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DESIGN OF FLEXIBLE AND ADAPTABLE HEALTHCARE BUILDINGS OF THE FUTURE – A BIM APPROACH

The UK's Government Construction adviser announced that all the public construction will be implemented with BIM in the coming years. This decision affects dramatically the design phase of healthcare facilities as by 2016, BIM is mandatory in the implementation of the design process. Moreover, The UK Construction Strategy plan does not offer for investigating the multidisciplinary design space of possible solutions. The uncertainty that impacts on healthcare (demographic trends, changing patterns of disease, technological advances and clinical knowledge) has led healthcare policy makers to take action to manage demand for healthcare services and the supply enabled by healthcare infrastructure. A state of the art review of literature identified that healthcare facilities are not designed to be change-ready and that owners of such facilities have dynamic requirements. To future-proof healthcare facilities a design process is required to offer a collaborative, parametric lean construction practice that enables the design team to generate and analyse flexible healthcare building design spaces based on multi-stakeholder requirements. BIM and Integrated Project Delivery (IPD) offer dynamic decisions early in the design process. Here, IPD, the RIBA Outline Plan of Work 2012 and the BIM Guide from the Computer Integrated Construction Research Program were used to define the exact information exchange between the parties in a BIM-based construction process for change-ready healthcare facilities. A generic process map is derived from the literature for future testing and is presented in respect to the principles and philosophies of process protocol.

Keywords: conceptual process map, design space, flexibility, healthcare facilities, parametric modeling.

INTRODUCTION

The NHS along with the Private Finance Initiative (PFI) was procuring over 70 new hospitals by 2002 (Worthington, 2002). RIBA (2007) outlined the Work Plan of such contracts but the suggested process did not provide a building that was adaptable nor the process of design was BIM oriented. Similarly the RIBA (2012) Outline Plan of Work is indeed updated to BIM working methods but yet again the design process does not provide a facility that can respond to change. Moreover, PFI contracts do not support flexibility; the "2020 vision" highlighted that many of the healthcare buildings could be obsolete the day the start (Worthington, 2002). Kendall (2005) argued that many large facilities become "complete" over time, incrementally, but are never really finished. Moreover, Kendall argued that it is not appropriate to design for one fixed solution; since the organization's requirements (and consequently the building's requirements) are constantly changing through time; so the design must allow the building to adapt to future circumstances. Current approaches, referred to the Pre-BIM stage, have been characterised by their inability to deliver *collaboration* among the stakeholders as well as asynchronous workflow. Automation and sharing of information such as quantities, cost estimates and specifications is neither derived from the design documentation nor linked from other documentation. Taking advantage of technology in order to deliver better outcomes is at a minimum level (Succar, 2009).

Doubts have been expressed, as to whether new healthcare buildings being built today are able to adapt to society's changing needs in the future (Worthington, 2002). The NHS Confederation briefing (2010) explained that new buildings should be capable to provide efficient, safe, quality environments to meet the needs of a modernised health service. Accordingly, buildings are linked to healthcare systems and while systems are evolving through time, so buildings have to follow in order to have consistency in the healthcare sector. Finally, the understanding that there is no best solution (de Neufville & Scholtes, 2011) will force the project team to deliver a design modifiable to new circumstances rather than one which responds to fixed requirements.

Integrated Project Delivery (IPD) requires all participants to start as early as possible in the implementation of a BIM project (AIA, 2007). Proposals for BIM implementation are continually developed and additional participants are added to the project to make the required modifications, and updates to eventually maximize the project's deliverables (CICRG, 2010). BIM has been characterized by the UK Government's chief construction adviser Paul Morrell as *"unstoppable"* regarding its rise in construction (Fitzpatrick, 2012). Additionally, Morrell sees such potential in involving BIM in design, construction and operation of buildings that by 2016 all public construction projects over £5 million will be implemented with BIM. Kymmell (2008) stated that BIM is not a single static model of a project. The components and the information that shape a BIM model are continuously evolving as the project steps from one phase to the other. Significant changes might occur to both the 3D designed components and their linked non-3D information. The recognition of this continuous change makes BIM a dynamic process.

The design process entails proposals, testing and modifications. During conceptual design, it is necessary to justify the design concept step by step. This justification will provide the design team the required knowledge to understand the relationship between the suggested scenarios and the design's responses to these scenarios. The objective of this validation is to strengthen the proposed solutions, used methodology, methods, tools, etc. It is important to know when and what kind of decisions should be made, and how to make them. It is not unusual to see conflicting objectives which render decision making challenging.

Recognition of changing design criteria and requirements brings parametric modeling to the forefront. This new design approach has the ability to adapt and respond to the aforementioned issues, making parametric modeling an effective approach for the designer who investigates solutions for complex and dynamic designs. Research so far has explored systematically many of the possibilities using scenario planning and parametric processes of the requirements and the designs (Gane 2011; Koppinen & Kiviniemi 2007), but this does not necessarily mean the resulting design itself will be flexible. It only means that the resulting design is the best design at the time for that set of known requirements and scenarios. What if the requirements or scenarios change in an unforeseen way? Or what if one of the requirements is that the building must be change-ready? The following paragraphs explore this need for flexible designs.

Aims and Objectives

The aim of this paper is to propose a conceptual process map to apply BIM for implementing flexibility in healthcare facilities.

The objectives of the paper are to:

- develop a state-of-the-art through a review of literature on design theory, flexibility and BIM implementation;
- identify benefits of adopting flexibility early in decision making;
- categorise types of flexibilities regarding function, capacity, flow and time; and
- identify key requirements, stakeholders and design methods to affect the conceptual design process.

METHODOLOGY

Information for the literature involved collecting of both online and offline publications. Literature search was categorised into three basic categories: healthcare; flexibility; and BIM. Literature review was used to recognise healthcare drivers and to identify flexibility as potential solution. BIM technology is suggested as a prism to reinforce design for flexibility and a conceptual process map was developed to describe a conceptual design process (see fig. 1).

1. LITERATURE REVIEW

1.1 Design Logic

Simon (1969) described design as a problem itself that requires answers. A design problem cannot be solved from a single best solution, but from a set of satisfactory solutions. Hence, the designer is expected to define or redefine or change the design problem as it is determining through time while exploring the *design space* of possible solutions (Cross, 2001). The process can be divided into two environments: the *inner environment* of the design problem represents the alternatives, a set of variables that require an understanding of the design and operation of the system. The *outer environment* is a set of parameters derived from system's requirements and a set of probability distribution; the key performance drivers. Krishnamurti (2006) described how the design team seeks to provide solutions to problems through the following equation:

design space = problem space + solution space + design process;

and further explained that the design process and the design problem are banded together. Akin (2001), as described by Krishnamurti (2006), analysed the design process as the sum of the design knowledge and strategy, whereas strategy refers to the search the design team carries out and design knowledge stands for all the means the design team uses to represent the multiplicity it needs and finds useful. Such representations could be the design's team actions, design states etc.

Two strategies occur to explain the process of constructing a *design space* according to Fricke (1996); *Stepwise process-oriented*, where the design team is considering all the relevant problem areas and holds a more abstract level of solutions before becomes more concrete; and *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.

1.2 Design process towards BIM

The key principles behind the design process according to Kagioglou et al. (2000) and later defined by Koppinen and Kiviniemi (2007) are:

Whole project view: The whole process of the project is documented from recognition of a need to the whole life-cycle of the project, that is operation and maintenance;

Progressive design fixity: The planning of BIM implementation is formed throughout updating the design information. When the design solution becomes concurrent the information can be more detailed and the detailed process of the design begins;

A consistent process: The ability of a BIM process to provide with its generic properties a consistent application. A concurrent design process will reduce uncertainty experienced by the stakeholders;

Stakeholder involvement/Teamwork: As the name suggests, Building Information Modeling is a process that focus on information and particularly it requests from the stakeholders to have the right information at the right time. Consequently, decision-making is encouraged and enforced in the process;

Co-ordinator: Effective coordination between the stakeholders as well as the coordination of their design models is fundamental; and

Feedback: Positive and negative feedback can be useful to improve processes and identify improvements.

1.3 Types of Flexibility to support design knowledge

Flexibility is the proposed solution to contemporary problems related with technological, social and economic changes (Kronenburg, 2007). Flexibility can be discussed from the perspective of how the building is changing. The designer can find in types of flexibility the *design knowledge* he seeks in identifying the design process he needs and finds useful. Slaughter (2001) discussed types of changes that may occur regarding its *function*. For a healthcare facility, such changes may occur in *re-using existing functions* – upgrading an existing space for better performance; *creating new functions* – creating an existing space for additional functions; or *changing for different functions* – altering the space for different functions to apply. This *spatial transformation* will allow the space to adapt to different circumstances. Kronenburg (2007) categorised this kind of transformation under adaptable strategies.

The second type of flexibility is related to the *structural transformation* of the building to meet specific performance requirements. In this situation, problems may occur regarding its *capacity*. Changes in capacity may occur from changes regarding the building's *volume* and/or *loads*. These sorts of changes focus on *size*. Structural transformation is more rigid than in strategies that occurring in spatial transformation and because in some situations the structure is affected, these types are also more expensive. Kronenburg (2007) categorised this kind of transformation under transformable strategies. Lastly, the third type of flexibility is related to changes regarding the building's *flow*. Changes in *environmental* flows may require a change to occur due to a climatic change and change in flow of *people/things* may occur from an organisational change.

Additionally flexibility can be considered from a *time* perspective. De Neufville et al. (2008) categorized flexibility into three types that could be applied in healthcare: *Operational*, *Tactical* and *Strategic* flexibility. Each type of flexibility can be considered as moving from one level to the next and forcing the building to adapt to changing needs more dynamically.

- *Operational* or *short-term* flexibility is the lightest form of flexibility and the easiest as it can be applied on a daily or weekly basis. Systems that can adapt to that strategy are light systems such as furniture systems and are less cost effective and money-saving while endorsing a rapid on-going change;
- *Tactical* or *mid-term* flexibility deals with space. Light components can be used to change the space of the area and therefore giving the preferred result. In order for this potential to work, the initial cost of the structure should be higher than the standard cost and it is also applied in more than a week; and
- *Strategic* or *long-term* flexibility is a strategy that hospitals can apply considering the end use of the facility. The effort of hiring this option is to significantly increase the life expectancy of the structure.

3 DISCUSSION OF THE CONCEPTUAL PROCESS MAP

From an IPD perspective, the *design space* is usually formalised not by a designer, but by the planning team. The planning team adopts a *stepwise process-oriented* approach because of the many requirements that have to justify - the *outer environment*; and due to BIM technology, the members provide multiple design disciplines - the *inner environment*. Apart from reduction of design errors, the planning team also offers an insight into design problems and presents opportunities for a design to be continuously upgraded. This multi-aspect design collaboration and exchange of knowledge applies value engineering much earlier than in Pre-BIM phase and finally provides a future-proof design. The structure of the proposed conceptual process map is in respect to the principles and philosophy of the Process Protocol as was undertaken by the University of Salford.

3.1. Building requirements and stakeholders

Identification of the planning team is particularly important in an IPD project. The owner, designers, contractors, engineers, major specialty contractors, facility manager, and project owner have to be identified as early as possible (CICRG, 2010). The team can be subdivided into two categories: the *primary* participants; and the *key supporting* participants. The allocation of a member to a category depends on their importance and evolvement throughout the project's lifecycle (AIA, 2007). In this phase, the planning team's main aim is to satisfy the client’s business goals and requirements. Additionally in this phase the determination of *what* is going to be built, *who* will built it and *how* is established is satisfied (AIA, 2007). The client organisation's requirements as well as the engineering requirements are the first step that needs to be documented and managed. For a healthcare project a set of probabilistic distribution may derive from the need to establish projections of annual demand, whereas the Activity Database (ADB, at set of standard designs endorsed by the Department of Health) provides technical specifications (engineering requirements) which the design should follow. In more detail, such requirements can cover the building type (derived from ADB), the various aspects of the organisation's aims, operational activities, spatial needs, condition requirements and costing target. Cost estimation as early as possible helps to determine the price of different factors and enables realistic designs later in the process. Accordingly, other stakeholders' requirements (electrical, civil, and mechanical) need to be documented and discussed in order the *deliverables* to be discussed.

The design team's interest is to deliver a change-ready facility, therefore the *deliverables* that occur from briefing and spatial program are a categorisation of spaces depending on the need to be flexible as, *flexible spaces* (FS), *inflexible spaces* (IS) and *partially flexible spaces* (PF). For example, highly serviced environments such as clinics have more needs than consulting rooms have. Due to their needs to serve patients more effectively, they are likely to change more frequently. In this respect, the area that will be used for consultation can be less expensive and also less flexible whereas the clinic area that needs to be change-ready and therefore highly flexible could probably cost more to be built. Additionally, the planting system has to be in a respectful distance from a clinic that has been scheduled for possible expansion in order to allow the building to accommodate changes whenever it is required.

3.2. Design Brief Implementation

In the second phase of the conceptual process map the *inner environment* is taking place in order the inception of the conceptual adaptable product to be formed. It is critical that the team members evaluate the importance of the information they developed in the *outer environment*, as the information will be used again in subsequent phases (CICRG, 2010). Brand (1995) argued that scenario planning (SP) has become so turbulent that traditional forecasting seems useless. SP can provide different directions and options of different assumptions. It helps the design team explore the future Built Environment from different angles. This exploration can be utilised through the investigation of the application of the various types of flexibility (see 1.3). SP is suggested to be the mean that will bring important assumptions as to what is required to be considered for the design decision of the building; in other words, implementing a planning approach of possibilities of different parts of the building that could be able to change at different levels providing value for money and also to be more valuable as a construction (Francis, 2010). A brief categorisation of different levels of spaces that derives from requirements is described in 3.1.

Activities such as *Target Value Design (TVD)* can be used as a mean for cost estimating. The design team optimises the client's requirements as well as the engineering requirements as they were set in the previous phase. TVD is following the principles of Lean Construction methods and is applicable especially in large healthcare projects (Tiwari et al., 2009). Adoption of TVD means that cost is a target (target costing) that should never be exceeded. This can be achieved through tracking the cost estimate and budget by using model cost estimating to inform TVD at this stage. Whereas in Pre-BIM, delivery approaches, cost comes after design; in a TVD approach cost sets the limit as to what should be designed in order not to overcome it. Flexibility is measured and implemented in response to cost. From the discussion in 1.3 it derives that a change in windows (environmental flow) will cost less when compared to a vertical expansion (change in loads).

The constructors as *key supporting* participants of the project are used as advisers (AIA, 2007) on topics in which they are specialists. The main project team can identify how to provide flexibility in the project based on three construction applications (Slaughter, 2001). As further investigation to their applicability these approaches are not strict, in a manner that they should be implied individually and fixed. They can perfectly be combined to accomplish the desired solution that is entitled to find answers to a forthcoming situation.

- The first approach *separating systems* is based on architect Frank Duffy and then elaborated by Brand (1995). In short, different parts-layers of the building structure have different lifespans. Design for flexibility allows that layers to be replaced or changed whenever needed;

- the second approach is referred to as *prefabrication*. Modular design supports standardised units or standardised dimensions to support construction (Waskett, 2003). Prefabrication is described as an advanced construction technology and allows the building to be flexible in a short time while keeping low costs (de Neufville et al. 2008); and
- the third approach is to design for *overcapacity* so that to forestall future changes and needs. Adoption of this approach helps in cases were no replacement or extension of current capacity capabilities is welcomed. The contractors and subcontractors can advise the project with information regarding for example off-site components, materials' attributes and how the project can be benefited in terms of cost and flexibility.

3.3 Concept evaluation and approval

Parametric Modeling (PM) drives BIM to provide the project with objects that are attributed with information rather than vague lines (Autodesk white paper, 2007). Robinson (2007) argued that a BIM platform is ideal for visual project management to explore alternative scenarios due to its parametrical ability to present objects. PM has been described as a process of making geometric representations of a design with components and materials attributes that have been parameterized. Geometric entities and their relationships are represented within a BIM environment. PM offers the potential to perform transformations that occur from different configurations of the same geometric components (Turrin et al., 2011). Aish and Woodburry (2005) argued that parameterization offers the designer the ability to build a model

"as a typically infinite set of instances, each determined by a particular selection of values for the model's independent variables".

The latest BIM technology has offered the ability to define parametric constraints within the objects parameters so that when changes occur in the model, certain geometric relationships remain as their constraints impose them. Moreover, PM enables objects to self-configure their assemblies regarding a change that is made to alter the model. Each alternative solution that is generated in phase 3.2 through the various scenarios here is evaluated under the predefined set of requirements (see 3.1) and to narrow the number of alternatives a single model should accomodate, the model should be parametrically defined with constraints and attributes (Anderl & Mendgen, 1996). In this respect the project team will spend more quality time to measure the performance of each scenario and narrow the *design space* of solutions. The end of this third phase of conceptualisation will bring the completion of a conceptual adaptable product. After validation and conceptualisation of the *design space* of solutions the project team proceeds to the next phase of the project, that is the criteria design phase (RIBA, 2012).

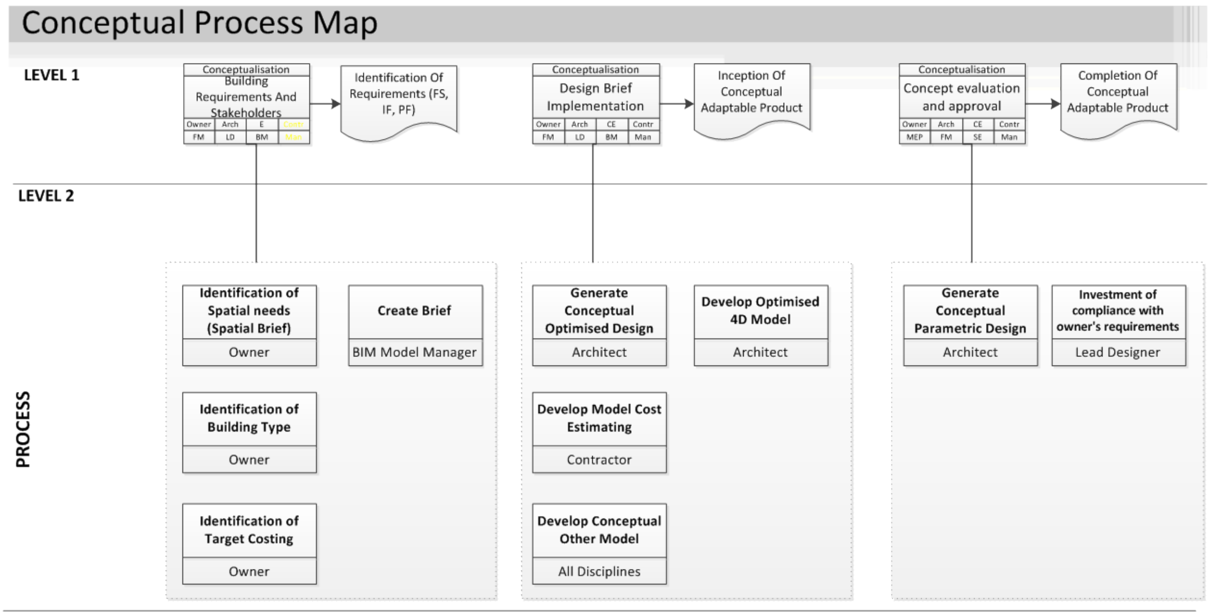

Fig. 1: Conceptual Process Map.

CONCLUSIONS

Design space can be complex and unfamiliar by considering an increased number of aspects. Moreover accepting a "best" solution may be a difficult process and also finding an "optimal" solution may be even more difficult, considering that the evaluation criteria are not clearly outlined (Watson, 2011). Design exploration with parametric modeling provides a flexible and responsive representation that the final product (and consequently the design) can respond to change. Moreover, the process is following the principles of IPD, as value engineering is achieved throughout the process by the participation of all team members during the early design-decision stage. However, the provided flexibility arises from the parameters the designer sets, in other words flexibility is limited and depended by the parameters. Additionally the load of information and the time needed to parameterise requirements to constraints and attributes of alternative solutions can be time consuming and requires effort and knowledge by the practitioner. Moreover, if there should be a change in the design fees and if yes then how they should be applied must be clarified. Lastly, questions arise as to how the procurement and ownership of a healthcare project that is designed to accommodate changes might be affected since most of the projects are under PFI contracts. This needs to be cleared out from both a capex (capital cost) and opex (operating cost) perspective.

FUTURE RESEARCH

This paper is part of an on-going research. Part of the future research will investigate to which extend BIM can offer different modes of interaction with the design-decision team (incremental improvements within the organisation), and/or potentially new forms of processes during the early design stage of change-ready healthcare projects (re-engineering the whole process). Furthermore, the suggested conceptual model map should be validated. Future methodology will be conducted in order to improve and validate the process map and surveys as long as case studies will be used for the validation.

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