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Comlay, Julie and Tzortzopoulos, Patricia

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Building Information Modelling [BIM] for energy efficiency in housing refurbishments

Julie Comlay
Department of Architecture and 3D Design, School of Art, Design and Architecture
University of Huddersfield, Huddersfield, UK.
J.Comlay@hud.ac.uk

Patricia Tzortzopoulos
Head of Department, Department of Architecture and 3D Design, School of Art, Design and Architecture
University of Huddersfield, Huddersfield, UK.
P.Tzortzopoulos@hud.ac.uk

ABSTRACT: Building Information modelling offers potential process and delivery improvements throughout the lifecycle of built assets. However, there is limited research in the use of BIM for energy efficiency in housing refurbishments. The UK has over 300,000 solid wall homes with very poor energy efficiency. A BIM based solution for the retrofit of solid wall housing using lean and collaborative improvement techniques will offer a cost effective, comprehensive solution that is less disruptive, reduces waste and increases accuracy, leading to high quality outcomes. The aim of this research is to develop a BIM based protocol supporting development of 'what if' scenarios in housing retrofits for high efficiency thermal improvements, aiming to reduce costs and disruption for users. The paper presents a literature review on the topic and discusses the research method for the research project (S-IMPLER).

Keywords: Building Information Modelling; low-income housing; retrofit; collaborative working.

1.0 INTRODUCTION

In 2010, the UK government made a significant commitment to upgrade the energy efficiency of 7.0 million British homes by 2020 aimed at reducing carbon emissions by 29% to address fuel poverty (DECC, 2012). Statistics suggest that the number of households faced with fuel poverty in 2009 reached 2.7 million (Hills, 2012). The NIHCS survey, 2009, indicates that over 25% of household income is expended on heating and lighting, in above 33,000 households in Northern Ireland. The targets are becoming increasingly challenging, at a national level, for reducing fuel poverty and the national carbon footprint. The carbon reduction target for the UK nationally is 80% by 2050, the UK Government has committed to support insulation for up to 1.5 million solid wall homes (DECC, 2011).

BIM has been described as a means to support energy efficiency of both new and existing buildings. BIM implementation in the UK construction industry is reaching improved adoption levels for construction of new projects; however, research and delivery of BIM in retrofit for housing is minimal. BIM offers the potential and opportunity to improve the retrofit process and deliver enhanced benefits and improved decision-making (Bercerik-Gerber et al., 2012). BIM for Retrofit has the potential to offer reductions in time and costs based on the virtual design that occurs before construction; clash detection reducing redesign and time on site due to reduced errors and improved scheduling (Hajian & Becerik-Gerber, 2009). Workflows are improved through collaboration and the reuse and interoperability of information.

This paper describes the Solid Wall Innovative Insulation and Monitoring Processes using Lean Energy Efficient Retrofit [S-IMPLER] (http://www.s-impler.com) research project, with a focus on the BIM implementation for retrofit of No Fines Concrete [NFC] solid wall housing. S-

IMPLER, in receipt of funding from Innovate UK [previously TSB], aims to investigate the retrofit of solid wall housing, to achieve a 60% reduction in monitored energy costs, with less disruption, at least 10% faster, without reductions in quality & safety. The research is a joint activity working with a housing association, two SME's, a contractor, academic institutions, a lean consultant and a construction research organisation. Several innovations from the research will be combined into a single attractive commercial proposition:

- an innovative surveying tool;
- a Building Information Modelling tool to allow client modelling of different options with costs and benefits;
- a whole house monitoring system to assess real energy performance;
- a new solid wall retrofit Certification scheme to transfer knowledge and assure quality.

BIM is one element of this collaborative research project, and the University of Huddersfield leads its development, in which both authors of this paper are involved. The BIM work package aims to devise a BIM Retrofit Protocol, which incorporates the use of 'what if' scenario testing for retrofit solutions, addressing the complexity of NFC solid wall housing. BIM is therefore utilised for predictive and evaluative energy analysis, 3D modelling, 4D BIM scheduling, 5D BIM cost analysis. The what-if retrofit scenarios will deliver an integrated solution that deals with the issues of high energy consumption due to poor thermal performance; reductions in the carbon footprint; internal mould and condensation issues, using constructive solutions that offer reduced disruption to the housing occupier.

The research approach selected is Design Science, which is aimed at solving real world problems through designing and testing innovative solutions (artefacts), and to inform theoretical knowledge (Holmström et al., 2009). Understanding how people acquire and create knowledge and the exchange mechanisms available to develop innovative solutions to real world problems requires a rich interaction between an extensive range of capabilities and expertise to deliver results (Dawson, 2005). The collaborative S-IMPLER research team, provide such range of capabilities. BIM is able to deal with the levels of complexity for retrofit in terms of the intricacy of numerous interactions and relationships between people, processes, management of information and technology.

The paper is organised as follows: Section 2 contextualises the research within current literature. Design Science Research as the selected research approach is detailed in Section 3. Section 4 discusses the research and section 5 details the conclusions from this initial research stage.

2.0 LITERATURE REVIEW

2.1. BIM

BIM can reduce inefficiencies present in the traditional management of project information, improve collaboration and offer the potential for efficient use of resources, reductions in costs and time. The technology for BIM and consequential improvements to work practices means that virtual prototyping is affordable, delivers financial savings and reduces construction time (Kiviniemi, 2011). BIM delivers efficiencies through data models with increasing levels of detail in the data as the project progresses. This leads to informed decision making, based on virtual prototypes, earlier in the design cycle, with potential for a reduction in costs and time on site for construction compared to traditional projects.

A 3D BIM model is the baseline required for BIM energy analysis, cost projections and scheduling, essential elements to deliver an effective BIM for retrofit solution that evaluates 'what if' scenarios. The value of BIM implementation is the enhanced capabilities and informed and improved decision making based on project aims (Eastman et al., 2011; Hajian &

Becerik-Gerber, 2009). BIM, in this research, is considered as a socio-technical system which is the interaction between process, information and people facilitated by technology, in this case BIM. The definition by Eastman et al., (2011) is comprehensive,

'..BIM as a modeling technology and associated set of processes to produce, communicate and analyze building models. ...BIM is a fundamentally different way of creating, using, and sharing building lifecycle data. ' (Section 1.4.6)

The UK construction industry is experiencing rapid change due to national and global policies in terms of carbon emissions, energy consumption and whole life cycle issues. The UK Government now requires Level 2 BIM adoption by 2016, on all projects funded by central government departments and their agencies (Cabinet Office, 2011). The implementation of BIM to generate design solutions has significant potential benefits which include carbon reduction, cost reduction, improved efficiency and lifecycle (BIMFM, 2012). The increasing pressure for the flexibility and longevity of buildings are achievable through BIM Implementation for retrofit. However, BIM implementation requires a common understanding, of the range of interactions between people, process, information and technology to develop its full potential (Baden-Fuller & Haefliger, 2013).

The digital representation of geometry with physical and functional characteristics of a built form, which include spatial relationships and geographical information is a 3D BIM model which aids communication with clients and user groups as the 3D model can interactively demonstrate the building. The data within the 3D BIM model changes in complexity as the project progresses through the delivery model and new dimensions are added such as time - 4D BIM, cost - 5D BIM and 6D BIM - operations and maintenance, increasing in content, interactions and level of detail throughout the whole life cycle.

4D BIM includes the added dimension of time. The use of 4D BIM software can offer improved site coordination, clash detection including time based clashes in schedules, materials planning and management. The use of clash detection software improves sequencing and work flows offering less disruption and allows for the scheduling of works. Control of the construction programme can be achieved through information data capture and flow in 'real time'. Adjustments to mitigate the effects of changes and to focus on achieving project deliverables with increased flexibility to respond to change are easily achieved through the use of 4D BIM. Overall, 4D BIM enhances communication and planning with a range of users and as a consequence can improve site safety and reduce project risk (Eastman et al., 2011).

To address BIM for retrofit, the issues of design, construction and maintenance require a multidisciplinary team working in collaboration, and implementation of changed workflows (Hajian & Becerik-Gerber, 2009). The challenge for S-IMPLER is to make informed decisions that identify the most cost-effective retrofit solutions in an optimal combination, to achieve requirements, delivered as suited to the individual homes by an integrated team. This is the basis for successful retrofit models and processes (Ma et al., 2012).

2.2. No-Fines concrete housing and fuel poverty

No-Fines Concrete is a housing system designed mid-1940's to cope with skilled labour and material shortages, reducing the construction time required and to meet increased demand for housing. Over 300,000 homes were built using NFC in the UK (Liddell et al., 2011, Reeves & Martin, 1989). The issues for occupants of NFC housing include high energy costs where the variability of the quality of the NFC construction is a significant factor, health issues as a result of condensation and mould growth, a high cost heating fuel type i.e. oil in the current energy market and the aged heating appliances, limits on the type of energy tariff available to the occupant and the lighting solution i.e. bulb type and the ventilation and window type i.e. single glazing.

The S-IMPLER research has undertaken significant investigation of the NFC properties for the research to ascertain the construction details that may be contributing to the issue, i.e. concrete slab floors which are constructed in such a way that the element creates a significant thermal bridge (Craig et al., 2013). NFC homes external walls have a *u*-value range of 1.9 W/m^2K to 2.0 W/m^2K; current *u*-value regulations require 0.3W/m^2K for housing (Sommerville et al., 2011). This factor in combination with the average age of this type of housing and the heterogeneous construction and detailing are indicative of the technical challenges for the S-IMPLER research.

Occupant use of energy controls are a significant factor for energy use; other contributing factors are the duration of occupancy of the home during a 24hr period, work patterns, health status, hobbies, drying washing internally, occupant ventilation of the home, age of the occupant i.e. elderly, infant. The differing definitions of fuel poverty have wide ranging effects on inclusion or exclusion as a household experiencing fuel poverty. The anomalies in the definitions as applied make the effects on households with high levels of energy use, significant and potentially limiting in accessing assistance. Statistically there is substantial and increasing divergence in households' ability to fund their energy needs. Hills (2012) identifies energy rating of dwellings ranging between E to G (NFC approximate rating) accounts for 90% of household experiencing the fuel poverty gap; 62% of this 90% are further affected by no access to gas and have properties that are classed as solid wall.

The UK government targets for uplifting households experiencing fuel poverty for 2010 have not been achieved and the 2016 target to eradicate fuel poverty entirely are trending the same way (Carbonbrief, 2013; Hills, 2012). Hills (2012) declares an expectation of a 10% reduction in fuel poverty based on 2009 levels, but the number of household expected to be in fuel poverty in 2016 ranges from 2.7 million to 3.0 million affecting 7.8-8.9 million individuals. The prevalence of refurbishment and retrofit solutions for existing housing, rather than new build, will increase due to the rising importance of national and global sustainable and environmental agendas combined with difficulties in delivery of new homes in sufficient quantities to meet demand. .

3.0 RESEARCH METHOD

Design Science Research [DSR] has originally been applied to research in organisational Information Systems. DSR is a research approach which seeks to resolve real-world issues, in a research context, through the development of an artefact aimed to solve an identified problem. Artefacts may contain constructs, models, methods and instantiations. DSR uses evaluation and iteration to deliver outcomes that make a novel contribution, solve a problem or deliver a more effective solution to the problem (March & Smith, 1995; Hevner et al., 2004). Most socio-technical systems can be functionally improved, as Boland et al., (2008) suggests to '...transform existing situations into more effective ones...' (p.12); the consequential organisational improvement may be on the basis of innovation where the concern has been with '... not how things are, but how they might be ...' (Simon, 1996, pxii). Boland et al., (2004) describes the use of DSR in organisations, policies and work practices as designed artefacts extends the research areas that utilise this research method.

The S-IMPLER research is designed with a creative problem solving approach, in the real-world, developing solutions through discovery (Hevner et al., 2004). Van Aken (2004) explains that 'design sciences' as a research approach used to develop valid and reliable research that creatively solves a construction problem to improve construction issues. The nature of the artefact in this research is the use of BIM for retrofit, which when developed using DSR delivers, as an output, a BIM Process for Retrofit for NFC solid wall housing. An extended research outcome is abstraction of the BIM for Retrofit protocol to a more generalised protocol as BIM for Retrofit in solid wall housing, which presents a solution for different contexts, which is work under development by the researchers, authors of this paper, in collaboration with others.

The Gregor & Hevner (2013) framework describes DSR as a 'new solution for a known problem'; BIM for Retrofit is a new solution artefact that offers an innovative solution for retrofit in housing. BIM facilitates the analysis of solutions against target criteria, construction sequencing - 4D BIM, clash detection, cost analysis - 5D BIM in a virtual context. The S-Impler research BIM output is a representative process which is systematic in approach and based in practice, for the retrofit of NFC solid wall housing. BIM energy simulation, 4D and 5D is used for analysis and evaluation of 'what-if' scenarios, ultimately offering an improved solution (Holström et al., 2009). The iterative cycles of the research design which are addressing the problem statement are sequential refinement cycles of the artefact and deliver significant improvement in a real world context. The narrowing between the current state and the goal state are an example of Means-Ends Analysis, the '...engine of design science.' (Holström, 2009, p71) this adds value to the constructs from the research.

Design Science research does not sit consistently within a single area of research perspectives as it is being undertaken. As Vaishnavi et al., (2007) propose design science research cycles through ontology, epistemology, methodology and axiology as the research progresses through the iterative refinement cycles, similar to hermeneutic processes in interpretive research. A consistent view of design science researchers is the belief in one stable physical reality as a constraint to a multiple world view, differentiating it from interpretive research. On this basis, design science researchers' work with multiple alternate world states, to evolve the design process and artefact as the research progresses, controlling and manipulating the research environment (Vaishnavi et al., 2007). The outputs of design science research are regarded as sufficient if there is a functional contribution to the issue and it works, Boland (2004) defines functionality as '...the betterment of the human condition' (p23).

DSR is based on the synthesis and symbolism of an artefact. Synthesis as the act of making when considered in construction and using design science research, creates specific understanding that is unique to the problem statement. The cycles of iteration to refine solutions also delivers understanding and knowledge regarding the constraints that affect the problem statement. Simon (1996) identifies the constraints of an artefact as the outer environment which are the external factors of influence and an internal environment which is the organisation of the artefact with interdependencies and relationships between its components. The design activity is the development of an interface between a set of functional requirements and an implementation solution, which delivers an artefact. The research output may be considered as 'invention' where the complex issues for retrofit are known but the process to realise a solution to BIM for Retrofit is unknown (McKenney & Keen, 1974).

3.1. Research Design

The S-IMPLER research aims to improve U-values, maximise heat retention, reduce heat loss, improve air tightness, deliver a ventilation strategy and assist householders with their energy consumption through increased awareness of controls and the interactions between use and energy demand. The programme will be delivered using BIM, lean and collaborative work flows and explore innovative technological solutions and supply mechanisms, establishing experience and expertise within the construction delivery team. Figure 1. details the activities, the influential external factors and the S-IMPLER BIM outcomes, demonstrating the interactive nature of the project aims, the range of activities to deliver the specific project outcomes and the overall complexity.

As described, this research is tested in the field and the resulting BIM protocol and S-IMPLER process looks to employ solutions derived from abstract knowledge, which have then been tested in a real-world environment and developed to be applicable as useful tools for construction professionals for retrofit of NFC solid wall housing (Vaishnavi et al., 2007). This prescription driven design science research delivers innovative and creative problem resolution using BIM for retrofit of solid wall houses (Schön, 1983). At this initial stage of the research the activities are described in Figure 1.

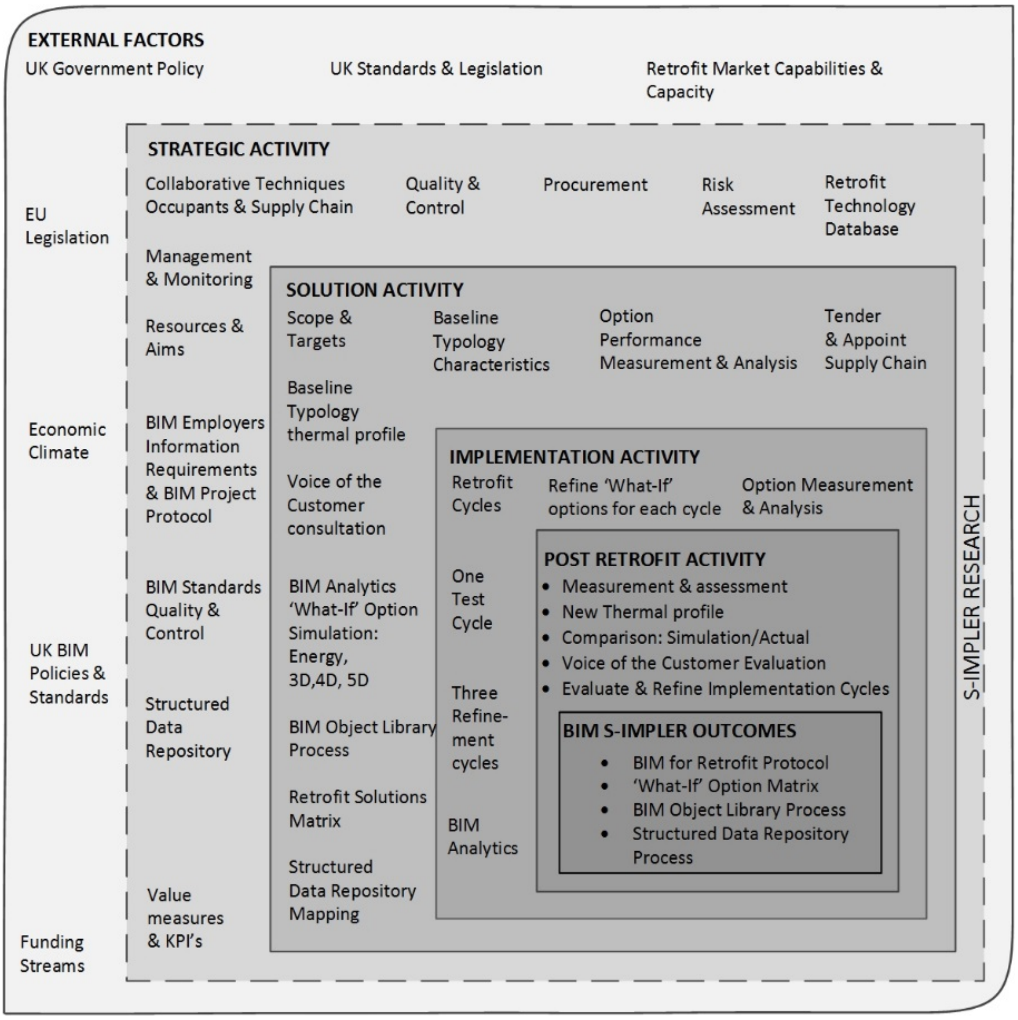

Figure.1 Activity Map for S-IMPLER Research – BIM element, developed by the authors

In order to assess the impact of BIM in the retrofit of NFC solid wall housing, the research design comprises a sample population drawn from the Northern Ireland Housing Executive [NIHE] tenant population. Six housing units, one void as a baseline unit, a second void test unit together with four households contained within a terraced block are selected for retrofit in this research. One test cycle is planned, followed by three retrofit cycles.

The test cycle will allow the research team and the supply chain to implement the initial proposed solution, the delivery strategy of the construction team, client and S-IMPLER partners and a trial of the flow of information and the implementation of BIM. This test cycle will be evaluated, revised and adjusted to incorporate evaluation findings. The subsequent cycles focusing on the BIM elements will be evaluated in terms of refining the BIM analytics of energy analysis, 4D BIM and 5D BIM together with process and protocol development and developed improvements to workflows.

The use of 4D BIM in S-IMPLER research has significant potential for improved communication with occupants, the construction team, the site team together with planning and scheduling construction activities achieving improved site safety and reducing disruption to the occupants and members of the community. The addition of cost is known as 5D BIM, which achieves reductions in the time required for the production of detailed, accurate cost information and allows for scenario testing of the design, material and the impact on budget and programme, which improves decision making. As a consequence, the increased accuracy, reliability and speed of supply of cost estimates means that budgets and contingency can improve cost certainty (Eastman et al., 2011).

The structured data repository process details the user interface to the wide range of different types of data, the relationship between the data and mapping of the different data types, together with validation and verification of the different data elements in the research. The process will incorporate a range of different types of data in the research, collected as a baseline dataset prior to commencement of the research and post retrofit:

- data gathered regarding occupant use and energy consumption;
- data captured during the forensic examination of the housing, which includes technical and graphical information types;
- Digital survey data captured using a digital design survey tool;
- BIM modelling including 3D - geometry, 4D - scheduling, 5D – cost, energy analytics.

Figure 2 details the BIM element of the S-IMPLER research and details the implementation cycles, as an iterative process. The technical solutions will be refined, contracting teams will improve with experience and the collaborative environment. The comparison of BIM analytic outputs baseline to actual, will inform decision making, this cyclical, iterative development and refinement will increase understanding of accuracy and tolerances when using simulation, establishing reliability.

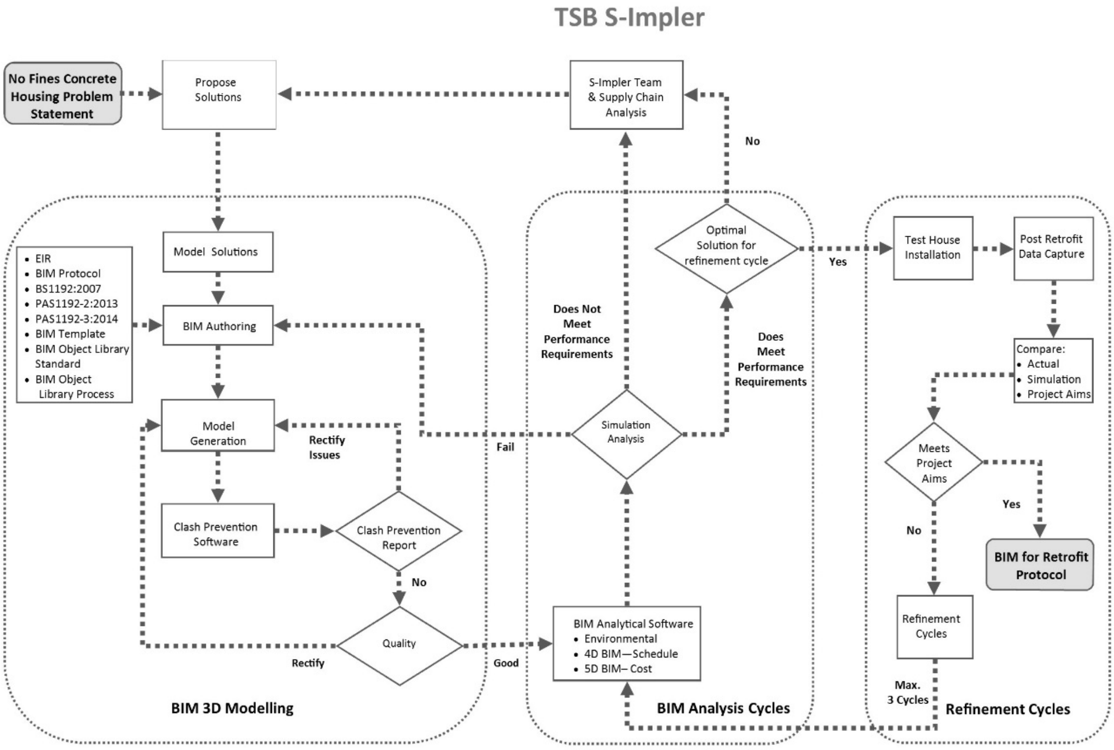

Figure 2. BIM Processes within the S-IMPLER Project, developed by the authors.

The expected BIM outputs for the S-IMPLER research are improved multidisciplinary work flows and communication, reduced coordination issues, improved productivity, creative solutions, cost reductions to meet the S-IMPLER research aims. The BIM development for the project is supported through the selection of BIM authoring software, a BIM Object library concept and the development of BIM process and protocols. Energy modelling based on a 3D BIM model will inform design and specification decisions through the iterative refinement cycles. The predictive performance modelling to calculate the buildings expected energy demand and the projected running costs and CO2 emissions will be evaluated and compared against actual performance measurements derived from whole house monitoring.

The refinement cycles, in combination with the BIM analytics in the research, facilitate the development of the BIM protocol for retrofit that focuses on the identification of solutions based on design variables to meet the retrofit targets identified; which, in this research include reductions in energy consumption, increased thermal efficiency and reduced CO2 emissions, solutions that meet some of the challenges for sustainable housing (Kapsalaki et al., 2012).

An additional research output is a BIM Object Library concept to access 2D and 3D representations of specified products, which includes product meta-data, properties and manufacturer details. Current standards are to be met to ensure quality, usability and consistency across all stages of a built assets lifecycle. The BIM Object library concept for S-IMPLER is software neutral to increase interoperability, accuracy and reliability of the contained information. Issues for consideration within the process are the maintenance of the library, accessibility by users and access controls. Verification and validation of BIM library objects are to be included and include a process for the creation of bespoke library objects.

In the context of the S-IMPLER research NFC retrofit is undertaken as a holistic approach due to the interactions of the constituent construction elements, the respective thermal properties, the construction details, usage patterns of occupants, heating fuel type and energy tariffs, the budget available for retrofits and funding streams together with a capable experienced research team and supply chain. As Rekola et al (2010) suggest, '...understanding the processes holistically play an important role in implementing BIM supported new integrated processes.' (p276). The interactions of these factors will affect the energy and thermal performance of the NFC housing and the effectiveness of the retrofit (Craig et al, 2013).

4.0 DISCUSSION

Housing retrofit brings renewal and meets the real world needs of building owners and occupants. The S-IMPLER research brings together a network of expertise to shape and deliver an ambitious solution for improved building performance. The research interventions are to improve the thermal characteristics for the management of the carbon profile, reduce CO^2 emissions, and improve the efficiency of energy use and user satisfaction. BIM implementation for retrofit has the potential to help create and maintain buildings that are more efficient, have lower carbon emissions, cost less to run and are more effective and safer places to live and work, extending their functionality and use (BIFM, 2012). Organisational challenges to successful retrofit programmes are local, national and global policy changes, the economic climate and funding streams as identified in Figure 1. At local and national level, year on year changes to budgets and programmes will affect the range of solution choices and outcomes achievable within acceptable parameters for return on investment (Craig et al., 2013).

5.0 CONCLUSIONS

This paper has outlined the principles for the BIM element of S-IMPLER research. The development of a BIM for Retrofit Protocol supporting 'what if' scenarios in housing retrofits for high efficiency thermal improvements, aiming to reduce energy costs by 60% and disruption to householders together with delivery of local, national and global targets on carbon emissions. The complexity of retrofit programmes for existing housing are addressed through a holistic and collaborative approach to resolving issues and interactions between a BIM for Retrofit Protocol, BIM analytics, construction teams, occupants and client which have been established for the S-IMPLER research. The work presented in this paper outlines the initial stages of comprehensive research in an area that has not been previously addressed in detail. Subsequent papers will present further developments and outputs of the project.

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