SUPPORTING FUTURE-PROOF HEALTHCARE DESIGN BY NARROWING THE DESIGN SPACE OF SOLUTIONS USING BUILDING INFORMATION MODELLING

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BIM has been characterized by the UK Government's chief construction adviser as unstoppable regarding its rise in construction and he further positioned BIM as mandatory for public projects in the UK by 2016. Moreover, large scale public projects such as healthcare facilities must be seen as a process, being able to meet the constantly changing demands imposed on healthcare infrastructure. Facilities should be designed as change-ready rather than to meet fixed requirements, therefore, the designer should accommodate as large section of design space potential solutions instead of mistakenly narrowing the response of the project to only one solution. Scenario based design was employed as research and design method for the proposed software modules which would extend the Activity Database (ADB). Two modules are proposed that will enable designers to improve their spatial design decisions for both new and refurbishment projects through partially automated knowledge extraction. Additionally, the integration of flexibility and standardisation concepts has been addressed. The proposed design approach is intended to provide rich knowledge representation at the early stages of the design process in less time and effort.

Keywords: decision theory, healthcare, information extraction, information technology, standardisation.

INTRODUCTION

The UK Government and industry provides standards and guidance for the design and construction process of healthcare facilities in order for the design process to address the needs of all the stakeholders (patients, medical staff, owners etc.) by defining procurement methods (NHS 2011), construction strategies (Cabinet Office 2011), overlay plans of work (RIBA 2012), and technologies to be used (CIMCIG Admin 2012). These result in more standardised processes and products. Additionally, programmatic requirements and best practice for the design of healthcare facilities are provided through Health Building Notes (HBN), Health Technical Memoranda (HTM), Activity Database (ADB) and in the DH Schedule of Accommodation. Additionally, the Department of Health commissioned the Procure21+ framework "to improve the procurement process for publicly funded schemes and create an

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environment where more value could be realised from collaboration between NHS Client and Construction Supply Chains" (NHS 2011).

In cognitive science, parallels have been frequently drawn between design and playing chess. Conceptual design has long being recognised as an ill-defined process (Reitman 1964, Simon 1974). An early design problem does not have a clear statement, the constraints are not clearly defined but fairly general objectives are set which leaves the designer with large choice of solutions representing a chess-like design approach which "is rather like playing with a board that has no divisions into cells, has pieces that can be invented and redefined as the game proceeds and rules that can change their effects as moves are made" (Lawson 2004: 20).

Global austerity measures are causing reduction of investments in all sectors, and the construction sector is no exception, however, owners are seeking other ways to overcome the financial crisis by investing in the application of the sustainability agenda; and for a building to be sustainable designers recognise that it has to also be flexible and adaptable (Krygiel and Nies, 2008). Yet, introducing sufficient flexibility to future-proof the design of healthcare facilities is still a rather abstract process. While a specialized (mostly architectural) body of research has identified various types of flexibility that a facility can satisfy, there is little research regarding how this can be captured in the design process through design standardisation.

Design standardisation can help to make flexibility quantifiable. With BIM technology there is potential to increase the procedural designer's knowledge to manage, apply, edit and test "chunks" of design information; rather than manipulate meaningless lines as one used to do in using previous CAD systems. The proposed design methodology is focused on two design aspects: to allow the user to test, during the conceptual stage, "what if scenarios" for future refurbishment in order to better future-proof the project; and to allow an automated comparative analysis to take place in existing refurbishment projects between an existing space and proposed alternatives in terms of cost, timescale duration and best matching attributes. Adoption of the proposed design methodology will allow parts of conceptual design to be standardised and automated in terms of narrowing the design space of solutions while better exploiting the power of IT. Eventually, this will allow testing more "what if scenarios" in significantly less time and with less effort. In this paper the theory underpinning the proposed design methodology is described whereas in the next phase this concept will be tested in various case studies.

Literature Review

Theories in Layout Planning

Different cognitive processes may be used to generate spatial layouts. Eastman (2001) described two extremes for design generation. The first extreme is external representation, where the design is composed and refined by the designer by controlling the symbols and structure of it. The other extreme is internal representation, where the designer builds up the design in his/her head until it satisfies the set criteria and then proceeds to the external representation. Recent advances in research seek to understand how the design process unfolds, and the role of computer systems in that process. This often leads to the design of human-computer interaction. Two paradigms describe two different worldviews: the computer-supporting-human paradigm and the computer-controlling-human paradigm. The latter, often referred to as emulating design (Cross 1999) can be compared to the computational process that chess-playing machines adopt. Efforts to adopt such a process failed in the history of design cognition. The example below can best describe such efforts.

In the mid-90s, a project "Can a machine make aesthetic judgments?" (Glaze et al. 1996) aimed to establish rules of aesthetically "bad" design since the research team concluded it was not possible to establish rules of aesthetically "good" design. The researchers collected amateur designs and submitted them to expert graphic designers to critique them. The team subsequently converted the comments on the "bad" design features into "rules", and later the team tested these rules by using themselves as "human-computers" (i.e. the team followed the instructions in a machine-like way). Finally, the team applied the rules to a new sample of drawings and compared the "machine" results with those of the human experts' critiques of the new drawings. The interesting point was that only a small number of rules could be applied to the new sample in order to eliminate common "bad" design features. What was even more interesting was that even the experts were found to be inconsistent in applying their own rules. The explanation given by the expert designers was that though the "rules" were correct, their applicability was not a standard in every case.

This experiment presents the notion that there are some things such as "aesthetic judgments" (or for the purpose of this study "flexibility judgements") in design where the "human attribute" cannot be emulated by the computer to a satisfactory degree. Consequently, there is a need to understand why people design first rather than try to automate how they design (Cross 2001). The first paradigm, often referred to as supporting design, accepts the computer to be the agent where, instead of controlling the design process it supports the thinking of designers by providing different capabilities, such as being web-based, learning and/or being pro-active (Lawson 2005) and that envision brings BIM into discussion.

Parametric Object-based Modelling

IT and specifically design computing has increased users' expectations. Parametric Object Modelling (POM) is linked to creativity in architectural practice and as the results of the survey by Ahmad et al. (2012) suggest, POM has the potential to enhance the whole process of design decision making and problem solving. POM engines use parameters to determine the behaviour of a graphical entity (the object) and define relationships between other modelling objects.

Object CAD technology may provide the same graphical and geometrical representation output as a parametric building modeler; but that does not mean that the information of the CAD model will be as rich as in the BIM model. "Current file-based CAD and object CAD tools may be used to some degree to support BIM, but require myriad supporting technologies and the aggregation of information across diverse, independent applications" (Autodesk white paper 2007:5). As a consequence, CAD and Object CAD technology cannot offer real time coordination (simultaneously updating a change in all views of the model) when a change in the design occurs and as a result integrity and confidence in decision making are put to question (Autodesk white paper 2007). POM offers a whole new approach to design, beyond CAD and Object CAD. For example, instead of capturing a wall by a set of lines using standard tasks such as offset, mirror etc., the designer can create an object by choosing it from a predefined library of object classes and instantiating that object. This parametric design paradigm has led to the creation of a library whereby whole healthcare rooms can be inserted into a design model, with their objects attributes, engineering requirements and clinical functions through the Activity Database's (ADB) add-on for BIM platforms.

The ADB add-on for BIM platforms

The ADB toolkit (first introduced in 1970s by the Department of Health (DH), the Social Services and in collaboration with the Regional Hospital Boards) contains information intended for use by healthcare estates and facilities professionals. The database comprises information regarding departments, rooms, assemblies and components and can be used in both the initial stages of the project, as well as in later stages (detailed design). Through ADB, the DH provides design standards that satisfy the department's requirements. The ADB add-on for BIM software allows the designer working in a CAD or BIM environment to insert a room with all its components directly in the layout. There is a list of all departments and all room types. It allows the designer to check the BIM model against the ADB Project Database. This automatically checks the room's equipment and if there are any mismatches the software will highlight them on the layout. Additionally, the designer can create schedules out of the layout in terms of room schedule or in terms of room equipment. Additionally, the existing ADB information architecture represents all rooms using a clear and precise set of attributes (ADB add-on white paper 2012).

During design, the designer can manipulate data of more than 1200 room variations – a vast amount of information to be managed, the add-on does not offer a method that will limit the design space of solutions within the BIM system. The designer is expected to exploit processes outside the BIM environment, such as retrieve information from previous projects, or to rely on his/her previous design experience or other design precedents (Lawson 2004) to identify possible solutions. This research offers insight to narrow the design space of information management where the system offers partially design knowledge according to the designer's preferences.

METHODOLOGY

Two modules are proposed to extend the ADB add-on that will enhance the information extraction experience within BIM. Scenario based design (SBD) was employed as method to develop the proposed modules. The modules extend the ADB add-on by: organising attributes of rooms and components into categories and subcategories, and sorting solution spaces based on the cost of applied changes or by the time they need to be fulfilled or by the number of attributes/filters that are satisfied. The two modules are described on the following sections. Due to limited space, only one refurbishment problem scenario is presented here. Problem scenarios referring to "what if scenarios" for testing future refurbishments during conceptual design are not discussed in this paper. Problem scenarios are the means to describe a user's engagement and her interaction with the system and "a key result of requirement analysis" (Rosson and Carroll 2002: 12).

Problem Scenario: The healthcare estates manager and the owner of "Town A Hospital" want to change a clinic's utilities room because it is of no use to the staff. They first open the BIM model to check whether the design team that built the facility some years ago included in the study any alternative scenario for the space in question but they do not find such information. They want to substitute the existing space with another space but they do not know what the best options for that particular space are, so they communicate with company X that has established its name in the field of healthcare design. Alex, who works for company X, receives an email with the BIM model of the healthcare facility for which an alternative layout was requested. She opens the BIM model and wonders about the choices she has to change the space in question to another space. She refers to the ADB room database but she gets stuck as there are more than 1200 room variabilities that she needs to check against the existing space. She then goes to Bob, the senior designer and asks him based on his experience working on previous healthcare projects if he ever faced a similar task of alteration of a space with analogous requirements. Bob tells her to open the file of "project B" they worked on 3 years ago.

Alex goes through the files of the project and she finds the original layout and the revised refurbished layout. She sees in the first layout a room similar to the utilities room in her current project that was later changed to another room type, but she cannot find what made this choice the best available solution so she goes back to Bob. Bob tells that was the option the owner preferred from a list of space solutions provided to him. Bob then forwards her an Excel spread sheet where the problematic room was checked against other rooms based on a list of engineering requirements (such as cost of refurbishment, clinical functions, environmental conditions, area constraints, duration of change etc.). Alex opens the file and marks down the nominated rooms and their cost refurbishment and forwards the file to the healthcare estates manager to decide what room is more suitable for the hospital's needs and budget.

THEORETICAL FRAMEWORK FOR FUTURE-PROOFING THE CONCEPTUAL DESIGN PROCESS

The discussion of this section presents the theoretical framework upon this study was based (Figure 1). The goal of narrowing the design space of solutions emerged from the concepts of decision making in design. Simon (1996) described design as a problem itself that requires answers. According to Newell (1979:5) "a problem space consists of a set of symbolic structures (the states of the space) and a set of operators over the space". Additionally, there is no linear process from problem to solution (Lawson 2004) and since there is more than one problem spaces (Newell 1979) design seems to be the only means to drive to "satisficing" solutions (Simon, 1996). Krishnamurti (2006) described a design space as the sum of the problem space, solution space and design problem.

The problem space is shaped only by the potential solutions that satisfy the established requirements. The solution space on the other hand is formed by all potential solutions for a given design problem. The design process consists of procedures used to develop candidate solutions from requirements. Akin (2001) analysed the design process as the sum of the design knowledge and design strategy, where strategy refers to the search the designer carries out and knowledge stands for all the means the designer uses to represent the multiplicity she needs and finds useful. Such representations could be the designer's actions, processes, design states etc.

Moreover, Fricke (1996) categorised strategy into Function oriented, where the designer focuses on one problem area, solving it from abstract to concrete level and then continues to seek answers to the following problems, and Step-wise process-oriented, where the designer considers all the relevant problem areas and holds a more abstract level of solutions before becomes more concrete. Regarding knowledge, from on-going research (Ahmad et al. 2013) it is recognised that "satisficing" healthcare design solutions will emerge from the application of flexibility, design standardisation and the information management abilities of BIM.

Application of Future-proofing Conceptual Design Process

Having discussed, in the previous section, the concepts driving the proposed process, the application have been discussed in this section (Figure 2). As previously mentioned, there is more than one design problem; consequently, for the design of healthcare facilities, such problems regarding information could be caused by many factors, for example: the information the design team receives from the brief with the client and the information the design team receives from computer systems, such as the vast information that is contained within the ADB add-on (Stage 1).

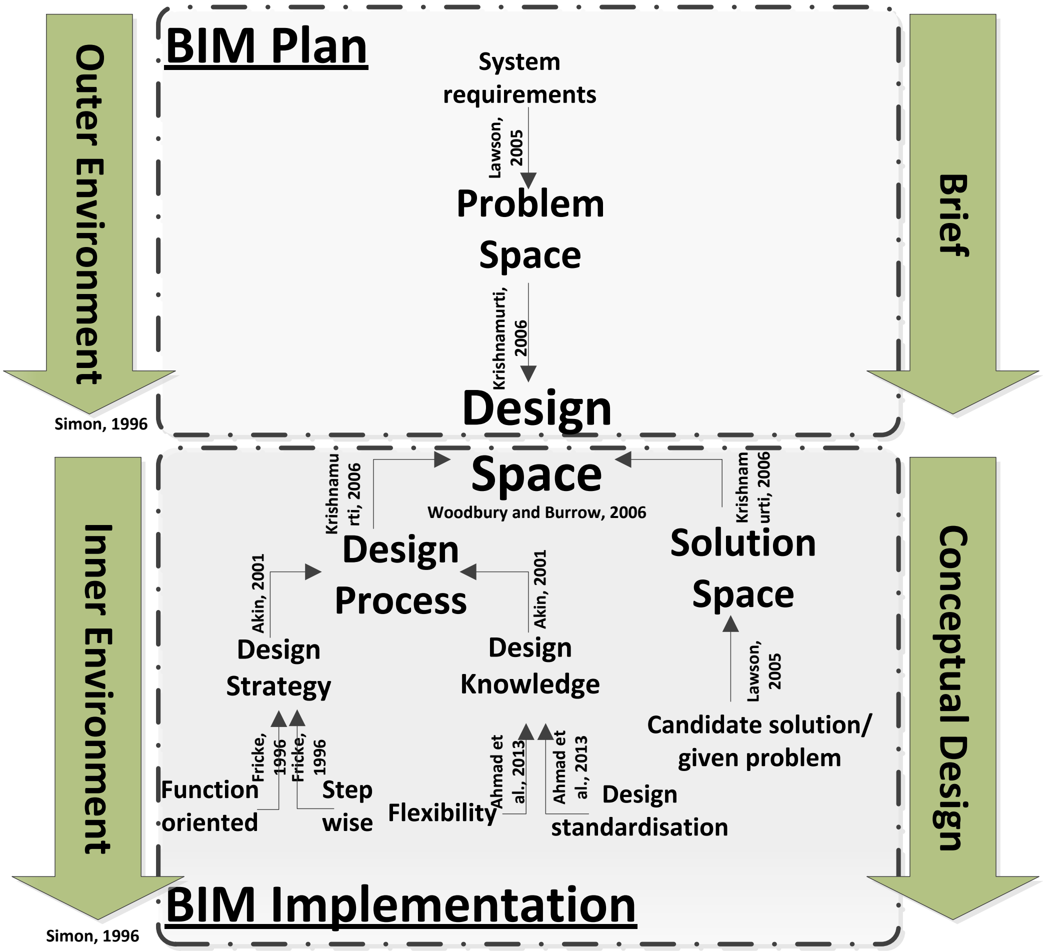

Figure 1: Theoretical framework-future-proof Healthcare design by narrowing the design space of solutions.

Future-proofing healthcare design towards "satisficing" solutions within BIM is achieved by adopting a function-oriented strategy, e.g. solving one problem (room or space) at a time (Stage 2). Automated design knowledge, the other component of the design process, is exercised by investigating two space attributes: flexibility and design standardisation (Stage 3). Design standardisation is applied in terms of managing the vast information that exists within the BIM system and BIM attributes are classified based on numerical and textual values. The BIM system identifies common information that is contained within the ADB rooms, such as attributes with the same textual values (e.g. Type A carpet) and numerical values such as width of a room. This process allows the grouping of ADB attributes into category filters and sub filters (Module 1). From literature, it is concluded that flexibility is clarified as the total force of two other forces-effects. The identified relationship between these two effects can be analysed with change effect being the independent variable and timescale duration effect being the dependent variable. Slaughter (2001) categorised flexibility in regard to change and three categories emerged, namely change in people/flow, spatial change and structural change. Alternately, De Neufville et al. (2008) categorised flexibility in regard to time, hence the three categories that emerge are short-term, mid-term and long-term. The three stages of change effect provide knowledge regarding the duration of a substitution of two spaces. For example, a change from Type A Office to Type B Office can be short term if involves only a change of people. On the other hand, if it evolves demolition of walls to extend the area then it is a spatial change (Module 2).

Another way to measure the proposed alternative solutions is to assign refurbishment costs to substitutions between the existing space that is nominated to be substituted and the proposed alternative solution spaces that emerge from Module 1. For example, the utilities room that was to be substituted would be checked against the list of rooms that emerge from Module 1 (Stage 3a) and then the user will prompt the computer to sort out the alternative list of solutions from least expensive to most expensive substitution. Therefore, the independent variable this time is change effect and the dependent variable is cost effect (Module 2).

The mechanisms that emerged from the function oriented strategy and the automated design knowledge drives finally towards a space of solutions, that is a list of proposed ADB rooms that results to a narrowed design space of satisfactory solutions (Stage 4) and finally the design team along with the owner of the project can conclude in choosing the most effective alternative spaces that emerge through the aforementioned process.

Modules for Supporting Design Space

The existing ADB information architecture represents all rooms using a clear and precise set of attributes. In a BIM model, ADB information is captured within the rooms or the components of the rooms. The two modules described below were developed to address the issues that emerged in the problem scenario where Alex the designer was struggling to find a quick and reliable solution as she could not handle all this vast information that was contained within ADB. The first module is the option to categorise attributes based on what they represent. For example, the spatial category will include the subcategories, length, width, height, area and volume. The user will be able to choose one or more subcategories of that category, so that when the query search presents a list of results, only spaces that satisfy all the preselected options will appear. Through that action the user can filter the vast amount of proposed rooms that is available in the ADB database. For instance, Alex might want to keep the same flooring material (material attribute) and the medical equipment (components attribute) to the room the estates manager wants to substitute, so she clicks only on those filters that satisfy the briefing requirements. She then runs the query and only rooms with the same selected attributes will appear as possible solutions. That means that the designer has to be careful about what filters apply otherwise the results will not satisfy the brief requirements.

Module 2 allows the user to compare the items (rooms) which are proposed by the first module against three criteria: cost of change, timescale of change and best matching attributes. One way to test which option fits best is to consider the cost of converting the existing room type to the proposal being considered. Cost of changes can be assigned from a database that will contain cost linking data of rooms. The database would contain data that derive from the following procedure: the existing room will have to be checked against all other proposed rooms in terms of refurbishment changes. No actual costs will be provided as detailed costing can only emerge in detailed design, instead a matrix will be created that will contain cost factors among changes of spaces. The matrix can be pre-computed and then the database can be inserted in a BIM platform e.g. Revit though the Revit API. Beyond cost, the second criterion to consider when assessing nominated spaces would be to estimate how much time will take for the refurbishment to be completed.

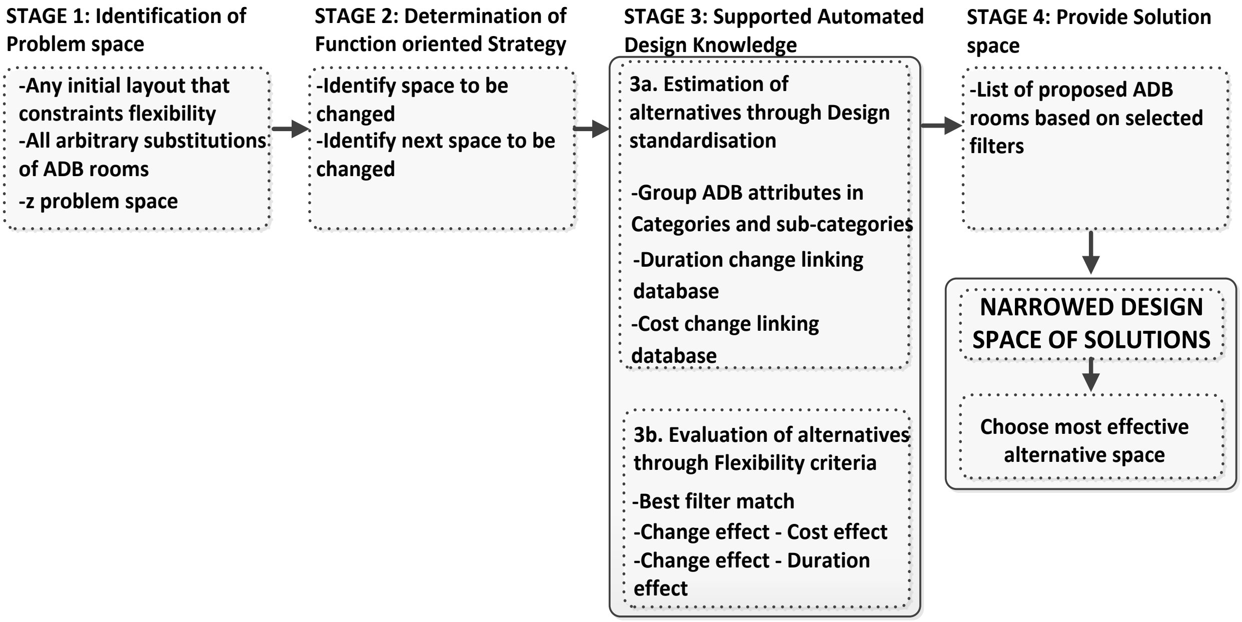

Figure 2: The process of narrowing the design space of solutions in a BIM add-on to the Activity Database (ADB).

As discussed earlier, flexibility is analysed in a change frame format and in a time frame format. Another database can be created therefore to provide knowledge regarding the duration for a change to be completed. The ADB room coding list (Department of Health, 2012) contains information of the room categories and sub categories. These room subcategories are further analysed into room variabilities. The tree map hierarchy of the ADB room coding list will provide the first knowledge about the factors of duration regarding a change. Due to shallow structure of hierarchy a further analysis will be applied, in other words a change will be assigned to one of the three aforementioned types of changes and then further categorised to short, mid or long term change and using First Order Logic the process can be automated. Lastly, the third option to sort out the proposed alternative solutions is by ranking the items regarding how many filters and sub filters are fulfilled. Hence spaces that fulfil all selected filters will appear on a higher rank than spaces that fulfil fewer filters. The proposed Human-Computer Interface experience is based on the principles of the aforementioned theoretical framework.

The first module applies principles/notions/concepts from the function oriented design strategy as described by Fricke (1996), and the need to support knowledge extraction within conceptual and refurbishment design through design standardisation. The second module applies rules from the concept of flexibility (change frame vs. time frame and change frame vs. cost frame).

CONCLUSIONS AND FUTURE RESEARCH

Previous attempts to apply design standardisation and emulate standard design processes failed to provide satisfactory results or have not yet matured to address the problems that emerge during conceptual design. Some designers adopt top-down processes whereas others prefer bottom-up processes (Lawson 2005). Construction projects are becoming more and more complex, and the amount of information the designer is expected to handle is exhausting. Therefore, information extraction becomes more important than ever. This research presents an innovative method to extract spatial information that usually needs to be extracted manually by the practitioner when making design decisions. The proposed design methodology narrows the design space of satisfactory solutions by integrating the concepts of flexibility and design standardisation. This is based on three approaches: consider the cost of making a space change, providing knowledge regarding which alternative space is more cost efficient; consider the duration needed for a change, providing knowledge regarding which alternative space is more time efficient; and provide knowledge regarding which of the proposed alternatives satisfies the most criteria-filters that have been set by the user, based on existing ADB metadata. These three approaches become criteria in the ADB add on for BIM to sort out proposed solutions. These proposed solutions emerge after introducing design standardisation in ADB rooms via extracting the information they contain. This is achieved by automatically identifying common design components and attributes. Finally, the parameter of inserting cost links and timescale duration links within the ADB rooms applies value engineering at the early design stages of the project.

Further on-going research will provide adequate support for the proposed modules. Both aforementioned modules need to be developed and tested in various case studies to evaluate and test their performance. The filter categories need to be justified by the end users. The Engineering Requirements of the filters will be collected through interviews with various stakeholders. Architects specialised in healthcare design, BIM and the ADB plug in will be interviewed in both new and refurbishment projects they participated. Clients will be asked regarding the quality of feedback they would like to receive in the early stages of a project. For the cost database, professionals will be asked about cost refurbishment changes and what procedures they follow to estimate them.

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