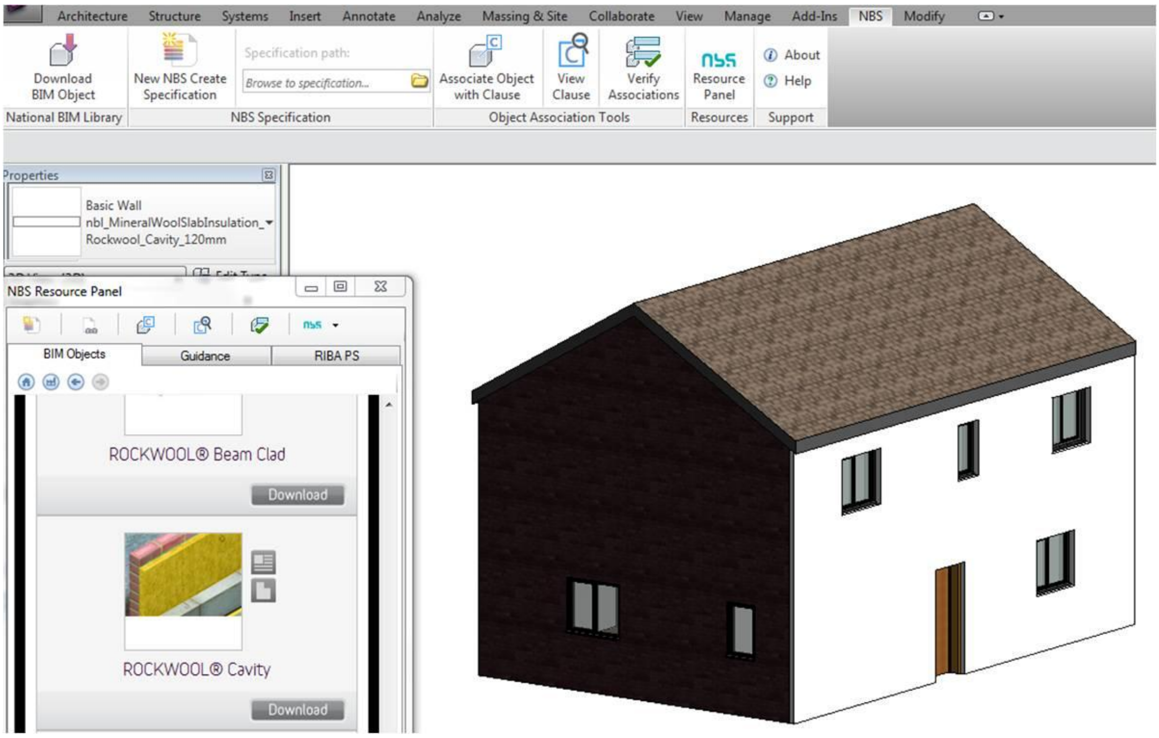
This research has used a sample detached solid wall house to demonstrate how housing refurbishment information can be modelled and visualized by current BIM software as shown in Figure 5. A solid wall house was chosen since the majority of survey respondents indicated that they dwell on a house built before 1944 (see Table 2).

Figure 5. External wall insulation demonstration in BIM—pre-refurbishment.



Currently, the NBS provides an open BIM library that provides BIM formatted construction material information such as dimensions, material specification and manufacturer. The Figure 6 represented the construction of external wall insulation on the sample solid wall house using the objects provided by NBS. The outcome of refurbishment can be visually checked if customers prefer it or not. In addition, before customers and construction professionals finalize a refurbishment solution, customers are able to customize their homes by exploring various refurbishment options based on the aesthetic (finished look), various materials and thermal performance. Construction professionals can also achieve customer oriented design practice through BIM, and explain the outcome of refurbishment effectively in 3D.

Figure 6. External wall insulation demonstration in BIM—post-refurbishment.



The initial cost was indicated as the most influential decision making factors for homeowners and construction professionals when determining refurbishment measures and materials (see Tables 5 and 6). Thus, it is essential to estimate accurate cost for a refurbishment project as much as possible to make informed decision from the early stage of design phase. As shown in Figure 7, BIM has a function named Material Quantity Take-Offs that calculates quantities and volumes of construction materials instantly, and reflects any changes of designs on quantities and volumes automatically. Traditionally, material quantities and cost estimations have been surveyed by quantity surveying professionals; however, the total construction cost and the environmental impact in terms of embodied CO_2 can be calculated and checked without complicated process in BIM as shown in Figure 7.

Once a refurbishment measure is applied to a BIM model, the changes are immediately reflected in material quantities, volumes and costs as shown in Figure 8 at the top. In this research, external wall insulation with mineral wool insulation provided by the NBS BIM library has been used for demonstration purpose. However, the current BIM objects have limited information about cost and embodied CO_2 as shown in Figures 7 and 8. If information about various materials becomes available, more reliable cost estimation can be provided to the customers, and eventually, more financially and environmentally feasible refurbishment solutions can be achieved.

Figure 7. Material take-off function in BIM (Revit 2013)—pre-refurbishment.

Material Quantity Take-Off								
Level	Family and Type	Material: Name	Material: Cost	Material: Embodied CO2	Material: Area	Material: Vol	Total Cost	Total Embodied CO2
Ground Floor	Floor: Timber Suspended Floor	Wood Sheathing, Chipboard	£24.56		67 m^2	1.47 m^3	£1645.14	
Ground Floor	Floor: Timber Suspended Floor	Structure, Timber Joist/Rafter Layer	£7.79		67 m^2	15.07 m^3	£521.81	
First Floor	Basic Ceiling: Generic	Gypsum Wall Board	£28.04	0.00	65 m^2	0.00 m^3	£1810.55	
First Floor	Basic Ceiling: Generic	Gypsum Wall Board	£28.04	0.00	64 m^2	0.00 m^3	£1807.19	
First Floor	Floor: Timber Suspended Floor	Wood Sheathing, Chipboard	£24.56		67 m^2	1.47 m^3	£1645.14	
First Floor	Floor: Timber Suspended Floor	Structure, Timber Joist/Rafter Layer	£7.79		67 m^2	15.07 m^3	£521.81	
B1010375: 6					397 m^2	33.09 m^3	£7951.64	
	Basic Roof: Cold Roof - Timber	Wood	£0.00	0.00	90 m^2	2.26 m^3	£0.00	
	Basic Roof: Cold Roof - Timber	Structure, Timber Truss Joist/Rafter	£12.49	0.00	90 m^2	13.56 m^3	£1128.93	
	Basic Roof: Cold Roof - Timber	Roofing, Tile	£66.01	0.00	90 m^2	3.43 m^3	£5966.45	
	Basic Roof: Cold Roof - Timber	Roofing Felt	£5.83	0.00	90 m^2	0.00 m^3	£526.96	
Loft	Floor: Roof Ceiling Joist	Structure, Timber Joist/Rafter Layer	£7.79		67 m^2	6.70 m^3	£521.81	
B1020400: 5					429 m^2	25.95 m^3	£8144.15	
	Basic Wall: Ext - 215 - Brick	Brick, Common	£87.59		54 m^2	11.43 m^3	£4712.52	
	Basic Wall: Ext - 215 - Brick	Plaster	£10.77		54 m^2	1.08 m^3	£580.77	
	Basic Wall: Ext - 215 - Brick	Brick, Common	£87.59		42 m^2	9.11 m^3	£3709.69	
	Basic Wall: Ext - 215 - Brick	Plaster	£10.77		42 m^2	0.85 m^3	£456.14	
	Basic Wall: Ext - 215 - Brick	Brick, Common	£87.59		49 m^2	10.34 m^3	£4267.18	
	Basic Wall: Ext - 215 - Brick	Plaster	£10.77		49 m^2	0.98 m^3	£525.98	
	Basic Wall: Ext - 215 - Brick	Brick, Common	£87.59		39 m^2	8.43 m^3	£3433.69	
	Basic Wall: Ext - 215 - Brick	Plaster	£10.77		39 m^2	0.78 m^3	£422.20	
B2010100: 8					368 m^2	42.98 m^3	£18108.17	

Figure 8. Material take-off function in BIM (Revit 2013)—post-refurbishment.

Material Quantity Take-Off								
Level	Family and Type	Material: Name	Material: Cost	Material: Embodied CO2	Material: Area	Material: Vol	Total Cost	Total Embodied CO2
	Basic Wall: nbl_MineralWoolSlabl	nbl_MineralWoolSlabInsulation_Rock	£0.00		49 m^2	5.79 m^3	£0.00	
: 1					49 m^2	5.79 m^3	£0.00	
Ground Floor	Floor: Timber Suspended Floor	Wood Sheathing, Chipboard	£24.56		67 m^2	1.47 m^3	£1645.14	
Ground Floor	Floor: Timber Suspended Floor	Structure, Timber Joist/Rafter Layer	£7.79		67 m^2	15.07 m^3	£521.81	
First Floor	Basic Ceiling: Generic	Gypsum Wall Board	£28.04	0.00	65 m^2	0.00 m^3	£1810.55	
First Floor	Basic Ceiling: Generic	Gypsum Wall Board	£28.04	0.00	64 m^2	0.00 m^3	£1807.19	
First Floor	Floor: Timber Suspended Floor	Wood Sheathing, Chipboard	£24.56		67 m^2	1.47 m^3	£1645.14	
First Floor	Floor: Timber Suspended Floor	Structure, Timber Joist/Rafter Layer	£7.79		67 m^2	15.07 m^3	£521.81	
B1010375: 6					397 m^2	33.09 m^3	£7951.64	
	Basic Roof: Cold Roof - Timber	Wood	£0.00	0.00	90 m^2	2.26 m^3	£0.00	
	Basic Roof: Cold Roof - Timber	Structure, Timber Truss Joist/Rafter	£12.49	0.00	90 m^2	13.56 m^3	£1128.93	
	Basic Roof: Cold Roof - Timber	Roofing, Tile	£66.01	0.00	90 m^2	3.43 m^3	£5966.45	
	Basic Roof: Cold Roof - Timber	Roofing Felt	£5.83	0.00	90 m^2	0.00 m^3	£526.96	
Loft	Floor: Roof Ceiling Joist	Structure, Timber Joist/Rafter Layer	£7.79		67 m^2	6.70 m^3	£521.81	
B1020400: 5					429 m^2	25.95 m^3	£8144.15	
	Basic Wall: Ext - 215 - Brick	Brick, Common	£87.59		54 m^2	11.43 m^3	£4712.52	
	Basic Wall: Ext - 215 - Brick	Plaster	£10.77		54 m^2	1.08 m^3	£580.77	
	Basic Wall: Ext - 215 - Brick	Brick, Common	£87.59		42 m^2	9.11 m^3	£3709.69	
	Basic Wall: Ext - 215 - Brick	Plaster	£10.77		42 m^2	0.85 m^3	£456.14	
	Basic Wall: Ext - 215 - Brick	Brick, Common	£87.59		49 m^2	10.34 m^3	£4267.18	
	Basic Wall: Ext - 215 - Brick	Plaster	£10.77		49 m^2	0.98 m^3	£525.98	
	Basic Wall: Ext - 215 - Brick	Brick, Common	£87.59		39 m^2	8.43 m^3	£3433.69	
	Basic Wall: Ext - 215 - Brick	Plaster	£10.77		39 m^2	0.78 m^3	£422.20	
B2010100: 8					368 m^2	42.98 m^3	£18108.17	

5. Methodology

This research consists of a desk study, a questionnaire survey, and semi-structured interviews. First, in order to improve external validity and obtain large number of responses, this research targeted the homeowners but randomly selected the target respondents from the three main geographical regions in England: the North, the Midland and the South. Three hundred homeowners were targeted via local communities, refurbishment project related websites such as SuperHomes, and personal contact information retrieved from local organizations. Secondly, in order to understand similarities and differences of refurbishment priorities between homeowners and construction professionals, the questionnaire survey was sent to local authorities, architects and construction professionals as a focused group. One hundred professionals were targeted via construction professional bodies such as the Chartered Institute of Building (CIOB), the Royal Institution of British Architects (RIBA), the Building Research Establishment (BRE), the British Board of Agrément (BBA), the Centre of Refurbishment Excellence (CoRE) and personal contact information retrieved from EcoBuild 2012, 2013 and GreenBuild Expo 2013.

The web-based questionnaire was comprised of nine questions designed to explore the following three key factors about the importance of decision making priorities between homeowners and construction professionals (three key factors defined through three brainstorming sessions with 5 academics and 5 housing professionals); (a) refurbishment priorities amongst elements of a house; (b) the importance of refurbishment measures; and (c) the importance of refurbishment materials. The questions consisted of multiple choices and rating questions that obtains facts and inquires about personal opinions as a customer and subject matter experts. The questions mainly adopt the Likert scale. This research undertook Cronbach's Alpha test to confirm whether the questionnaire survey is structured in a reliable manner, and the survey result is acceptable as a relevant data set for statistical analysis [58]. After the completion of the web-based questionnaire survey, semi-structured interviews were conducted with homeowners, who addressed their interest about housing refurbishment, to obtain more enriched information about preferences. Due to the geographical distance, the semi-structured interviews were conducted via a phone and a web-based tool.

Finally, this research shows how housing refurbishment can be visualized by available BIM software and library components. Currently various BIM software such as the Autodesk Revit, Bentley, Tekla and ArchiCAD is available and the Revit Architecture was used to demonstrate how information is flowing and visualized as it is widely used in the architectural, engineering and construction (AEC) industry. An example component from BIM library by the National Building Specification (NBS) was taken.

6. Research Limitations

Regardless of the profiles of homeowners and their homes, the results have consistently shown similar refurbishment priorities for the elements of a house and preferences on the decision making factors such as initial cost particularly. However, respondents were randomly selected and the limited numbers of homeowners in the northern and southern regions were involved in the preference survey due to a lack of contact information compared to the Midlands. Further analysis and investigation in detailed profiles will be beneficial with stratified sampling by age, income, family, *etc.* Although the benefit of BIM regarding customizing preferences was identified (See Section 3), all the preferences except the external wall insulation were not confirmed through this research due to limited knowledge and experience in using BIM for housing refurbishment.

7. Conclusions

As an exploratory research, the purpose of this study is to understand the three major values of homeowners to adopt housing refurbishment and their preference; (a) refurbishment priorities amongst elements of a house; (b) the importance of refurbishment measures; and (c) the importance of refurbishment materials. The results of this research show that homeowners have a tendency to refurbish the roof and window the most, although the priority between them would be slightly different by the build year of their homes. It is interesting to note that construction professionals consider the external wall refurbishment more important because they are aware that the wall is a critical component for energy efficiency improvement on existing houses. When a decision of the housing refurbishment is made, homeowners put more weights on the initial cost, whereas construction professionals consider the effectiveness of refurbishment. These results imply both groups have quite different perspective on refurbishment elements, and there is a gap of knowledge between homeowners and construction professionals. These gaps and preferences in refurbishment elements and materials should be understood and reflected in customer's requirements as they are very irregular and bespoke. The customers should be informed of the impact on their preferences of refurbishment elements and materials by construction professionals who are able to provide a comparative analysis between refurbishment alternatives. Therefore, this study enables construction professionals to understand customers' value in order to bridge the gap between their preferences, and provide affordable and allowable refurbishment solutions to customers.

This research identified that it is important to prepare detailed BIM objects and dataset for successful BIM adoption in the housing sector. Without reliable information about construction materials and designs in terms of cost and embodied CO_2, the application of BIM concept cannot add more value to the customers and the construction industry. This research has gone some way towards enhancing a better understanding of homeowners' preference and BIM application in the UK housing refurbishment. Future research should identify if there is any changes of homeowners' perception by age, location, *etc.* after the concept of BIM is applied to housing refurbishment. The future research will investigate housing refurbishment information modeling for a specific type of houses and validate how useful a BIM based housing information model is for both homeowners and construction professionals.

Acknowledgments

The authors gratefully acknowledge the cooperation of 112 homeowners and 39 construction professionals involved in UK housing refurbishment for the provision of the data.

Author Contributions

The co-author contributed actively to this research project and the writing and review of this article.

Conflicts of Interest

The authors declare no conflict of interest.

References

1. Autodesk. Building Information Modeling for Sustainable Design. Available online: http://images.autodesk.com/adsk/files/bim_for_sustainable_design_oct08.pdf (accessed on 10 March 2014).
2. Kelly, M.J. Retrofitting the existing UK building stock. *Build. Res. Inf.* **2009**, *37*, 196–200.

3. Boardman, B. *Home Truths: A Low-Carbon Strategy to Reduce UK Housing Emission by 80% by 2050*; Environmental Change Institute: Oxford, UK, 2007.
4. Summerson, G.M. Lessons Learnt from Piloting BREEAM Domestic Refurbishment. Available online: http://www.breeam.org/filelibrary/breeam%20refurb/cibse_technical_symposium_gavin_summerson_Paper_102.pdf (accessed on 10 March 2014).
5. Itard, L.; Meijer, F. *Towards a Sustainable Northern European Housing Stock: Figures, Facts and Future*; Delft University Press: Amsterdam, The Netherlands, 2008.
6. Construction Products Association. An Introduction to Low Carbon Domestic Refurbishment. Available online: http://www.barbourproductsearch.info/CPA-Low-Carbon-Domestic-Refurbishment-file017103.pdf (accessed on 10 March 2014).
7. Utley, J.I.; Shorrock, L.D. Domestic Energy Fact File 2011. Available online: http://www.decc.gov.uk/assets/decc/11/stats/climate-change/3224-great-britains-housing-energy-fact-file-2011.pdf (accessed on 10 March 2014).
8. Thorpe, D. *Sustainable Home Refurbishment*, 1st ed.; Earthscan: London, UK, 2010.
9. McMullan, R. *Environmental Science in Building*, 6th ed.; Palgrave: Basingstoke, UK, 2007.
10. Department of Energy and Climate Change (DECC). *Heat and Energy Saving Strategy*; DECC: London, UK, 2009.
11. Reeves, A. Achieving Deep Carbon Emission Reductions in Existing Social Housing: The Case of Peabody. Ph.D. Thesis, De Montfort University, Leicester, UK, September 2009.
12. Killip, G. *Building a Greener Britain; Transforming the UK's Existing Housing Stock*; Federation of Master Builders: London, UK, 2008.
13. Sebastian, R.; Haak, W.; Vos, E. BIM Application for Integrated Design and Engineering in Small-Scale Housing Development: A Pilot Project in The Netherlands. In Proceedings of the International Symposium CIB-W096 Future Trends in Architectural Management, Tainan, Taiwan, 2–3 November 2009.
14. National Institute of Standards and Technology (NIST). Cost Analysis of Inadequate Interoperability in the U.S. Capital Facilities Industry. Available online: http://fire.nist.gov/bfrlpubs/build04/PDF/b04022.pdf (accessed on 10 March 2014).
15. Ipsos MORI. *Eco Chic or Eco Geek?*; The Desirability of Sustainable Homes: Milton Keynes, UK, 2006.
16. Energy Saving Trust (EST). *Trigger Points: A Convenient Truth, Promoting Energy Efficiency in the Home*; EST: London, UK, 2011.
17. Construction Industry Council (CIC). *Growth through BIM*; CIC: London, UK, 2013.
18. National House Building Council (NHBC). *Building Information Modelling—An Introduction for House Builders*; NHBC Foundation: Milton Keynes, UK, 2013.
19. Department of Energy and Climate Change (DECC). *Consumer Needs and Wants for the Green Deal*; DECC: London, UK, 2011.
20. Burton, S. *Handbook of Sustainable Refurbishment—Housing*, 1st ed.; Earthscan: Abingdon, UK, 2012.
21. Lomas, K.J. Carbon reduction in existing buildings: A transdisciplinary approach. *Build. Res. Inf.* **2010**, *38*, 1–11.

22. Mills, B.; Schleich, J. Residential energy-efficient technology adoption, energy conservation, knowledge, and attitudes: Ananalysis of European countries. *Energy Policy* **2012**, *49*, 616–628.
23. Jenkins, D.P. The value of retrofitting carbon—Saving measures into fuel poor social housing. *Energy Policy* **2010**, *38*, 832–839.
24. Firth, S.K.; Lomas, K.J. Investigating CO_2 Emission Reductions in Existing Urban Housing Using a Community Domestic Energy Model. In Proceedings of the 11th International IBPSA Conference, Glasgow, UK, 27–30 July 2009; pp. 2098–2105.
25. Nair, G.; Gustavsson, L.; Mahapatra, K. Owners perception on the adoption of building envelope energy efficiency measures in Swedish detached houses. *Appl. Energy* **2010**, *87*, 2411–2419.
26. Nair, G.; Gustavsson, L.; Mahapatra, K. Factors influencing energy efficiency investments in existing Swedish residential buildings. *Appl. Energy* **2010**, *38*, 2956–2963.
27. Davies, P.; Osmani, M. Low carbon housing refurbishment challenges and incentives: Architects' perspectives. *Build. Environ.* **2011**, *46*, 1691–1698.
28. Stieß, I.; Dunkelberg, E. Objectives, barriers and occasions for energy efficient refurbishment by private homeowners. *J. Clean. Prod.* **2013**, *48*, 250–259.
29. Banfill, P.; Simpson, S.; Haines, V.; Mallaband, B. Energy-led retrofitting of solid wall dwellings: Technical and user perspectives on airtightness. *Struct. Surv.* **2012**, *30*, 267–279.
30. Killip, G. Products, practices and processes: Exploring the innovation potential for low-carbon housing refurbishment among small and medium-sized enterprises (SMEs) in the UK construction industry. *Energy Policy* **2013**, *62*, 522–530.
31. Menassa, C.C. Evaluating sustainable retrofits in existing buildings under uncertainty. *Energy Build.* **2011**, *43*, 3576–3583.
32. Thuvander, L.; Femenías, P.; Mjörnell, K.; Meiling, P. Unveiling the process of sustainable renovation. *Sustainability* **2012**, *4*, 1188–1213.
33. Ma, Z.; Cooper, P.; Daly, D.; Ledo, L. Existing building retrofits: Methodology and state-of-the-art. *Energy Build.* **2012**, *55*, 889–902.
34. Doran, D.; Douglas, J.; Pratley, R. *Refurbishment and Repair in Construction*; Whittles Publishing: Caithness, UK, 2009.
35. Schlueter, A.; Thesseling, F. Building information model based energy/exergy performance assessment in early designs stages. *Automat. Construct.* **2009**, *18*, 153–163.
36. Leblanc, H.; Nitithamyong, P.; Thomson, C. Developing a Knowledge Management Framework to Promote Sustainable Social Housing Refurbishment Practices. In Proceedings of the 26th Annual ARCOM Conference, Leeds, UK, 6–8 September 2010; pp. 819–828.
37. Gupta, R.; Chandiwala, S. Understanding occupants: Feedback techniques for large-scale low-carbon domestic refurbishments. *Build. Res. Inf.* **2010**, *38*, 530–548.
38. Her Majesty's Government (HM Government). *Building Information Modelling—Industrial Strategy: Government and Industry in Partnership*; HM Government: London, UK, 2012.
39. Basbagill, J.; Flager, F.; Lepech, M.; Fischer, M. Application of life-cycle assessment to early stage building design for reduced embodied environmental impacts. *Build. Environ.* **2013**, *60*, 81–92.
40. Government Construction Client Group. Strategy Paper for the Government Construction Client Group from the BIM Industry Working Group. Available online: http://www.bimtaskgroup.org/wp-content/uploads/2012/03/BIS-BIM-strategy-Report.pdf (accessed on 10 March 2014).

41. Grilo, A.; Jardim-Goncalves, R. Value proposition on interoperability of BIM and collaborative working environments. *Automat. Construct.* **2010**, *19*, 522–530.
42. British Standards Institution (BSI). *Constructing the Business Case: Building Information Modelling*; British Standards Institution and Building SMART UK: London/Surrey, UK, 2010.
43. Redmond, A.; Hore, A.; Alshawi, M.; West, R. Exploring how information exchanges can be enhanced through Cloud BIM. *Automat. Construct.* **2012**, *24*, 175–183.
44. Bryde, D.; Broquetas, M.; Volm, J.M. The project benefits of Building Information Modelling (BIM). *Int. J. Proj. Manag.* **2013**, *31*, 971–980.
45. Building Research Establishment Ltd. (BRE). *Putting a Price on Sustainability*; BRE: Watford, UK, 2005.
46. Chung, K.W.L.; Mak, S.K.D.; Ho, K.K.A. Application of Building Information Modelling (BIM) in Public Housing Development in Hong Kong. In Proceedings of the HKU-HKHA International Conference 2013, Hong Kong, 2–3 May 2013; pp. 51–60.
47. Allen Consulting Group. Productivity in the Buildings Network: Assessing the Impacts of Building information Models. Available online: http://www.acilallen.com.au/cms_files/acgbuildingsproductivity2010.pdf (accessed on 10 March 2014).
48. Arayici, Y.; Coates, P.; Koskela, L.; Kagioglou, M.; Usher, C.; O'Reilly, K. Technology adoption in the BIM implementation for lean architectural practice. *Automat. Construct.* **2011**, *20*, 189–195.
49. Kim, K.P.; Park, K.S. BIM feasibility study for housing refurbishment projects in the UK. *Organ. Technol. Manag. Construct.* **2013**, *5*, 756–774.
50. National Building Specification (NBS). NBS National BIM Report 2013. Available online: http://www.thenbs.com/pdfs/NBS-NationlBIMReport2013-single.pdf (accessed on 10 March 2014).
51. Eastman, C.; Teicholz, P.; Sacks, R.; Liston, K. *BIM Handbook: A Guide to Building Information Modelling for Owners, Managers, Designers, Engineers and Contractors*, 2nd ed.; John Wiley & Sons: Hoboken, NJ, USA, 2011.
52. Banahene, K.O.; Tuuli, M.M. Towards a Framework for Briefing for Building Information Modelling (B4BIM) Enabled Projects. In Proceedings of the HKU-HKHA International Conference 2013, Hong Kong, 2–3 May 2013; pp. 66–77.
53. Building Services Research and Information Association (BSRIA). The Soft Landings Framework for Better Briefing, Design, Handover and Building Performance In-Use. Available online: https://www.bsria.co.uk/services/design/soft-landings/ (accessed on 10 March 2014).
54. Forns-Samso, F. Use of Building Information Modeling (BIM) in Facilities Management. In Proceedings of the CSCE (Canadian Society for Civil Engineering) Annual General Meeting and Conference, 3rd International/9th Construction Specialty Conference, Ottawa, Canada, 14–17 June 2011.
55. Howard, R.; Bjork, B. Building information modelling—Experts' views on standardisation and industry deployment. *Adv. Eng. Inf.* **2008**, *22*, 271–280.
56. Succar, B. Building information modelling framework: A research and delivery foundation for industry stakeholders. *Automat. Construct.* **2009**, *18*, 357–375.
57. Gadermann, A.N.; Guhn, M.; Zumbo, B.D. Estimating ordinal reliability for Likert-type and ordinal item response data: A conceptual, empirical, and practical guide. *Pract. Assess. Res. Eval.* **2012**, *17*, 1–13.

58. Building Research Establishment Ltd. (BRE). The Government's Standard Assessment Procedure for Energy Rating of Dwellings. Available online: http://www.bre.co.uk/filelibrary/sap/2009/sap-2009_9-90.pdf (accessed on 10 March 2014).