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Using Building Information Modelling (BIM) to Design Flexible Spaces with Design Standards in Healthcare Facilities

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Abstract: This paper explored key factors that can enhance the designer`s role when designing space for flexibility with the focal use of building information modelling (BIM) and design standardisation. An exploratory study was conducted using a questionnaire survey. The questionnaire was piloted to a Web-based Group (48 responses) and then it was distributed to the top 100 UK architectural firms (10 responses) based on the *Building Magazine*, (2010). Both descriptive and inferential statistics were used. The questionnaire survey included both open ended and close ended questions. The paper provides empirical insights about how design standardisation and flexibility can be applied with BIM. It suggests that embedding flexibility can be enhanced with BIM by supporting the generation of different design options and scheduling design tasks with different information attached. The results also showed that strategies such as "adapting," "contracting" and "expanding" are more beneficial than other flexible strategies. Regarding standardisation and flexibility, the results showed that although standardisation is not the panacea of providing flexible solutions, it is indeed applied and applicable in construction projects that require flexibility. The chosen research approach measures, records and reports the perceptions and worldviews of the respondents. Therefore, the research findings are based on how reality is formed by the participants and their experiences. With that in mind, the information identified was used to draw some noteworthy findings that provide detailed information on embedding flexibility in healthcare buildings.

Key words: Conceptual phase, BIM, flexibility, healthcare design, standardisation.

1. Introduction

The concept of flexibility in healthcare design is not new. Healthcare buildings are in continuous change, but their future cannot be predicted with a high degree of accuracy [1]. Buildings must be seen as a process, being able to meet the ever changing demands of the facility users. There are two practices that can be utilised by owners with dynamic requirements [2]. These are:

Scrap and build practices: in this approach, design and construction assumes fixed programmatic requirements. As a result, renovations are expensive when change in use is required. If renovation is not viable, then demolition might be the best solution;

And stock maintenance practices: in this approach, design and construction emerge by consideration of current requirements and "provision for unknown future uses and technical upgrading" [2].

The application of stock maintenance practices is continuously increasing over the years in the operational life cycle of healthcare facilities. The INO Hospital in Bern, Switzerland [2]; the Addenbrooke's Hospital in Cambridge, UK [3]; the St Olav's Hospital in Trondheim, Norway [4] and the Health Care Service Corporation Building in Chicago, USA [5] are some of the many examples showing that healthcare managers and owners are choosing flexible strategies in order to deal with the ever-changing demands. From these examples, it can be seen that stock maintenance practices are well established in the design and construction process of healthcare projects. Due to the new Government's BIM Construction

Strategy plan [6]; it is important to understand how these practices should be implemented now that BIM is the default IT platform for the design and construction processes. Both architects and engineers are requested to be BIM-able to a certain level by 2016 in order to operate successfully the on-going rapid technology invented for such complex design problems (healthcare facilities) with other stakeholders. As such, level 2 BIM is expected to be adopted by the Architectural, Engineering and Construction (AEC) industry by 2016 [7]. Additionally, there is little research regarding the impact of healthcare space standardisation on hospital designs [8].

A questionnaire survey was designed to explore key factors that can enhance the designer`s decision-making when designing space flexibility during healthcare refurbishment with the use of BIM. The questionnaire targeted architectural designers with healthcare experience. Literature suggests design standardisation and BIM as individual concepts that can add value to the design of healthcare facilities. Driven by this notion, a hypothesis is framed that designers with higher healthcare and BIM experience are of the view that the applications of standardisation and BIM can enhance flexible space design. The basis of this hypothesis was that novice users will not be able to fully explore BIM whereas experienced users would have identified best practices to achieving more flexible and standardised designs with BIM support.

2. Literature Review

2.1 Towards Flexible Healthcare Facilities

The Department of Health (DH) [9] stated that when a facility is empowered by flexibility an "annual savings of up to £1.8billion are achievable". Pommer et al. [10] stated that "Hospitals are constantly under construction with on-going renovation and expansion to accommodate new modalities, new protocol, and new technologies". Furthermore Gupta et al. [11] stated that flexibility should be the cornerstone of the design as it allows the facility to grow and expand in cases of building upgrades, and can also change its internal functions. Over the years, many healthcare facilities are becoming obsolete while their lifespan has not reached its peak level. These are mostly caused by changes in demographics, operational running cost, technological hospital demands, operational and functional spaces requiring constant attention over the lifecycle of the facility. Ignoring these factors in a given healthcare facility tends to reduce its functional existence by increasing operational cost causing early re-construction, re-development or large refurbishment. Adams [12] argued that a flexible hospital could be designed today, but be used for a different function in the future. Intelligent spaces that can adapt to growth in population are one of the factors that initiate flexibility in the future. Flexibility is important when adapting to the needs and appeals of healthcare facility users. When a facility adapts to changes, it tends to increase the lifespan of a facility and reduces the need for major refurbishments. It is difficult to predict the future of hospitals with a high degree of accuracy [3]. For example, hospital bed numbers should increase in the case of population increment, but the exact population is difficult to be forecasted. Flexibility is viewed as an option that can be switched on or off when required. Therefore, a facility is supposed to be able to expand and increase its number of beds when required. Neufville et al. [3] argued that flexibility can improve value for money in hospital infrastructure investment. They also argued that to achieve value in hospitals, contractor-clients relationships should not be encouraged, rather public and private relationships should be motivated to enable long-term partnerships to deliver cost efficiency and shared benefits over the life cycle of a facility. Carthey et al. [13] described flexibility at a micro and macro level. Micro flexibility can be initiated in a building system within 5-10 years (short-term), while macro flexibility can be achieved within 50-100 years (long-term).

Slaughter [14] discussed the types of changes that may occur. The first depends on the function. In a healthcare facility, such changes may occur when re-using existing functions — upgrading an existing space for better performance; creating new functions — creating spaces for additional functions; or changing for different functions — altering the space for different functions to take place. This spatial transformation will allow the space to adapt to different circumstances. Pati et al. [15] and Kronenburg [16] among others defined these as adaptable strategies. The second type of flexibility is related to the structural transformation of a building to meet specific performance requirements. For example, to expand the capacity of a facility; change in capacity may lead to increment in the building's volume and/or loads. Transformation is more rigid, it may involve spatial development which includes the structure of a facility. This type of change is more expensive and takes a long time to conduct. The third type of flexibility is related to changes in the building's flow. Changes in environmental flows may require a change to occur due to a climatic change; change in flow of people/things may occur from an organisational change level.

2.2 Impact of BIM in Design Creativity

Reddy [17] stated that "BIM provides architects with infinite freedom to showcase their creativity". Lee [18] stated that the early adoption of BIM increases not only productivity but also creativity in building design process. While Moreira et al. [19] described that there is a need to examine the influence of BIM tools on design creativity. Creativity and digital technology work alongside each other, but creativity can be achieved through the use of technology as a medium to express imaginative thoughts. The designer is expected to be innovative and creative, while technology empowers the designer to achieve conceptual imaginations at different levels [20]. Creativity and BIM can facilitate the ability to embed flexible strategies within a healthcare facility. BIM tools allow design imaginations to be explored in a BIM environment. Some of the benefits when using creativity and BIM are: providing design details of a virtual building using models and simulation to enable stakeholders to understand better the scope of work that needs to be done; allowing the extraction of different views from models; collaborative work; automation; and analysis and evaluation of models to save project time and cost. BIM helps to conduct projects with more confidence and also allows the exploration of the nature and scope of work at the early project stages. Furthermore, Eastman et al. [21] described that alternative designs can be generated using "what if" scenarios with different BIM tools. For example the DProfiler™ can be employed to optimise different design options. Therefore, there is a need to explore the ability of "what if" scenarios at different levels such as short-term and long-term levels.

2.3 Design Standardisation in Healthcare with BIM

Standardisation means different things to different people in healthcare and BIM literature. In healthcare, standardisation is discussed in various terms. The UK Government and building industries addresses standardisation from many aspects some of them are focusing on procurement methods such the Procure21 and recently the Procure21+ procurement framework which is designed to "improve the procurement process for publicly funded schemes and create an environment where more value could be realised from collaboration between NHS Client and Construction Supply Chains" [22] Additionally, the Health Building Notes (HBN) [23] is another effort by the DH to identify the best practice standards in the planning and designing phases of healthcare facilities. The series identifies specific and/or service requirements and inform the design and construction teams. Other series of publications have also been released to support best practices. The Health Technical Memoranda (HTM) [24] identifies healthcare specific standards for building components as well as the design and operation of engineering services. The Activity DataBase (ADB) [25] is another release, this time a software tool that is used as an add-on in BIM platforms and contains information for briefing, design and commissioning for new build and refurbishing healthcare buildings in acute and community settings. Standardised spaces are generally accepted to support process and workflow, and consequently they should improve performance and productivity [8]. Reiling [26] stated that with standardisation, processes should be more reliable and simplified; it also reduces reliance on short-term memory and it promotes an average process to be followed by those unfamiliar with the surrounded environment to achieve work safety and efficiency. There is little research evidence relating to the impact of space standardisation and BIM on healthcare delivery. Standardisation is mostly discussed in BIM literature in terms of interoperability, which is concerned with product-model data exchange in project communication. Thus, this study investigates the effect of design standardisation on practitioners who design with BIM products.

3. Methodology

The population for the questionnaire survey included architectural firms in the UK and academics in the built environment. The pilot study was conducted first; it was uploaded to the members of a Web-based Group and a total of 48 responses were received. The pilot survey was revised and the main survey was conducted. The main study focused on soliciting the opinion of the top 100 UK Architectural firms based on the Building Magazine league table 2010. Out of 100 invitations, 10 responses were recorded.

The aim of the questionnaire survey was to explore the key factors that can enhance the designer's role when designing space for flexibility in healthcare facilities with the use of BIM. The survey was grouped into four sections: 1. background information of the respondents; 2. designing flexible healthcare spaces; 3. standardisation of healthcare space; and 4. flexible space design with BIM. The questionnaire survey targeted respondents such as architectural designers, healthcare planners and BIM users with healthcare experience in the AEC industry. A cross-sectional descriptive survey was designed as the preferred type of data collection as it enables a large set of opinions to be collected in a relatively short time.

Both quantitative and qualitative data were collected, open ended and close ended questions were employed. Open ended questions were analysed by grouping responses into major categories. For example, the respondents were asked to identify spaces that commonly change. Their responses varied from multi bedroom to single bedroom etc. which eventually were grouped under a major category "bedroom". According to the Department of Health [27] it is described as Room Coding list. The questionnaire survey respondents were asked to put their answers in a ranking order. Eventually the scores emerged by assigning points to each ranked answer. For instance, the respondents were asked to identify six spaces that change most frequently in a ranking order. The first given answer would get six points, the second gets five points and so on. Close ended questions were employed and respondents were asked to rate their agreement with statements using a five-point Likert scale. Respondents that opted for Highly Effective (HE) and Effective (E) were grouped together to estimate the proportion of "successes" of the question in context. The responses were then transformed to interval variables. Interval data "are considerably more useful than ordinal data" and "to say that data are interval, we must be certain that equal intervals on the scale represent equal differences in the property being measured" [28]. As such the difference between each five-level Likert item is the same.

The sample proportion of successes was used to estimate the unknown population proportion. The analysis of the responses involved both descriptive and inferential methods. As a result, the number of successes and the number of failures are not at least 15, a simple practical adjustment first introduced by Edwin Bidwell Wilson in 1927 was employed, the "plus four estimate". In short, "the adjustment is based on assuming that the sample contains four additional observations, two of which are successes and two of which are failures" [28].

3.1 Pilot Study

Pilot Sample: Members of Web based Group.

Relevance of pilot sample to this research: the web based sample was selected due to the diversity of the professionals within the group. There are individual understandings and definitions of BIM from different stakeholders; perhaps it was important to explore the different opinions of stakeholders within the AEC industry. Who are the webs based sample? (CNBR) Yahoo group is the Co-operative Network for Building Researchers; it is a basic mail list for people interested in building research. This group includes professionals such as project managers, architects, contractors, real estate managers, researchers, industry professionals' and so on. Members share news about conferences, journals, vacancies, new books, new findings and so on. Locations of members of this sample are unknown; it is possible that participants could be from any part of the world, the group is open to all professionals around the world. The questionnaire survey responses recorded from this sample were a total of 48. The questionnaire survey was uploaded on the CNBR Yahoo group website; the total number of people who received the invitation cannot be specified, there are a over 3000 registered members on the website, but only registered members who had set their accounts to receive updates would have seen the link without logging on to the CNBR Yahoo group web page.

Fig. 1 shows the pilot sample to include architects, BIM users, planners, academics and others; the category "others" was also provided to the questionnaire respondents as a space to identify other specific professions, but only one response was recorded.

Fig. 2 shows the years of healthcare design experience and BIM experience of pilot sample, where 20 (41.6%) of the respondents have no healthcare and BIM experience, 20 (41.6%) of the respondents have 1-5 years of BIM experience and 3 (6.25%) of them have also BIM experience, 19 (39.6%) have 11-20 years of experience in healthcare and 5 (10.4%) have more than 20 years of healthcare experience. Lastly, none of the respondents has over 20 years of BIM experience.

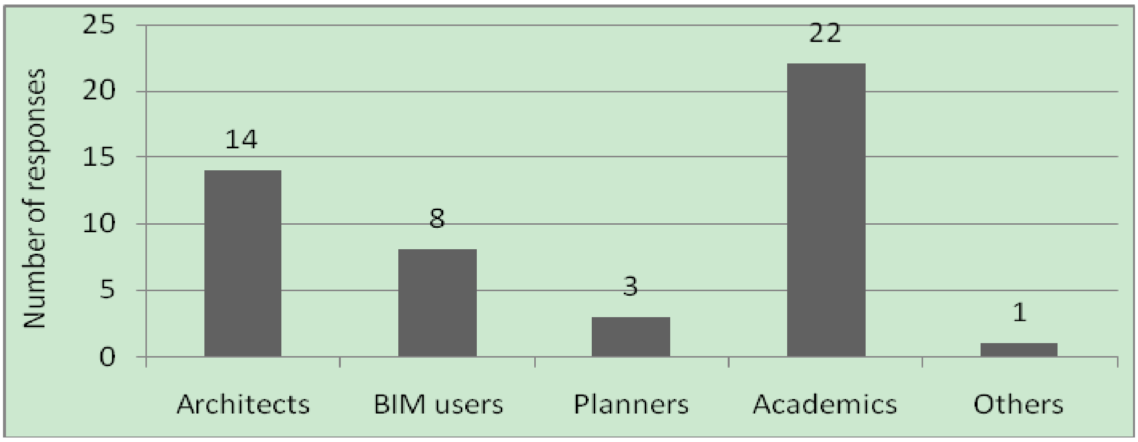

Fig. 1 Profession most relates to Web-based Group (48 total).

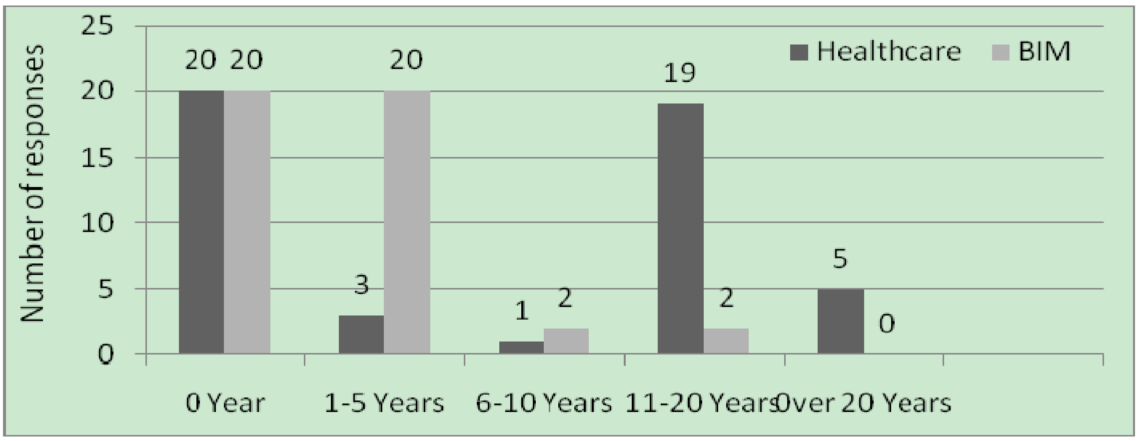

Fig. 2 Years of healthcare experience within Web-based Group.

3.2 Pilot Study Findings and Analysis

3.2.1 Designing Flexible Healthcare Spaces

The pilot study respondents were asked to rank the spaces that rapidly change in healthcare facilities. Based on the code list for ADB rooms [27], the responses were grouped in major categories. For instance, entrance, waiting area and reception area were grouped under the "Entrance/Reception/Waiting" category. The questionnaire survey respondents were asked to indicate the spaces that rapidly change in a hierarchy order ranking, with the first choice receiving six points and the last receiving only one point. The results in Fig. 3 showed that "laboratories" are ranked first, followed by "bedrooms" and "operating theatres".

Similarly, they were asked to identify the top three important considerations for designing flexible spaces (Fig. 4). Again, the responses were grouped into categories. The pilot sample ranked "standards" first, "services" second and "identification of spaces" being the third most important. Equipment, standard spaces and specifications were grouped under "standards". Staff and patient needs were grouped under the category of "services". The third important consideration was "identification of changing spaces" included quotes-issues such as "suggest spaces for expansion", "categorize spaces for expansion", "allow reasonable spaces for expansion", "identify spaces that could expand" and "highlight spaces that are expected to change in the future".

Table 1 shows the ranking of the effectiveness for the different flexibility concepts. It was estimated with 95% confidence that between 78.1% and 96.9% of the population would rank "modular design" first. "Flexible furniture/equipment" was ranked second

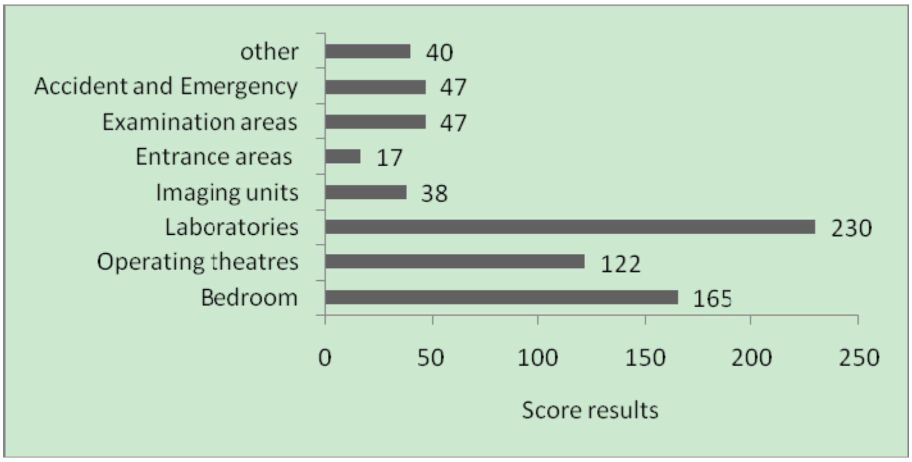

Fig. 3 Spaces that frequently change in healthcare facilities (Web-based Group).

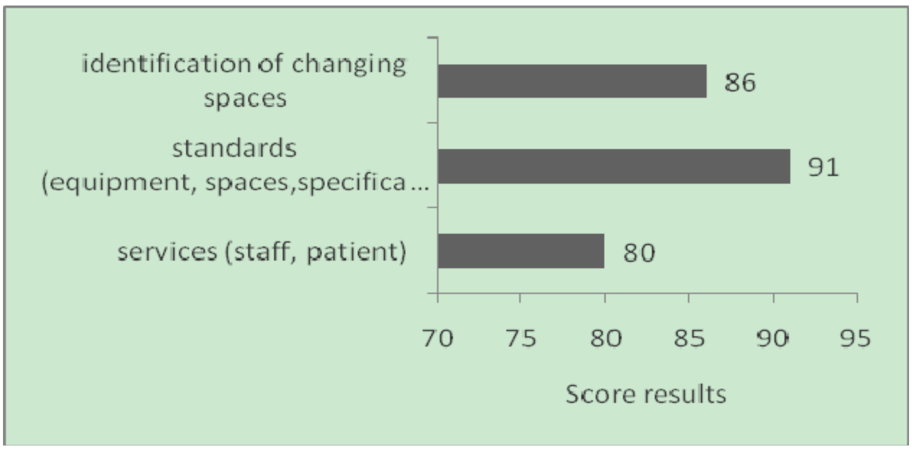

Fig. 4 Top three important considerations for designing flexible spaces (Web-based Group).

Table 1 Confidence intervals for pilot sample on the effectiveness of the following flexibility concepts.

Web-based group	95% confidence interval results		
	Upper limit	Lower limit	Sample proportion
Modular design	0.969	0.781	0.875
Shell space	0.800	0.533	0.667
Flexible curtain walls	0.578	0.297	0.438
Flexible furniture/equipment	0.855	0.603	0.729
Multipurpose foundations	0.535	0.132	0.333
Flexible partitions/internal walls	0.884	0.325	0.604

with 95% confidence between 60.3% and 85.5% and lastly, "shell space" was ranked third, with 95% confidence that between 53.3% and 80.0% of the population would find the aforementioned concept HE/E. A complete view of the respondents' choice and the 95% confidence intervals of the population are given in Table 1.

3.2.2 Standardisation of Healthcare Space

The respondents were asked to rate their agreement with three statements regarding how standardisation affects the concept of flexibility. The general impression is on the positive side that standardisation does not necessarily hinder flexibility in healthcare spaces. The respondents did not significantly support any of the three given statements (Table 2) and the agreed proportions were significantly low. Specifically, it was estimated with 95% confidence that between 23.8% and 51.2% of the population would believe that standardisation "creates rigid spaces/layout". The rest of the statements were rated even lower, which gives the notion that the population would believe standardisation does not impede flexibility.

3.2.3 Flexible Space Design with BIM

The following questions refer to the role of BIM and how effective or ineffective it can be when designing flexible healthcare spaces. In Table 3 the respondents were asked to state the level of effectiveness of using BIM for analysing and evaluating flexible healthcare spaces to inform decisions on two scenarios: for short-term and long-term basis. The results are not satisfactory enough to conclude that BIM is effective or ineffective in informing decisions on short term or long term basis.

The respondents were asked to rate their agreement within two scenarios (short-term or long-term basis) regarding the effectiveness of using "what if" scenarios with BIM in the design of flexible healthcare spaces. The results (Table 4) look quite close to the previous question. The responses cannot provide a positive opinion whether "what if" scenarios can provide a positive impact on the design of flexible healthcare facilities.

The respondents were then asked to state their degree of agreement that BIM tools hinder design innovation and creativity. The results showed that the population would believe BIM tools hinder innovation and creativity. The population's agreement is between 60.3% and 85.5% with 95% confidence. Finally, the respondents were asked to rate the effectiveness of using BIM for analysing, evaluating and modelling flexible healthcare facility space in the following design

Table 2 Proportions and confidence intervals for pilot sample on standardisation impeding flexible space opportunities.

Web-based Group	95% confidence interval results		
	Upper limit	Lower limit	Sample proportion
Creates rigid spaces/layout	0.512	0.238	0.375
Produces interrelationships of spaces that are highly complex	0.444	0.181	0.313
Hinders modularity layout concept	0.219	0.031	0.125

Table 3 Proportion and confidence intervals for pilot sample for the effectiveness of using BIM for analysing and evaluating flexible healthcare spaces to inform decisions.

Web-based Group	95% confidence interval results		
	Upper limit	Lower limit	Sample proportion
Short-term basis	0.641	0.359	0.500
Long-term basis	0.703	0.422	0.563

Table 4 Confidence intervals for pilot sample on the effectiveness of using "what if" scenarios with BIM in the design of flexible healthcare spaces.

Web-based Group	95% confidence interval results		
	Upper limit	Lower limit	Sample proportion
Short-term basis	0.641	0.359	0.500
Long-term basis	0.703	0.422	0.563

strategies: "expanding", "contracting", "relocating" and "adapting". The respondents found BIM HE/E in three out of four concepts, and it was estimated that the population between 60.3% and 85.5% with 95% confidence would believe BIM is effective. "Adapting" was chosen the least strategy that is benefited by BIM (48.8%-76.2% with 95% confidence). The 95% confidence intervals for all strategies are given in Table 5.

3.2.4 Discussion of Findings for Pilot Sample

Even though the pilot study was not the main study, some helpful conclusions can be drawn. Design standards have been characterised as the most significant consideration when designing flexible spaces which was further supported by the disagreement that standardisation impedes flexible design opportunities. Also the importance of "identifying spaces that rapidly change" was highlighted as a noteworthy factor that needs to be considered. The results were less conclusive regarding the effectiveness of BIM in certain tasks such as the use of BIM for analysing and evaluating flexible healthcare spaces on short-term or long-term basis, and to use BIM for "what if" scenarios. This uncertainty of survey results on whether BIM is effective can be explained by the background information that 50% of the respondents have no experience of BIM which eventually limits the conclusions that could be drawn regarding BIM.

The questionnaire survey was presented in two different formats. These include an online web link and MS word document. After the pilot study, this research further explored findings from architectural firms. Findings from the pilot study showed that some of the questions were left unanswered by the respondents. Therefore, during the main study some questions were omitted, while others were refined. Further information was provided in the "more information" section on the online questionnaire survey and the definitions of key issues in question such as flexibility, standardisation and BIM were presented in the beginning of each section of the questionnaire survey presented in MS Word format.

Table 5 Confidence intervals for pilot sample on using BIM for analysing, evaluating and modelling flexible healthcare facility space strategies.

Web-based Group	95% confidence interval results		
	Upper limit	Lower limit	Sample proportion
Expanding	0.855	0.603	0.729
Contracting	0.855	0.603	0.729
Relocating	0.855	0.603	0.729
Adapting	0.762	0.488	0.625

3.3 Main Study

Main sample: Top 100 UK architectural firms based on the Building Magazine, 2010.

To draw a representative sample, the quota sampling method was chosen [29]. The research interest is on UK Healthcare facilities. Therefore, only architectural firms that are based in the UK were considered. Next, the experts' opinion on design knowledge in terms of flexibility and design standardisation was measured. Architects with experience in the field of healthcare design were questioned. The top 100 UK architectural firms were ranked by the Building Magazine based on UK firms with the highest number of UK chartered architects. They were selected for their practical experience in the design of buildings in and outside the UK as described by Building Magazine. The architectural firms contacted for the purposes of this research were UK based and most of the architectural firms have international offices around the globe. Therefore, with both UK and international architectural working experience, the participation of such firms would provide robust practical data that this research can analyse and evaluate. All of the aforementioned firms were contacted; out of the 100, only 10 architectural firms responded (10%).

3.4 Background Information

Fig. 5 presents the years of healthcare and BIM experience for the main sample. The level of experience in this sample is spread across different frames which gives a variety of experience in the two fields of interest. Based on the collected background information, inferential tests were applied to estimate the population's beliefs and to test the aforementioned hypothesis. The sample can be classified as a good sample for exploring the application of BIM in healthcare facility design, as healthcare design experience is satisfied and also the sample is experienced in the application of BIM. Over 50% of the sample has over 10 years of both healthcare and BIM experience. But it is noteworthy to understand that the sample is small.

4. Analysis of Questionnaire Findings

4.1 Designing Flexible Healthcare Spaces

Regarding which spaces are most likely to be altered in healthcare facilities, the main sample ranked "operating theatres" as the first space that frequently needs to be changed, followed by "bedrooms" in second place and "laboratories" in third place. The same procedure for ranking the responses was used for the pilot study. The complete ranked spaces are presented in Fig. 6. It is noteworthy to understand that the same three categories were identified by the Web-based group but in a slightly different order.

The main sample ranked "standards" as the first most important consideration for designing flexible spaces, followed by "services" and "cost". Unlike the pilot sample, the main sample suggests "cost" as an important factor that needs to be considered in the design stage (Fig. 7). The degree of effectiveness of six flexibility concepts is presented in Table 6. Three flexibility concepts "modular design", "shell space" and "multipurpose foundations" were rated equally HE/E and with 95% confidence that between 67.4% and 100% of the population would believe these three concepts are HE/E.

Furthermore, correlation tests did not show any strong evidence that designers with experience in healthcare or in BIM tend to find more effective one concept of flexibility over the other (Table 6). Further correlation tests between the six flexibility concepts revealed that there are strong correlations among the concepts: "flexible partition"; and "shell space" ($r_s(10) = 0.913$, $p = 0.000$); "flexible partition" and "flexible furniture" ($r_s(10) = -0.922$, $p = 0.000$); and finally, "flexible furniture" and "shell space" with ($r_s(10) = -0.866$, $p = 0.001$).

Furthermore, this study explored the opinion of architects on standardisation impeding flexible space opportunities by providing specification that could: produce rigid spaces/layout; produce interrelationship of spaces that are highly complex; or hinders modularity concept layout (Table 7). There is a need to explore the application of standardisation in flexible healthcare spaces to achieve added value, cost effectiveness and cost efficiency [8].

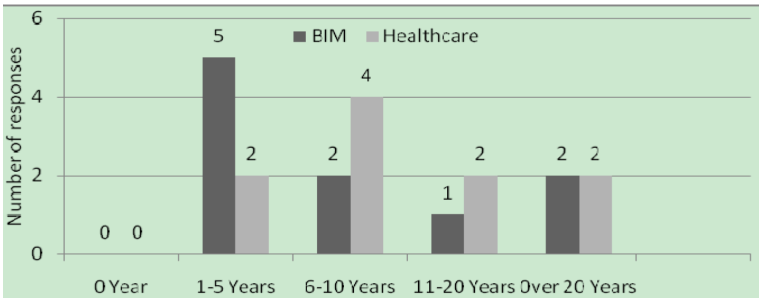

Fig. 5 Years of BIM and Healthcare experience within main sample.

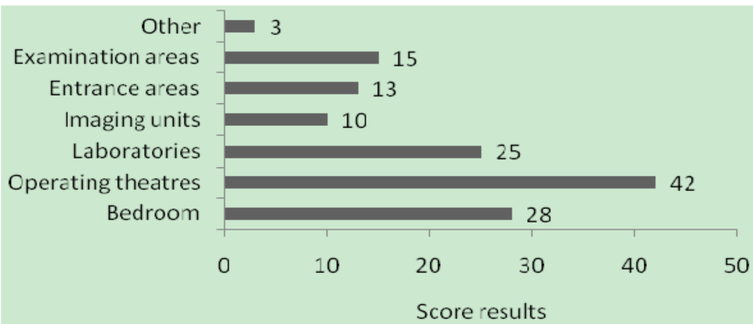

Fig. 6 Spaces that frequently change in healthcare facilities.

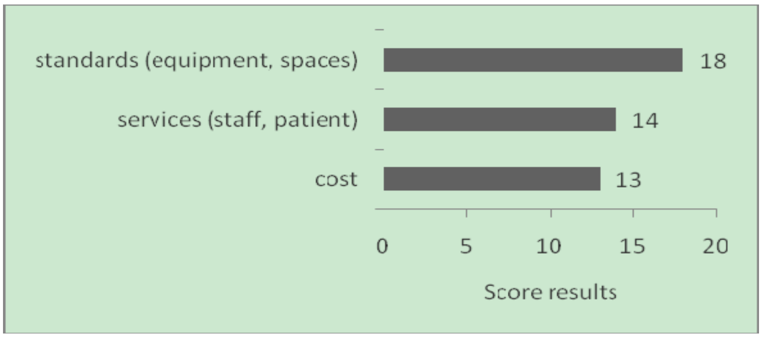

Fig. 7 Top three important considerations for designing flexible spaces.

Table 6 Proportions, 95% confidence intervals and Spearman's rho on degree of effectiveness regarding specific flexibility concepts.

Main sample	95% confidence interval results			Correlations	
	Upper limit	Lower limit	Sample proportion	BIM experience	Healthcare experience
Modular design	1.000	0.674	0.857	-0.467	0.180
Shell space	1.000	0.674	0.857	-0.082	0.431
Flexible curtain walls	0.951	0.478	0.714	-0.140	-0.629
Flexible furniture/equipment	0.894	0.392	0.643	-0.018	-0.204
Multipurpose foundations	1.000	0.674	0.857	-0.612	-0.157
Flexible partitions/internal walls	1.000	0.571	0.786	0.063	0.179

Table 7 Correlation tests for various flexibility concepts.

			Modular design	Shell space	Flexible curtain walls	Flexible furniture	Multi-purpose foundation	Flexible partition
Spearman's rho	Modular design	Correlation Coefficient	1	0.764*	-0.375	-0.661*	0.218	0.697*
		Sig. (2-tailed)		0.01	0.286	0.037	0.545	0.025
		N	10	10	10	10	10	10
	Shell space	Correlation Coefficient	0.764*	1	-0.764*	-0.866**	0.048	0.913**
		Sig. (2-tailed)	0.01		0.01	0.001	0.896	0
		N	10	10	10	10	10	10
	Flexible curtain walls	Correlation Coefficient	-0.375	-0.764*	1	0.661*	0.327	-0.697*
		Sig. (2-tailed)	0.286	0.01		0.037	0.356	0.025
		N	10	10	10	10	10	10
	Flexible furniture	Correlation Coefficient	-0.661*	-0.866**	0.661*	1	0.082	-0.922**
		Sig. (2-tailed)	0.037	0.001	0.037		0.821	0
		N	10	10	10	10	10	10
	Multipurpose foundation	Correlation Coefficient	0.218	0.048	0.327	0.082	1	-0.174
		Sig. (2-tailed)	0.545	0.896	0.356	0.821		0.631
		N	10	10	10	10	10	10
	Flexible partition	Correlation Coefficient	0.697*	0.913**	-0.697*	-0.922**	-0.174	1
		Sig. (2-tailed)	0.025	0	0.025	0	0.631	
		N	10	10	10	10	10	10

* Correlation is significant at the 0.05 level (2-tailed). ** Correlation is significant at the 0.01 level (2-tailed).

4.2 Standardisation of Healthcare Spaces

Most of the respondents agreed that standardisation could affect flexibility in all three categories "some of the time" (Fig. 8). It was estimated with 95% confidence that between 64.0% and 100% of the population would believe that standardisation hinders modularity layout concept which is the strongest probability among the three statements. The statement that standardisation "creates rigid spaces/layout" was ranked second (with 95% confidence between 47.8% and 95.1%) and "produces interrelationships of spaces that are highly complex" was ranked third with significantly low probability (with 95% confidence between 31.2% and 83.1%).

The responses for each of the three statements were tested against the years of BIM experience as well as the years of healthcare experience the respondents had. There is no strong evidence to suggest that there is a linear correlation that architects with experience in healthcare or in BIM tend to agree that standardisation impedes flexibility in any of the three statements. The 95% confidence intervals for the population and the spearman's coefficient are presented in Table 8.

4.3 Flexible Space Design with BIM

The results suggest that BIM is effective for both short-term and long-term analysis and evaluation of flexible healthcare spaces with 95% confidence that between 57.1% and 100% of the population would believe BIM is HE/E on a short-term basis. While 67.4% and 100% of the population would believe BIM is effective on long-term basis. Spearman's tests revealed that there is strong degreasing linear correlation ($r_s(10)=-0.633$, $p=0.049$) for the respondents with high BIM experience that believed BIM is effective to inform decisions on short-term basis.

Finally, no evidence suggest that designers with more experience in healthcare or BIM find BIM more effective for analysing and evaluating flexible spaces on long-term basis. Detailed results are presented in Table 9.

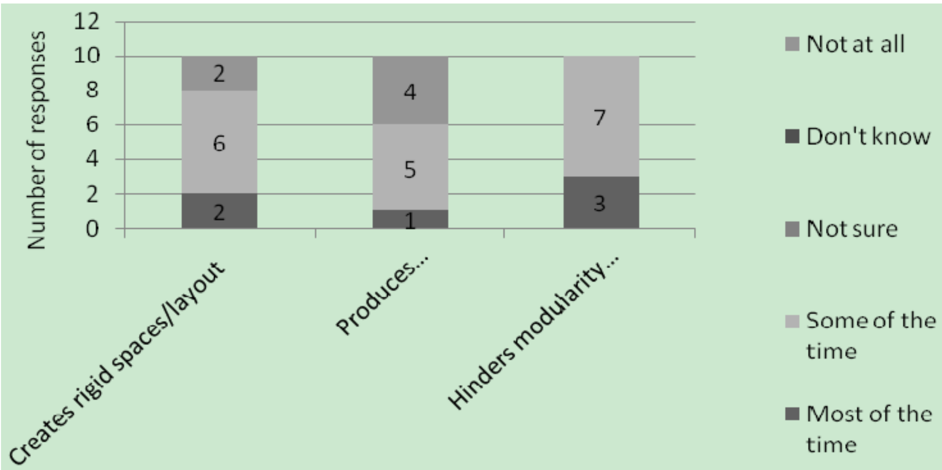

Fig. 8 Opinion of respondents on standardisation impeding flexible space opportunities.

Table 8 Proportions, 95% confidence intervals and Spearman's rho on standardisation impeding flexible space opportunities.

Main sample	95% confidence interval results			Correlations	
	Upper limit	Lower limit	Sample proportion	BIM experience	Healthcare experience
Creates rigid spaces/layout	0.951	0.478	0.714	0.384	0.000
Produces interrelationships of spaces that are highly complex	0.831	0.312	0.571	0.119	0.156
Hinders modularity layout concept	1.000	0.640	0.857	0.204	-0.157

Table 9 Proportions, 95% confidence intervals and Spearman's rho on using BIM for analysing and evaluating flexible healthcare spaces to inform decisions on short term and long term basis.

Main sample	95% confidence intervals			Correlations	
	Upper limit	Lower limit	Sample proportion	BIM experience	Healthcare experience
Short-term basis Sig. (2-tailed)	1.000	0.571	0.786	-0.633* 0.049	0.304
Long-term basis	1.000	0.674	0.857	-0.326	0.157

*Correlation is significant at the 0.05 level (2-tailed).

Next, the respondents were asked to rate the effectiveness of using "what if" scenarios in the design of flexible healthcare spaces on the same two decision foundations: short-term and long-term basis. It was estimated with 95% confidence, that between 23.8% and 76.2% of the population would find effective the use of "what if" scenarios on a short-term basis. On the other hand, between 67.4% and 100% of the population would find "what if" scenarios effective on a long-term basis. Finally, the Spearman's tests did not show any significant level of linear correlation between the respondents rating of the effectiveness of "what if" scenarios and the years of experience in healthcare or BIM (Table 10).

The respondents were then asked to agree or disagree that BIM tools hinder design innovation and creativity (Table 11). The results showed that the population would believe BIM tools hinder design innovation and creativity "all the time" (57.1%-100% with 95% confidence). Spearman's tests revealed there is strong degreasing correlation ($r_s(10)$=-0.638, p=0.047) for the respondents who Strongly agree/agree that BIM tools hinder design innovation and creativity "all the time" with experience in healthcare design.

In the last question, the respondents were asked to indicate their opinion about the effectiveness of using BIM for analysing, evaluating and modelling flexible healthcare facility spaces. The given strategies were "expanding", "contracting", "relocating", and "adapting". The responses vary and this can be seen on the relative low proportions in Table 12. The analysis showed that the population would believe that BIM is likely to benefit more projects that focus on "expanding" and "contracting" (23.8%-76.2% with 95% confidence) over projects that focus on "relocating" (0%-44.8% with 95% confidence) and "adapting" (1.6%-58.4% with 95% confidence). Regarding the Spearman's correlation tests, there is no significant linear correlation concerning the applied flexibility strategies and the years of experience the respondents have in BIM or in healthcare.

Table 10 Proportions, 95% confidence intervals and Spearman's rho on the effectiveness of using "what if" scenarios with BIM in the design of flexible healthcare spaces.

Main sample	95% confidence intervals			Correlations	
	Upper limit	Lower limit	Sample proportion	BIM experience	Healthcare experience
Short-term basis	0.762	0.238	0.500	-0.148	0.204
Long-term basis	1.000	0.674	0.857	0.490	0.039

Table 11 Proportions, 95% confidence intervals and Spearman's rho on the degree of dis (agreement) that BIM tools hinder design innovation and creativity.

Main sample	95% confidence intervals			Correlations	
	Upper limit	Lower limit	Sample proportion	BIM experience	Healthcare experience
all the time Sig. (2-tailed)	1.000	0.571	0.786	0.133	-0.638* 0.047

*Correlation is significant at the 0.05 level (2-tailed).

Table 12 Proportions, 95% confidence intervals and Spearman's rho on using BIM for analysing, evaluating and modelling flexible healthcare facility space strategies.

Main sample	95% confidence intervals			Correlations	
	Upper limit	Lower limit	Sample proportion	BIM experience	Healthcare
Expanding	0.762	0.238	0.500	-0.148	0.204
Contracting	0.762	0.238	0.500	0.004	-0.207
Relocating	0.448	0.000	0.200	0.118	0.284
Adapting	0.584	0.016	0.300	-0.131	-0.596

5. Conclusions and Future Research

The study's key findings regarding the three major fields of interest are presented below.

Designing flexible spaces: this research can conclude that the three types of changes identified by Slaughter [14]: spatial, flow; and structural are features of a rapid changing space. Findings from both samples identified "bedrooms", "operating theatres" and "laboratories" as the top three categories of spaces that are frequently subjected to change. Both samples identified "standards" as the most important consideration for design flexible spaces. Under standardisation hinders the knowledge of equipment specification and the different types of rooms to specify in a healthcare facility. Another concept that was ranked as important was "services" which calls for identifying practices and operations that meet the needs of facility users (staff and patients) at early design stages; information regarding standards and services is included in ADB. The functional services required define the type of MEP services desirable for the functional space design. Lastly, the main sample identified "cost" as an important consideration at the early design stages of a project. One effective method in construction management centred on cost is Target Value Design. The analysis also highlighted that designers find open building principles (shell space) highly effective; they also found adaptability strategies such as "flexible partitions" and "flexible furniture" highly effective.

Standardisation of healthcare spaces: The respondents' agreed that standardisation is not the panacea for designing flexible healthcare spaces and this is shown in Table 9 where the 95% confidence intervals showed a very strong probability with 64.0%-100% of the population were of the view that standardisation "hinders modularity layout concept". On the other hand "modular design" was ranked first among other flexibility concepts in Table 7. Modular design supports standardised units or standardised dimensions to support construction [30]. Modular design or prefabrication is described as an advanced construction technology that allows a building to be flexible at a short notice while keeping cost as a primary concern. In Addenbrooke Hospital, the use of such methods was applied and significant time efficiency was noted [3]. As a design principle, both samples agreed that "modular design" is a preferable choice for dealing with flexibility.

Flexible space design with BIM: the respondents were of the view that the use of BIM is effective in the design of flexible spaces on both long-term and short-term plans. Within the two bases of application, the respondents were of the opinion that BIM is exploited on a higher rate with regards to "long-term basis" concerning the design of healthcare facilities (Tables 9 and 10). Regarding the use of a flexibility strategy with BIM, the results showed that strategies such as "contracting" and "expanding" are more beneficial than strategies such as "adapting" or "relocating". Conversely, the respondents identified adaptability and open building as the most effective strategies for approaching flexible space design. Comparing these findings; it can be concluded that BIM as a process and technology should provide improved applications to meet users` demand in regards to the application of adaptability.

Regarding the hypothesis, experienced designers with healthcare and BIM experience were of the view that standardisation and BIM can enhance flexibility. The analysis did not provide clear evidence that there is a linear correlation. Further correlations tests (Table 7) revealed that there is strong correlation between two flexibility strategies: open building and adaptability, since respondents who chose "shell space" also chose "flexible furniture" or "flexible partition".

The aim of this preliminary study was to articulate the opinion of designers with healthcare and BIM experience on how satisfactory is design standardisation and BIM to accommodate flexible healthcare spaces. The study is essentially exploratory in nature, with a small but experienced sample. Hence, the findings should be considered with attention. Future research should consider possible methods of integrating standardisation and flexibility within a BIM environment. This will offer explorations in Human-Computer Interaction for new design practices. Another gap that was identified is the need for design guidelines that will focus on the application of conceptualising the design of flexible healthcare facilities with BIM. The guidelines should consider: identifying spaces that frequently change; design standards that should be employed in order to apply flexibility; applications that could allow explorations of "what if" scenarios and "design options" with BIM; and the evaluation methods within BIM that would test those scenarios.

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