USING 4D BIM IN THE RETROFIT PROCESS OF SOCIAL HOUSING

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Abstract
There is a large stock of solid wall homes in the UK presenting poor thermal insulation and low energy performance. Although the UK Government has supported improvement efforts in the area, the identification of appropriate technical solutions that effectively improve the existing stock remains a challenge. BIM offers opportunities for building performance optimisation, through improved design and simulation. This research investigates how BIM could improve the retrofit process for social housing. This paper describes a research project looking into the use of BIM to develop what-if scenarios for retrofitting existing 'no-fines' solid wall homes. The scenarios enable the analysis of alternative solutions considering costs, energy performance and user disruption. More specifically, this paper focuses on the use of 4D models to evaluate disruption for end users. The research process includes simulations, meetings, interviews, documents, and observations. Results indicate that the development of 4D BIM models supports a better understanding of the retrofitting process on site, enabling the definition of production processes with as minimal disruption as possible for users, whilst still delivering energy-oriented and cost effective solutions.

Keywords: *BIM, 4D, retrofit, social housing.*

Introduction
The UK has one of the oldest housing stocks in Europe, which has a strong identity and cultural significance. Such housing stock has approximately 13 million homes built before 1960 (RIBA 2013). These houses were built when the issue of greenhouse gases and climate changes were not a global concern. Thus, their design was not conceived to ensure energy efficiency or thermal comfort for its occupants. As a result, such housing requires high-energy input to achieve thermal comfort levels, which in the context of social housing may lead to fuel poverty.

The UK government is committed to reduce emissions of greenhouse gases by 80% by 2050. The DECC (Department of Energy and Climate Change), responsible for implementing actions to ensure the achievement of the aforementioned goals, conducted extensive research and identified that the existing homes are responsible for 27% out of the total of carbon dioxide emissions in the UK (TBS 2014). Furthermore, it is known that three quarters of the existing houses will still stand in 2050. Therefore, quality improvements are needed on the existing housing stock (HM Government 2010).

The work presented in this paper is part of a wider research project entitled Solid Wall Innovative Insulation and Monitoring Processes using Lean Energy Efficient Retrofit (S-IMPLER), funded through Innovate UK (http://www.s-impler.com). S-IMPLER 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 initiative with a housing association, two SME's, a contractor, academic institutions, a lean consultant, and a construction organisation. Several innovations derived from S-IMPLER project will be combined into a single proposition:

- an innovative surveying tool;
- a Building Information Modelling tool to allow client modelling of different retrofit options considering 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

The outcomes of S-IMPLER will be relevant to many of 6.9m UK's solid walled homes. BIM is one element of the SIMPLER collaborative research project, and the University of Huddersfield leads its development, which involves a team of researchers. 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 solid wall housing. BIM is therefore utilised for predictive and evaluative energy analysis, 4D BIM scheduling, and 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. This paper focuses on the utilisation of 4D BIM models to create what-if scenarios based on minimizing disruption for tenants, which is part of the BIM element in S-IMPLER. The investigation explores the utilisation of 4D BIM models to support the decision-making process when analysing alternative retrofit scenarios for solid wall homes with the aim of reducing occupiers' disruption.

BIM in Retrofit

In recent years, an increasing number of studies indicate the importance of retrofitting the existing housing stock in order to improve sustainability. Retrofit has received greater attention within the current research agenda given that it has a crucial role to meet sustainable targets (Kemmer; Koskela 2012). Given that a large share of the buildings that influence climate currently and in the future have already been built, efficient actions regarding retrofitting and renovation are demanded. Gholami et al. (2013) state that one of the challenging issues during the retrofit process is to find an approach that improves collaboration and integration during works.

Building Information Modelling (BIM) is an approach for managing construction project information, which includes functions needed to model the lifecycle of a building. BIM provides the basis for new designs and construction capabilities, and changes roles and relationships in the project team (Eastman et al. 2011). BIM tools enable stakeholders to manage project information across its several stages in a virtual environment and can be used for many purposes in new construction or in retrofits (Sheth et al. 2010). Thus, there is a potential to use BIM tools to assist the process of retrofitting, such as 4D BIM.

According to Kymmell (2008), 4D BIM simulates the construction process in a virtual environment. The main benefit of having the project in its virtual form is the possibility of experimenting construction activities and making appropriate adjustments before execution. Graphical simulations can reveal potential problems in their origins, and opportunities for their improvement in terms of construction works, equipment involved, spatial conflicts (logistics), security issues, among others (Eastman et al. 2011). Thus, simulation supports decision-making from the very early construction stages and facilitates the development of solutions (Capeluto; Ochoa 2014).

The simulation of construction's sequence is based on a preliminary programme, schedule of works and a BIM model. What-if scenarios can be visualized in 4D sequences to help communicate the advantages and disadvantages of various scheduling options (Kymmell 2008). Early 4D BIM simulation can provide to stakeholders a better understanding of the related processes and constraints that can affect construction operations.

Ultimately, 4D BIM simulation enables the understanding of potential disruption to occupants, which supports a better decision-process and mitigates the impact of construction activities on home environment. The 4D BIM simulations can be used as a visual management tool, given that images representing the different stages of the construction process can be displayed on site to workers. Dave et al. (2013) argue that collaborative planning can be enhanced with the support of 4D BIM, where the team visually gains deeper understanding of the project when compared to traditional approaches (i.e. meetings discussing the schedule of works).

In the context of project delivery in the retrofit of existing housing, an optimal solution is the one with the capacity to cope with compressed lead-times and to cause minimum disruption to occupiers. Site layout, temporary accommodations, site facilities and storage, logistics and the construction programme and time-scales might affect not only the residing family but also the neighbourhood. The effects on occupiers depend on the family profile and on the need for temporary relocation of the family for the duration of the works. In order to determine appropriate scenarios that are effective for saving cost and time, early stage simulation methods are likely to be helpful to overcome uncertainty, to evaluate the performance of different design strategies, and to and aid decision-making. One of the key elements highlighted by Sacks et al. (2009) about BIM is the rapid generation and evaluation of multiple construction plan alternatives through 4D visualization of construction schedules.

Research approach

The research approach adopted in this study is constructive research, also known as design science research. This approach aims to build an innovative solution, or an artefact, to solve a real problem. Such problem should be relevant to current practice, and the solution should provide theoretical contributions (Lukka 2003; Van Aken 2004; Holmström et al. 2009). Van Aken (2004) explains design science research as an approach used to develop valid and reliable research, which creatively solves a construction problem.

This study encompasses three sequential and interdependent stages: understanding the problem, development of a solution, and consolidation. This paper reports on partial results of a masters' study, focusing on the development of a method to create, analyse, and select what-if scenarios for housing refurbishment focused on disruption for tenants. It is noteworthy that this master's research is inserted into the context of S-IMPLER project.

The S-IMPLER project includes the retrofit of 7 houses. House 6 is the prototype house and is void. In addition, all houses are two-story, except the house 50 which is a bungalow. Figure 1 shows houses 44 and 45 before retrofit work started.

Figure 1: House 44-45 before retrofit works

These houses are located in Northern Ireland, and require a number of interventions for improving their energy performance with minimal disruption through cost oriented solutions. The retrofit work will be carried out in 4 different phases to enable analysis, learning and improvement between phases: Phase 1-A (House 6), Phase 1-B (houses 44 e 45), Phase 2 (houses 46 e 47), Phase 3 (houses 49 e 50), and Phase 4 (house 48), as illustrated in Figure 2.

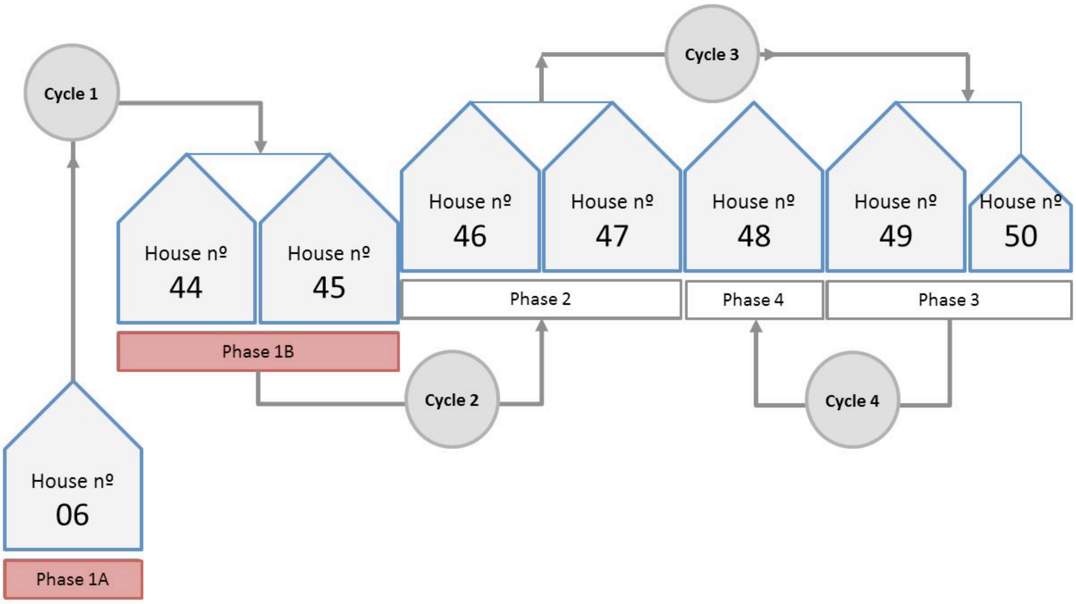

Figure 2: Planned retrofit construction sequence

The retrofit work consists of:

- replacing the old external windows and doors made of wood and single glass by openings made of PVC and double glass;
- strengthening of the existing loft insulation layer, and
- insulation of external walls using insulation dynamic boards and rendering;

This paper reports the use of 4D modelling in Phase 1A (House 6), which started on February 2015 and were completed by April 2015, and cycle 1, which corresponds to the period between the completion of Phase 1A and the end of July 2015.

Development and Results

- *House 6 (Phase 1A)*

Initially, a 3D model was developed for each house typology, based on existing plans (i.e. *.dwg files) and site visits. In addition, new insulation elements were modelled and added to the initial 3D model for House 6 (i.e. insulation boards, first-base coat, fibre glass reinforcing mesh) according to the building technology defined as part of the overall S-IMPLER project. By having these elements in 3D, the task of cross-referencing information from the 3D model and the schedule of retrofit works prior to 4D simulation was facilitated. Synchro Pro® was used to simulate the construction phases. The inputs required for this simulation were the 3D model, construction schedule, list of equipment to be used, and location of inventory of materials. Some of this information was based on the experience of practitioners involved in the project. The different trades were organised into task groups and identified by colour coding in the 4D model, so that their tasks were easily visualised in the simulation.

Collaborative planning meetings were carried out with the participation of the research team and project stakeholders to create an execution plan for each phase. The aim of those weekly meetings was to review and update the schedule of the retrofit process. Figure 3 illustrates a visual plan that was collaboratively produced at the site office.

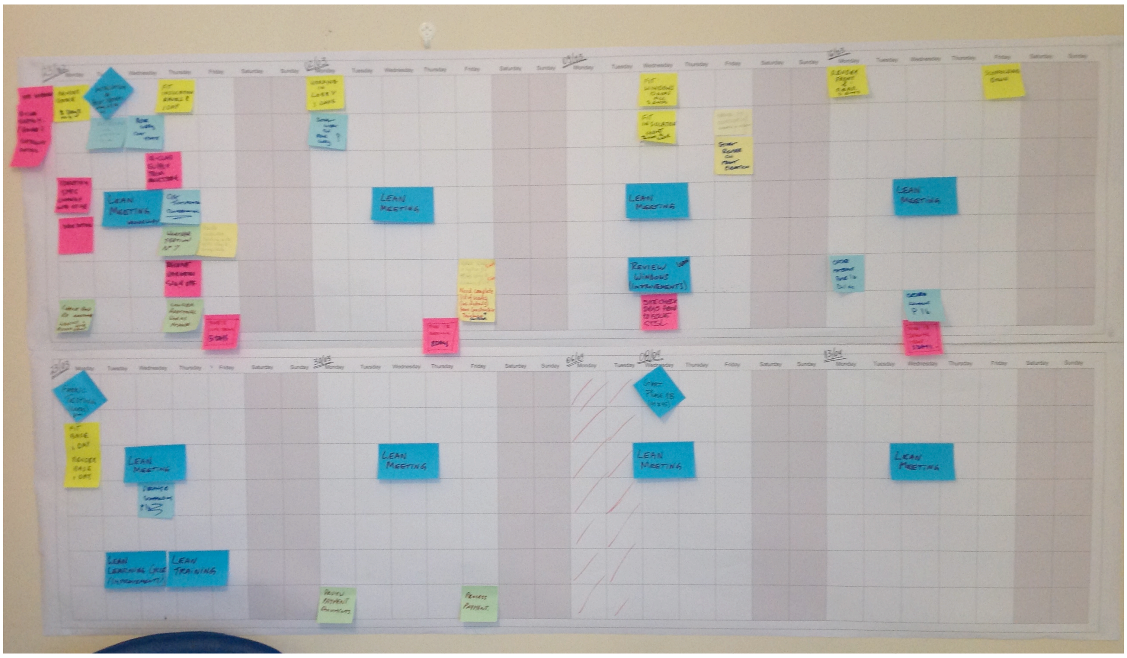

Figure 3: High-level construction schedule

Three 4D models were devised in Phase 1A. The first model was developed as a starting point for the execution of Phase 1A and was based on initial collaborative planning meetings and on guidelines provided by suppliers. The original plan was affected by restrictions found on site, such as delays in the delivery of the windows and absence of design details. As changes in the construction schedule occurred, these were incorporated and simulated in the second 4D model, taking into consideration the constraints and interferences found in the execution of House 6 (Phase 1A). Screenshots were generated from the second 4D model of House 6, were presented to site manager, and were displayed as a panel on site, as presented in Figure 4.

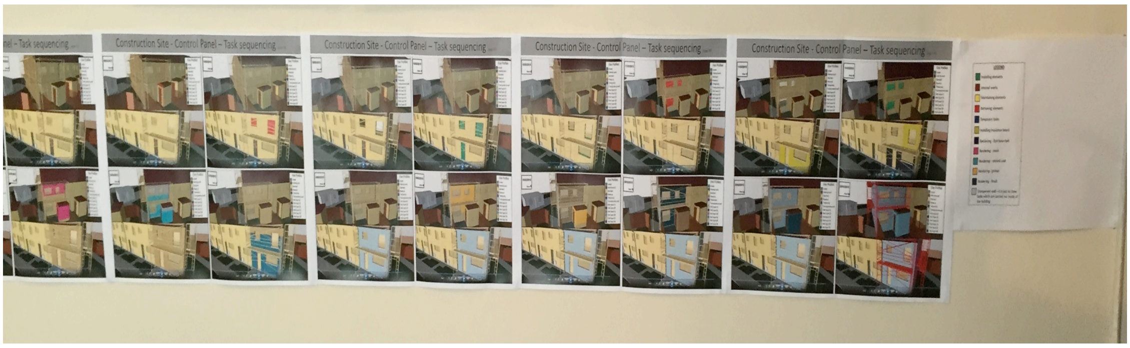

Figure 4: Retrofit work plan produced from screenshots of a 4D model

The role of those visual devices was to support the site manager to devise and update production plans at the collaborative planning meetings. Later, the third 4D model was developed considering the how the retrofit process was effectively undertaken in practice.

- *Cycle 1 (between Phase 1A and Phase 1B)*

Cycle 1 has produced four main outcomes: (a) a set of categories of disruption for tenants, based on the literature review, (b) 4D models of the Phase 1B, (c) characterization of disruption for tenants from the perspective of stakeholders, and (d) a method for creating what-if scenarios focused on disruption for tenants using 4D BIM.

(a) A set of categories of disruption extracted from the literature

A literature review about disruption for tenants was conducted and a set of categories of disruption was identified. Figure 5 summarizes the types of disruption found in the literature review.

Factors affecting end users	References
Disruption of gas provision: it happens when retrofit works affect the continuity of gas supply	(Whiteman and Irwig 1988; Wallace 1986)
Disruption of electricity provision: it happens when retrofit works affect the continuity of electricity supply	(Whitema and Irwig 1988; Wallace 1986)
Disruption of water provision: it happens when retrofit works affect the continuity of water supply	(Whitemanand Irwig 1988; Wallace 1986)
Disruption of access to the building: it happens when retrofit works block or limit the access of dwellers in their homes	(Whiteman and Irwig 1988; Jones 2013)
Disruption of everyday life: it happens when retrofit works disrupt the daily activities of residents, such as studying, cooking, taking a nap, etc., because spaces are being shared between dwellers and workers	(Wallace 1986; Vadodaria 2010; Ho 2009; Haines and Mitchell 2014; Fawcett 2014; Lee 2011)
Move out of home: it happens when retrofit works induce the dwellers to move out of their homes to avoid any inconvenient	(Wallace 1986; Vadodaria 2010; Ho 2009; Haines and Mitchell 2014; Fawcett 2014; Lee 2011)
Disruption by noise: it happens when retrofit works generate different levels of noise pollution provided by the use of tools such as hammers, mallets, etc.	(Whiteman and Irwig 1988; Miller and Buys 2011; Jones 2009)
Disruption by dirt: it happens when retrofit works generate different levels of physical waste such as dust, debris, etc.	(Whiteman and Irwig 1988; Miller and Buys 2011)

Figure 5: Table with factors affecting end users

(b) 4D models of Phase 1B

The first 4D model of houses 44 and 45 in Phase 1B was developed based on a previous schedule of the retrofit process, on the set of categories of disruption, and on the third version of the 4D model of House 6 in Phase 1A. For example, the tasks located at the front entrance and at the back entrance were not scheduled at the same time, in order to maintain access to the households. This 4D model was presented to client, site manager, foreman, designer, and suppliers of insulation of external wall. Considering the feedback from these stakeholders and the new schedule for Phase 1B, which was devised by the site manager and foreman, the 4D model was updated. The second version of the model was then developed and will be compared with future models at the end of this phase.

(c) Characterization of disruption for tenants from the perspective of stakeholders

Furthermore, the proposed set of categories of disruption for tenants was submitted to criticism by a client representative, project manager, site manager, foreman, designer, and suppliers of insulation of external wall, through a questionnaire which was sent by email. From the questionnaire, the set of categories of disruption was revised and extended, and an assessment of their importance was made from the stakeholders' perspective. Based on those categories, disruptions for tenants can be highlighted and characterized in 4D simulations to assist the creation of scenarios and to facilitate the comparison between them. At this stage, new factors of disruption were added: disruption of external environment (e.g., when the tenant performs some improvement out in the backyard such as a wood deck and it needs to be removed); and disruption in the parking spaces (e.g., when there is a reduction in parking facilities for residents by skips, vehicles of tradespeople and storage facilities for works). In order to obtain a deeper understanding of disruption for tenants, a new questionnaire was developed, and this will be applied to tenants.

(d) Method for creating what-if scenarios focused on disruption for tenants using 4D BIM

Considering the outcomes from the empirical study – Phase 1A and cycle 1 - a method for creating what-if scenarios with minimal disruption for tenants in social housing retrofit projects was developed. This method uses 4D BIM simulation to create what-if scenarios and seeks to understand how the disruption for occupiers can be minimized and avoided while the retrofit process is carried out. Also, this method enables the choice of an appropriate execution process to be used in further retrofits.

This method provides a wide support to the user when understanding, visualizing, and improving the production process in social housing retrofit projects, as well as in identifying and minimizing disruption for tenants. A schematic representation of the proposed method is shown in Figure 7.

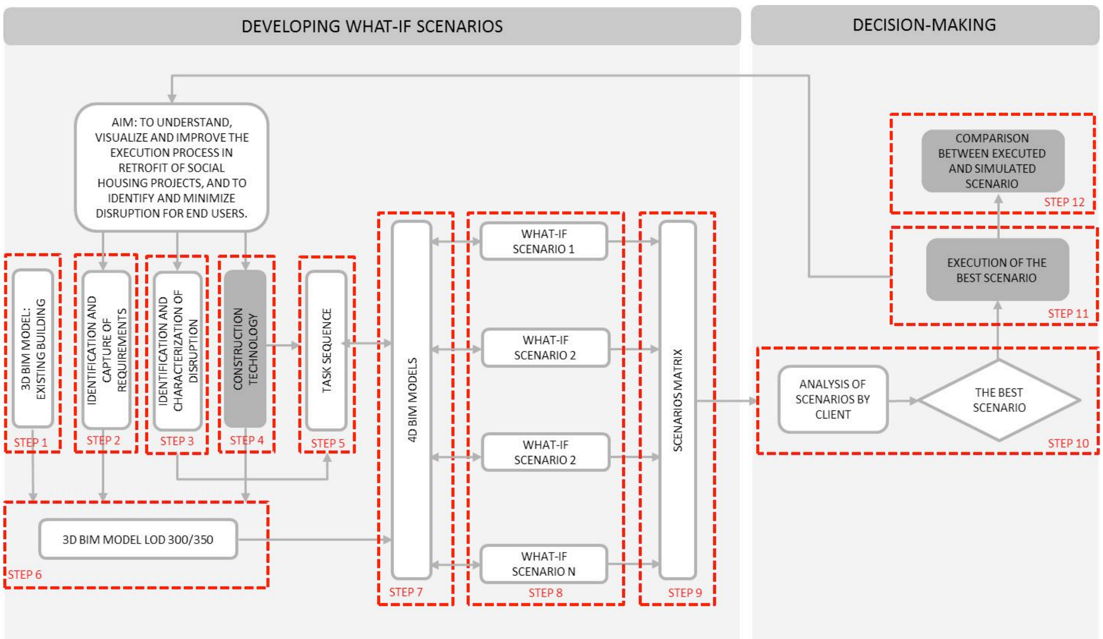

Figure 7: Method for creating what-if scenarios focused on disruption for tenants using 4D BIM

The method is divided into two main stages: developing what-if scenarios and decision-making. The stages comprise the following steps:

1. Development of a 3D BIM model of existing building: What-if scenarios are developed from 4D BIM models, therefore it is essential to have the 3D BIM model of the existing building. In most cases, the building that will be refurbished does not have an up to date documentation. Thus, it is necessary to make a detailed survey of the building comprising current measurements, and to identify technologies and construction materials used. This information is important for generating 3D BIM models.
2. Identification and capture of requirements: As this study refers to social housing, there are two main clients: the dwelling's owner and the dwelling's user. By knowing the main clients, relevant requirements for both of them are used in the development of the final product (refurbished building).
3. Identification and characterization of disruption: A characterization of disruption for tenants has been developed, and it comprises a set of factors. In this step, the types of disruption affecting tenants and the intensity in which they occur are investigated. This step influences directly step 5.
4. Definition of the construction technology: A set of alternatives in technology for executing works in the existing building should be investigated and defined. The client may consider other factors in the selection of these technologies, such as experience, time, cost, among others.
5. Definition of tasks' sequence: This step depends exclusively on the previously selected execution process. Each process might have a set of basic execution guidelines (e.g. items need to be installed before the insulation boards in the external walls in order to avoid future rework). Each execution process could generate several tasks' sequences. The number of sequences must be defined by the client who must consider minimizing disruption to tenants during retrofit works. This input is considered in the 4D BIM modelling.
6. Construction of a 3D BIM model LOD 300/350: Considering that the 3D BIM model of existing building has been developed, the type of execution process has been set, and clients' requirements have been understood, a 3D BIM model with the level of detail 300/350 must be developed. Also, in this step, several 3D BIM models could be modelled according to the defined process in step 4. This input should now be considered in the 4D BIM modelling.
7. Development of 4D BIM models: Each execution sequence added to its respective 3D BIM model, which has elements of the existing building and the building to be refurbished, will generate a 4D BIM model. In addition, each 4D model can create a what-if scenario. As changes in the sequence of activities occur, a new simulation scenario is created.
8. Creation of what-if scenarios: This step corresponds to creating several potential alternatives of retrofitting for a specific execution process. The number of what-if scenarios should be established by the client in order to proceed to the next step.
9. Elaboration of a scenarios' matrix: After the number of what-if scenarios has been defined, they should be compared against each other through a scenarios' matrix. A set of parameters should be used to assist the process of analysing and selecting the best scenario as part of the decision-making process performed by the client.
10. Analysis of what-if scenarios by the client: Based on the abovementioned matrix, the client is able to choose the best scenario for conducting retrofitting works.

11. Execution of the best scenario: After the best scenario has been chosen by client, a contractor, which has been defined by client, should execute it. The information derived from the execution of the chosen scenario will provide feedback the process and should be considered as an input for further developments. As an example, a survey with tenants can be performed to investigate whether the foreseen disruptions at the beginning of the process happened or if new disruptions emerged.
12. Comparison between scenarios: a comparison between the simulated and performed scenarios is recommended, in order to obtain additional information as a feedback for the process.

Discussion

The study developed in Phase 1A was important to explore 4D modeling and simulation, especially when presenting the retrofit planning process to the site manager and to the foreman. Furthermore, this stage reinforced the needed of creating what-if scenarios in order to minimize disruption for end users.

Currently, the retrofit execution plan on the S-IMPLER is performed by using stick notes on a board. This is relatively fast and straight-forward, but it can hide some execution issues, bringing possible rework and increased costs during the project. The retrofit execution plan requires the support of management and visualization tools to assist in carrying out the work. So there is a great potential for use of BIM 4D tool in this project. Although a visual device containing screenshots has been used on site in Phase 1A, its applicability has not achieved its central objective. A new attempt will be made in Phase 1B, as previous studies have proven that in new buildings the use of visual devices facilitates the application of the model 4D on sites (Sacks; Treckmann; Rozenfeld 2009; Bortolini 2015).

There are opportunities in terms of training in 4D modelling and simulation, as the site manager and foreman had limited knowledge about the topic. It was agreed with participants that it is more difficult to visualize the 4D simulation in retrofit projects than in new construction because some elements are already existing parts of the building.

The study developed in Cycle 1 was important to understand what disruption for tenants is, and how the use of 4D BIM models can minimize it. Some studies point to the difficulty to conduct refurbishment in buildings where users remain in the site during works, but very few of them indicate what are the disruptions that can be found in these works. Thus, it was important to create a set of categories of disruption based on literature review.

Although the method was devised, steps 1 to 7 have been partially used. So far, the critical points of the method are: to identify and capture clients' requirements, to assess the influence of a dwelling's owner and/or a dwelling's user as main clients, and to define the construction technology without client's support. Consequently, it is necessary to collect more information with external suppliers in order to fine tune the tasks sequencing.

Conclusion

This paper described how 4D models are explored in the improvement of construction planning, particularly in the reduction of occupiers' disruption in retrofit projects. The findings presented in this paper are part of an ongoing study.

First main finding of this paper is the identification and characterization of disruption for tenants when the retrofit works are carried out. It is highlighted the need to identify and to characterize disruption for tenants using three sources of evidence: literature review, stakeholders' perspective, and tenant's point of view. Thus, a survey assessing tenants' perception about disruption can gather relevant inputs to refine and build what-if scenarios. An accurate definition of disruption would enable the creation of alternatives for executing works on site.

Second main finding is the method for creating what-if scenarios using BIM 4D. This proposed method was devised to guide public or private companies retrofitting social housing. This method will support the decision making process when choosing the most appropriate solution from a user's disruption perspective.

In the retrofit context, 4D modelling should be increasingly used by contractors and subcontractors to make collaborative decisions concerning occupiers and neighbour's disruption. As different scenarios considering a wide range of factors affecting tenants (i.e. noise, pollution) will be simulated, it is expected that reduced disruption is achieved.

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