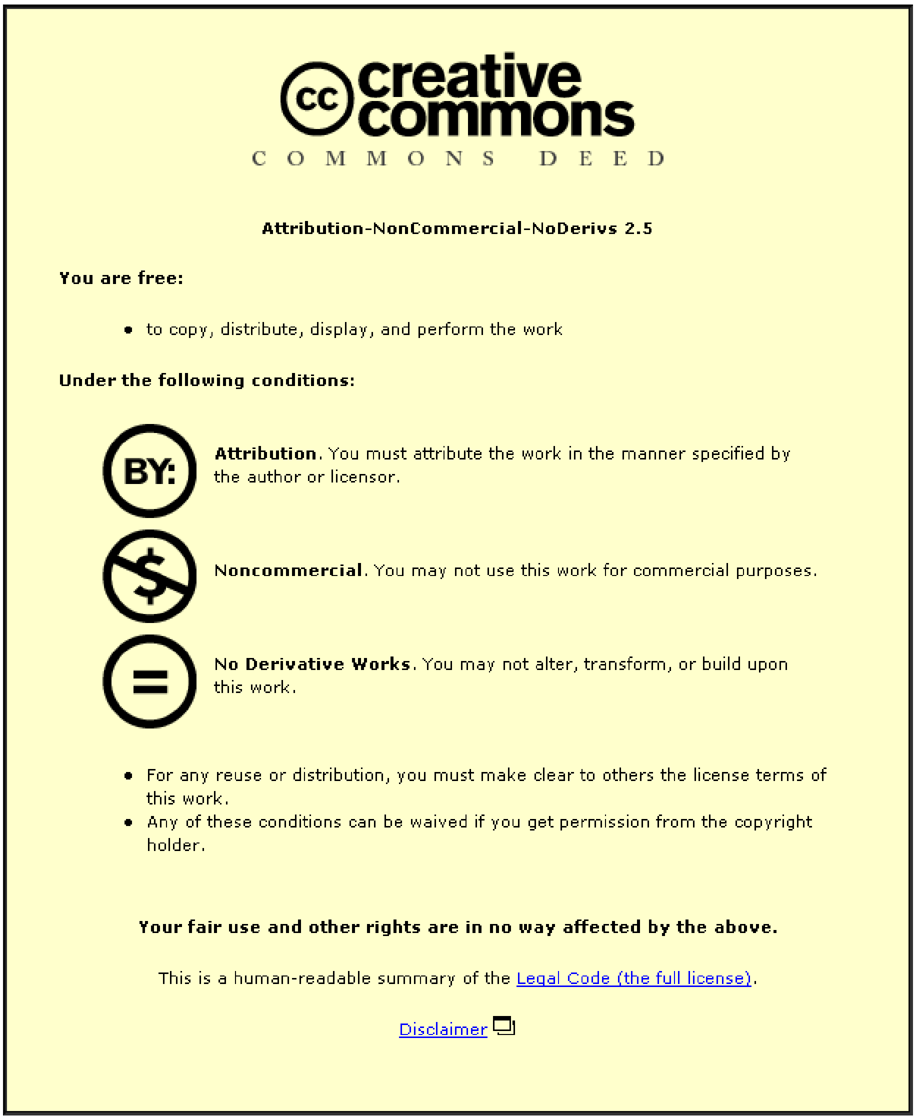


LOUGHBOROUGH UNIVERSITY

SCHOOL OF CIVIL AND BUILDING ENGINEERING

A Dissertation thesis is submitted in partial fulfilment of the requirements for the award of the degree Doctor of Philosophy (PhD) at Loughborough University

THE USE OF REFURBISHMENT, FLEXIBILITY, STANDARDISATION AND BIM TO SUPPORT THE DESIGN OF A CHANGE-READY HEALTHCARE FACILITY

BY

AHMAD MOHAMMAD AHMAD

A917204

2013

ABSTRACT

Healthcare in the UK is a very important sector; it provides state of the art accommodation that meets the need of patients, visitors, medical professionals and other staff. The UK Government is currently cutting costs within the different sectors of the economy, while there are raising figures in UK National Health Service (NHS) spending. These are due to a growing and ageing population, advancement in modern healthcare delivery and special needs for different facility users. There is a UK Government proposal set out that "*requires the delivery of £15-20 billion in efficiency savings over the three year period from 2011*" (Department of Health, 2010-2015). This study has understood that cost savings can be achieved by adopting and implementing a framework that supports refurbishment, flexibility, standardisation and Building Information Modelling (BIM). These cost savings can be achieved through Mechanical Engineering and Plumbing (MEP) clash detections using (BIM). 65% of hospital designs are centred on MEP services (interviews). The NHS needs to save cost when responding to possible future changes without compromising the quality of standard provided to the public. A change-ready healthcare facility is proposed to address the issue of change and the design of quality spaces that can enhance effectiveness and efficiency in the delivery of health and social care. A change-ready healthcare facility can be described as a facility that accommodates known or proposed future changes creating novel pathways to increase the quality and life span of facilities. There is also a large chunk of NHS estates that is underutilised EC Harris, (2013). Therefore, healthcare facilities need to respond to future changes in order to optimise their spaces. To achieve quality and cost efficiency in healthcare buildings, key considerations are refurbishment and reconfiguration, optimisation of flexibility, maximising standardisation and implementation of BIM.

This research explores opportunities to save costs, time and improve quality of healthcare facilities by making emphasis on the design delivery process. Therefore, the new RIBA Plan of Work 2013 was used as a mechanism to help translate ideas into physical form and yet has been hindered by lack of development and ability to keep up with technological development such as BIM. This is the rationale for developing a framework. The RIBA Plan of Work is accepted nationally.

Due to the UK BIM mandate by 2016, this research is focused on the use of BIM to support both space standardisation and space flexibility within a refurbished or new building. Space is a vital component competent in every healthcare facility. It provides the environment for healthcare services to be performed, and links one functional *space* to another, it can be designed for multifunctional usage. Healthcare spaces are complex entities due to the range of services and technology they support and the number, variety and quality of requirement combined with a rapidly changing environment. Flexibility enables a facility to easily respond to changes, while the introduction of standardisation supports staff performance by reducing the reliance on memory which will reduce human error. But the main question that emerges from current literature is how healthcare designers and planners manage healthcare spaces that cannot easily be standardised due to the constraints of existing structures, diversity in patient and staff needs?

With analysis of different flexibility frameworks in the Architecture, Engineering and Construction (AEC) industry, there is a need to improve the existing frameworks. Therefore, a framework for designing a change-ready healthcare facility was developed through a sequence of data analysis starting with literature, preliminary data, questionnaire survey and interviews. Three frameworks for designing a change-ready facility were revised, organised and merged to produce a state of the art framework. Three frameworks were revised as different research methods were required. The successful framework can guide the design process of embedding different flexible *design options* for a defined project brief to save costs and improve design efficiency. The framework was validated with some of the top 100 architectural practices in the UK, NHS Estates, facility managers and the RIBA through an interview process.

Further research and development arising from this research focuses on the process of applying BIM to record or identify key decisions taken for each of the different *design options* generated from a single brief to inform the designers, clients or other stakeholders involved while collaborating. Findings of this research are described in five peer-reviewed papers.

KEYWORDS: *Refurbishment; flexibility; standardisation; BIM; healthcare; change-ready facility*.

“The only certainty in healthcare is change” Gressel and Hilands, (2008).

ACKNOWLEDGEMENTS

I will like to begin by thanking Almighty Allah. I am grateful to EPSRC for providing support towards the PhD programme. I would like to take this opportunity to express my sincere gratitude towards my supervisors Professor A.D.F. Price and Dr. Peter Demian for their continuous exceptional support, patience, tolerance, assistance, encouragement, guidance, and inspiration towards the completion of my PhD thesis.

Many have contributed towards this endeavour with too many people to mention. My appreciation goes to all the companies, organisations and individuals that collaborated during the different stages of this research. I will like to thank the entire HaCIRIC Team for their support and guidance. I will also want to thank Professor Tarek Hassan for his unwavering support. I will also want to thank Dr. Michael Phiri, Professor Stephen Emmitt and Professor Chimay Anumba for their guidance.

I also like to extend my warm gratitude to my family and friends: and all the members of the Research Hub, School of Civil and Building Engineering.

TABLE OF CONTENT

CERTIFICATE OF ORIGINALITY .... **I**
ABSTRACT .... **II**
ACKNOWLEDGEMENTS .... **IIV**
TABLE OF CONTENT .... **V**
LIST OF TABLES .... **XII**
LIST OF FIGURES .... **V**
ACRONYMS AND ABBREVIATIONS .... **VIII**
LIST OF APPENDIXES .... **IX**
1 CHAPTER 1: INTRODUCTION TO THE RESEARCH **1**
1.1 Introduction 1
1.2 Research Background 4
1.3 Research Justification 6
  1.3.1 The Need for refurbishment in healthcare 7
  1.3.2 The need for flexibility in healthcare 9
  1.3.3 The need for standardisation in healthcare 10
  1.3.4 The need for BIM in healthcare 11
1.4 Problem Identification 12
1.5 Importance and purpose of research 16
  1.5.1 The main drivers and reason for this research 16
  1.5.2 The scope of the research 17
1.6 Research questions 17
  1.6.1 Refurbishment in healthcare 17
  1.6.2 The application of flexibility in healthcare 18
  1.6.3 The application of standardisation in healthcare 18
  1.6.4 The application of BIM in healthcare 19
1.7 Aim and Objectives 19
  1.7.1 Aim of the research 19
  1.7.2 Objectives of the research 20
  1.7.3 Research scope, target and output 23
1.8 Outline research method 26
1.9 Thesis structure 28
1.10 Chapter summary 29
2 CHAPTER 2: LITERATURE REVIEW- UNDERSTANDING THE APPLICATION OF RFSB **30**
2.1 Refurbishment 30
  2.1.1 Refurbisment process 30
  2.1.2 A refurbished healthcare space 33
  2.1.3 Challenges of refurbishment 35
2.2 Flexibility 35
  2.2.1 Flexibility processes 36
  2.2.2 A flexible healthcare space 38
  2.2.3 Challenges of flexibility 39
2.3 Standardisation 41

2.3.1 Standardisation processes 42
2.3.2 A standardised healthcare space 43
2.3.3 Challenges of standardisation 44
2.4 BIM....44
2.4.1 Overview of BIM....45
2.4.1.1 Different understandings of BIM….46
2.4.1.2 Manifestation of BIM…...48
2.4.1.3 Industry Foundation Classes (IFC) Objects…...48
2.4.1.4 Advantages of IFC Objects…..50
2.4.1.5 BIM dimensions…..52
2.4.2 BIM benefits 52
2.4.2.1 BIM benefits in the design phase….52
2.4.2.2 BIM benefits in the pre-construction and construction phase…….53
2.4.2.3 BIM benefits for facility management….54
2.4.3 Inter-organisational use of BIM....54
2.4.4 BIM Implementation Plans....56
2.4.4.1 BIM implementation scopes…. 57
2.4.4.2 BIM implementation cost…...57
2.4.4.3 Challenges of implementing BIM…...59
2.5 Discussion....61
2.6 Chapter summary....65

3 CHAPTER 3: LITERATURE REVIEW-EXPLORING THE APPLICATION OF RFSB IN HEALTHCARE PROJECTS....66

3.1 Healthcare sector in the UK....66
3.1.1 Organisational structure of the UK health system 67
3.1.2 The UK NHS estates....68
3.2 Change-ready healthcare facilities....70
3.2.1 Refurbishment and change-ready healthcare facilities 70
3.2.2 Flexibility and change-ready healthcare facilities 71
3.2.3 Standardisation in change-ready healthcare facilities....71
3.2.4 BIM in change-ready healthcare facilities 72
3.2.5 Procurement deliveries and change-ready healthcare facilities…..74
3.3 Change-ready Healthcare facility design....76
3.3.1 Special needs of healthcare facilities 76
3.3.2 Needs of a flexible healthcare facility 77
3.3.3 Facility procurement processs....78
3.3.4 Process of designing a healthcare facility....82
3.3.5 Challenges of healthcare facilities 83
3.3.6 Proposed area of research focus....84
3.4 Discussion of the analysed literature used for designing the framework 88
3.4.1 Exploring BIM capabilities from different defintions 88
3.4.1.1 Definition of BIM from academicians…...89
3.4.1.2 Definition of BIM from AEC industry and other organisations….91
3.4.1.3 Definition of BIM from software and hardware vendors….92
3.4.2 Exploring concepts and planning appraoches for flexibility 94
3.4.3 Exploring processes of embedding flexibility in a design....97
3.4.4 Exploring different flexibility frameworks....98
3.4.5 Exploring standards within flexible designs....102
3.5 Approaches towards the development of a framework from analysed literature....106
3.6 Chapter summary....110

4 CHAPTER 4: RESEARCH DESIGN AND METHODOLOGY 111
4.1 Introduction 111
4.2 Research application 113
  4.2.1 Pure research 113
  4.2.2 Applied research 113
  4.2.3 Research application adopted 114
4.3 Research objective 114
  4.3.1 Descriptive 114
  4.3.2 Correlation 115
  4.3.3 Exploratory 115
  4.3.4 Explanatory 115
  4.3.5 Research objective adopted 115
4.4 Research paradigm 116
  4.4.1 Ontological considerations 116
  4.4.2 Epistemological considerations 117
  4.4.3 Empirical considerations 117
  4.4.4 Philosophical position of research adopted 118
4.5 Research methodology 118
  4.5.1 Quantitative research 121
  4.5.2 Qualitative Research 121
  4.5.3 Mixed methods 123
  4.5.4 Research strategy adopted 124
4.6 Research approach 125
  4.6.1 Deductive research 125
  4.6.2 Inductive research 125
  4.6.3 Research approach adopted 127
4.7 Research methods 128
  4.7.1 Research methods adopted 129
    4.7.1.1 Interview 129
    4.7.1.2 Exploratory questionnaire survey and interviews 130
    4.7.1.3 Questionnaire survey 131
      4.7.1.3.1 Questionnaire survey sampling 131
      4.7.1.3.2 Method of questionnaire survey analysis 133
    4.7.1.4 Interviews 135
      4.7.1.4.1 Type of interview design 135
      4.7.1.4.2 Approach to interview design 135
      4.7.1.4.3 Type of interview questions 136
      4.7.1.4.4 Transcribed interviews 137
      4.7.1.4.5 Method of interview analysis 138
      4.7.1.4.6 Adopted interviews 139
4.8 Research tasks 140
  4.8.1 Research objectives and methods adopted 141
  4.8.2 Research work and methods adopted 141
  4.8.3 Rejected methods, theories and approaches 142
  4.8.4 Organisational structure of research data 143
  4.8.5 Primary data populations and samples 145
4.9 Data validity and reliability 146
  4.9.1 Reliability 146
  4.9.2 Validity 146
  4.9.3 Validation and reliability adopted for this research 147

4.10 Chapter summary....149

5 CHAPTER 5: PRELIMINARY RESEARCH- EFFECTIVE APPLICATION OF FSB WITHIN REFURBISHMENT PROJECTS....150

5.1 Introduction....150
  5.1.1 Aim and objectives of the preliminary research....150
  5.1.2 Preliminary research....151
  5.1.3 Background of questionnaire survey and interview respondents....151
  5.1.4 Limitation of the research methods....153
5.2 Preliminary questionnaire survey....153
  5.2.1 Aim and objective of preliminary questionnaire survey....153
  5.2.2 BIM use in healthcare....154
  5.2.3 Flexibility in healthcare....154
  5.2.4 Refurbishment in healthcare....154
  5.2.5 Findings of preliminary questionnaire survey....155
    5.2.5.1 Preliminary questionnaire findings on refurbishment....155
    5.2.5.2 Preliminary questionnaire findings on flexibility……………...156
    5.2.5.3 Preliminary questionnaire findings on standardisation………..…158
    5.2.5.4 Preliminary questionnaire findings on BIM……………….……..159
5.3 Preliminary interviews....160
  5.3.1 Aim and objective of preliminary interviews....161
    5.3.1.1 Aims of preliminary interviews………………………………..161
    5.3.1.2 Objective of the preliminary interviews…………………………161
  5.3.2 The application of flexibility and standardisation....161
  5.3.3 Broadness of topics....162
  5.3.4 Findings of preliminary interviews....162
5.4 Space standardisation and flexibility (Secondary data)....164
  5.4.1 Space standardisation and space flexibility in healthcare delivery?....164
    5.4.1.1 Barriers to standardisation in healthcare delivery……………....165
    5.4.1.2 Tools for achieving flexibility and standardisation within……...166
  5.4.2 Space standardisation and space flexibility in healthcare refurbishment....168
    5.4.2.1 Impact of space flexibility and standardisation on refurbishment drivers……………………………………………………………….....168
    5.4.2.2 Proposed relationship between flexibility and standardisation within refurbishment scales of work…………………………………………...169
  5.4.3 Flexibility, standardisation and BIM in healthcare refurbishment....170
    5.4.3.1 Effective use of standardisation………………………..……...171
    5.4.3.2 Effective use of flexibility…………………………..………...173
    5.4.3.3 Effective use of BIM……………………………………………174
5.5 Strategic approach towards the combined application of RFSB within a healthcare facility design process....174
5.6 Chapter summary....179

6 RESEARCH UNDERTAKEN (QUESTIONNAIRE SURVEY): ORGANISING THE APPLICATIONS OF RFSB WITHIN A CHANGE-READY HEALTHCARE FACILITY....180

6.1 Questionnaire introduction....180
  6.1.1 Background of respondents....180
  6.1.2 Sample one: Top 100 UK architectural firms based on the Building Magazine 2010....181
  6.1.3 Sample two: Web based group (CNBR)....182

6.1.4 Other samples considered 182
6.1.5 Method of analysis 184
6.2 Designing flexible healthcare spaces 192
6.2.1 Healthcare spaces that rapidly changes 192
6.2.2 Designing principles for achieving flexibility 194
6.2.3 Important stakeholders making flexibility decisions 195
6.2.4 Important factors to consider when designing flexible spaces 196
6.2.5 Effectiveness of some flexibility concepts 197
6.3 Standardisation in flexible healthcare space 200
6.3.1 Important stakeholders making standardisation decisions 200
6.3.2 Standardisation and flexible healthcare space design 201
6.4 BIM supporting flexible healthcare space design 203
6.4.1 Creativity with BIM 203
6.4.2 What if scenarios with BIM 206
6.4.3 BIM use for analysing and evaluating flexible healthcare space 207
6.4.4 BIM use for adapting, expanding, converting and relocating space 208
6.4.5 Important considerations when sharing information with BIM 210
6.5 Refinement of the framework developed from literature review analysis 210
6.6 Limitation of questionnaire survey 215
6.7 Chapter summary 215

7 CHAPTER 7: RESEARCH UNDERTAKEN (INTERVIEWS): ORGANISING RFSB WITHIN A CHANGE-READY HEALTHCARE FACILITY 216

7.1 Interview Introduction 216
7.1.1 Aim of the interviews 216
7.1.2 Objectives of the interviews 217
7.1.3 Interview sampling 217
7.1.4 Method of interview analysis 218
7.1.5 Interview findings categories 220
7.2 The role of BIM in healthcare 221
7.2.1 Project delivery methods that allow more collaborative BIM 223
7.2.2 Which project delivery method facilitates the ability to embed flexibility? ..224
7.2.3 Core BIM activities to embed flexibility 226
7.2.4 What are possible risk and uncertainties when designing flexible spaces with BIM? 228
7.3 Embedding flexibility with standards 229
7.3.1 Requirement for achieving standards when embedding flexibility 229
7.3.2 Who manages the flexible design with BIM? 230
7.4 Core requirements for achieving quality refurbishment 231
7.4.1 Top three considerations for healthcare refurbishment 233
7.4.2 Managing constraints of refurbishment (functions, space and flow) 234
7.5 The cost effective and cost efficient refurbishment 235
7.5.1 Project delivery method 236
7.5.2 Constraints 237
7.5.3 Best practices 238
7.6 Integrating flexibility and standardisation processes 241
7.6.1 Standardisation process 241
7.6.2 Flexibility process 242
7.6.3 The combined applications of flexibility and standardisation processes 243
7.6.4 Applying BIM process 247
7.6.4.1 BIM implementation…....247

7.6.4.2 BIM maturity levels……………………………………………248
7.6.5 Flexible design Parameters 254
7.7 Discussion..254
7.8 Framework revised from interview findings 257
7.9 Limitation of interviews 261
7.10 Chapter summary...261

8 CHAPTER 8: FRAME WORK DEVELOPMENT, VALIDATION AND DISCUSSION..262

8.1 Introduction 262
8.2 Framework development process 263
8.2.1 Framework generated from literature review 264
8.2.2 Framework Revised from questionnaire survey 267
8.2.3 Framework generated from interview findings.....................................269
8.3 Components of Cost effective and cost efficient change-ready FACILITY designs ..272
8.3.1 Modelling different design options with BIM 272
8.3.2 Parameters that facilitates decision making (designer and client) 273
8.4 The framework validation 273
8.4.1 Evaluation of the framework 274
8.4.2 Background of the invited samples...274
8.4.2.1 Sample One…………………………………………….........274
8.4.2.2 Sample Two……………………………………………………275
8.4.2.3 Sample Three……………………………………………………..275
8.4.2.4 Sample Four……………………………………………………276
8.5 Discussion..276
8.5.1 Validation participants 276
8.5.1.1 Findings from interviewees…………………………...……..277
8.5.1.2 Concerned raised by interviewees…………………………………285
8.6 The framework revised by validation interviews 289
8.7 Framework implementation strategy...290
8.8 Barriers to implementation of the framework 291
8.9 Chapter summary..294

9 CHAPTER 9: CONCLUSION, RECOMMENDATIONS AND AREA OF FURTHER RESEARCH. 295

9.1 Conclusion..295
9.2 Findings from research objectives..296
9.2.1 Objective 1 296
9.2.2 Objective 2 297
9.2.3 Objective 3 299
9.2.4 Objective 4 301
9.2.5 Objective 5 302
9.2.6 Objective 6 303
9.3 ResponseS to the research questions 304
9.3.1 Response to research question category 1 304
9.3.2 Response to research question category 2 307
9.3.3 Response TO research question category 3 308
9.3.4 Response to research question category 4 310
9.4 Contribution to knowledge 312
9.5 Implications of the research..313
9.5.1 Practical implication of the research..313

- 9.5.2 Theoretical implication of the research 314
- 9.5.3 Implication of research to facility users 314
9.6 Research limitation 315
- 9.6.1 Limitation of the framework 315
- 9.6.2 Time and resources constraints 315
- 9.6.3 Limitation of sample size 316
9.7 Recommendation 316
- 9.7.1 Recommendation for healthcare designers and planners 317
- 9.7.2 Recommendation for the NHS 317
- 9.7.3 Recommendation for future research 318
9.8 Closing remarks 319

Reference 320

LIST OF TABLES

Table 1.1: *Problem statement*…...15
Table 1.2: *Research aim and objective*…………………………………………………21
Table 1.3: *The relationship between the research objectives and the research tasks* 24
Table 1.4: *List of peer-reviewed papers* 25
Table 2.1: *What is flexibility?* 36
Table 2.2: *Application of BIM in different projects. Source: Gao and Fischer (2008, p. 42)*.62
Table 2.3: *Application of BIM in different projects. Source: Gao and Fischer (2008, p. 42)*.63
Table 3.1: *Relationship between the framework component and healthcare delivery outcomes* 75
Table 3.2: *Scope of Research focus within the building delivery process. adapted from Gray and Hughes (2001) and the RIBA Plan of Work (2007).*.................................86
Table 3.3: *Narrowing the research focus within the Design Stages adapted from Gray and Hughes (2001) and the RIBA Plan of Work (2007).*......................................87
Table 3.4: *List of identified BIM stakeholders*...89
Table 3.5: *Definition of BIM by academicians* 90
Table 3.6: *Definition of BIM by AEC industry or other organisation* 91
Table 3.7: *Definitions of BIM by software and hardware vendors* 92
Table 3.8: *Keywords described by the different categories of BIM stakeholders in the BIM definitions stated above* 93
Table 3.9: *Key BIM features used to develop the framework for designing a change-ready healthcare facility, inspired by NIBS, (2007)*...93
Table 3.10: *Flexibility considerations, requirements and building systems. Source: Carthey et al., (2010, p. 109)* 95
Table 3.11: *Planning and concepts for adapting a facility*..96
Table 3.12: *Planning and concepts for expanding a facility* 97
Table 3.13: *Flexibility options to consider for facility flexibility. Source: Allahaim et al. (2010) quoted Guma (2008) and Mun (2006)*..98
Table 3.14: *Analysis of different frameworks related to flexibility, adaptability and healthcare facilities* 102
Table 3.15: *Classification of flexible building elements. Source: Finch (2009, p. 10)* 105
Table 3.16: *Analysis of different flexible building elements, modified from Carthey et al. (2010); Brand (1994); and Taylor et al. (2011)*..105
Table 3.17: *Literature review findings supporting the framework guidelines for designing a change-ready healthcare facility*...107
Table 4.1: *Quantitative and qualitative research features described Bryman and Bell (2011, p. 410); Ruddock (2008); Ruikar (2004); and Brewer (2007) Marshall and Rossman (2011); Pope and Mays (2006)*..123
Table 4.2: *Features of different research methods. Source: Yin (1994, p.6)*……………….129
Table 4.3: *Advantages and disadvantages of research surveys.*...129
Table 4.4: *Advantages and challenges of questionnaire surveys*…………………………..131
Table 4.5: *Comparison of different questionnaire survey methods. Source: Knight and Ruddock, (2008); Silverman (2004)*..133
Table 4.6: *Methods of questionnaire survey analysis. Source: Farrell, (2011)* 134
Table 4.7: *Weighting factors used in the analysis of the Likert questions; type A* 134
Table 4.8: *Weighting factors used in the analysis of the Likert questions; type B* 134
Table 4.9: *Weighting factors used in the analysis of the Likert questions; type C* 134
Table 4.10: *Research techniques applied* 141

Table 4.11: *Research road map* 142
Table 4.12: *Research population and samples used for this research* 145
Table 4.13: *Reliability and validity of research*..........148
Table 5.1: *Refurbishment in healthcare*..........156
Table 5.2: *Flexibility in healthcare*..........157
Table 5.3: *Standardisation in healthcare*..........159
Table 5.4: *BIM use in healthcare*..........160
Table 5.5: *The impact of space flexibility and space standardisation on refurbishment drivers. Source: Ahmad et al. (2011)*..........175
Table 6.1: *Ranking of top 100 UK architects* 184
Table 6.2: *Maximum and minimum number of respondents and years of BIM experience from both samples* 187
Table 6.3: *Maximum and minimum number of respondent and years of healthcare experience from both samples* 189
Table 6.4: *Maximum and minimum number of respondent and percentage of BIM use on projects from both samples*..........190
Table 6.5: *Spaces that frequently changes in healthcare facilities (Sample One)*..........193
Table 6.6: *Spaces that frequently changes in healthcare facilities (Sample Two)* 193
Table 6.7: *Top three flexibility design principles from (Sample One)*..........195
Table 6.8: *Top three flexibility design principles from (Sample Two)* 195
Table 6.9: *Top four important stakeholders making flexibility decisions from (Sample One)* 196
Table 6.10: *Top four important stakeholders making flexibility decisions from (Sample Two)* 196
Table 6.11: *Top three important considerations for designing flexible spaces from (Sample One)*..........197
Table 6.12: *Top three important considerations for designing flexible spaces from (Sample Two)*..........197
Table 6.13: *Ranking on the flexibility concepts from both (Sample One and Two)* 199
Table 6.14: *Top four most important stakeholders making decisions during the selection process of the most effective standards from (Sample One)* 200
Table 6.15: *Top four most important stakeholders making decisions during the selection process of the most effective standards from (sample two)*..........200
Table 6.16: *Opinion of the questionnaire survey respondents on standardisation impeding flexible space opportunities from Sample One and Two*..........203
Table 6.17: *Questionnaire survey findings used to further develop the framework for designing a change-ready healthcare facility* 213
Table 7.1: *Details of firms that participated in the research interviews* 218
Table 7.2: *Interviewee code prefixes detail* 219
Table 7.3: *Interview responses on the need for BIM in healthcare facility design* 221
Table 7.4: *Interview responses on the best project delivery method that allows more collaborative BIM*..........223
Table 7.5: *Interview responses on the best project delivery method for embedding flexibility* 224
Table 7.6: *Interview responses on the core BIM requirements for achieving a flexible design* 226
Table 7.7: *Interview responses on possible risk and uncertainties when design with BIM*...228
Table 7.8: *Interview responses on the requirement for achieving standards when embedding flexibility*..........229

Table 7.9: *Interview responses on the consultant that manages the flexible design with BIM strategy in a healthcare project*..230
Table 7.10: *Interview responses on the core requirement for achieving quality refurbishment when embedding flexibility*...231
Table 7.11: *Interview responses on the top three considerations for healthcare refurbishment* 233
Table 7.12: *Interview responses on managing constraints of existing factors such as functions, spaces and flow*...234
Table 7.13: *Breakdown of the second category of the interview analysis focused on themes* 235
Table 7.14: *Cost effective and cost efficient refurbishment……………………………………..240*
Table 7.15: *Tension within the combined application of flexibility and standardisation (Interviewees: AF-1, AF-2, AF-5 and AF-8)…………………………………………………....245*
Table 7.16: *Integrating flexibility and standardisation………………………………………….246*
Table 7.17: *The process of applying BIM………………………………………………………….251*
Table 7.18: *Change-ready design parameters that could facilitate the decision making process……………………………………………………………………………………………….253*
Table 7.19: *Framework keys and references……………………………………………………..260*
Table 8.1: *Phases of the framework generated from interviews*...269
Table 8.2: *Background of the validation participants* 277
Table 8.3: *Summary of the results from validation of the framework* 278
Table 8.4: *Validation questions and results (interviewee P1)* 279
Table 8.5: *Validation questions and results (interviewee P2)* 280
Table 8.6: *Validation questions and results (interviewee P3)* 281
Table 8.7: *Validation questions and results (interviewee P4)* 282
Table 8.8: *Validation questions and results (interviewee P5)* 283
Table 8.9: *Validation questions and results (interviewee P6)* 284

LIST OF FIGURES

Figure 1.1: *The Life cycle of a building. Source: Palgrave (2011, p. 6)* 8
Figure 1.2: *A growing and ageing population. Source: World Population Ageing (2009)....* 13
Figure 1.3: *Causes of failure of buildings. Source: Palgrave (2011, p. 13)*...........................15
Figure 1.4: *The combined applications of flexibility and standardisation within a refurbishment project through the use of BIM in healthcare*.........................22
Figure 1.5: *Overlapping of the framework components* 23
Figure 1.6: *Summary of research outputs*……………………………………………………27
Figure 2.3: *Flexible space concept. Source: Battisto and Allison (2002, p. 40)* 39
Figure 2.4: *Stages of BIM development. Source: Sheth (2011) quoted Dix, (2009)*...............45
Figure 2.5: *BIM description. Source: (NIBS, 2007, p. 21)* 47
Figure 2.6: *BIM uses at different levels. Source: VTT (2006, p. 33)* 55
Figure 2.7: *BIM uses with examples. Source: VTT (2006, p. 35)* 55
Figure 2.8: *Cost implementation annotation. Source: Hardin (2009)*...................................58
Figure 2.9: *Relationship between phasing, prototyping and baseline model. (Chellappa, 2009, p. 94)*...64
Figure 3.1: *NHS Structure. Source: NHS Choice, (2012b)*...67
Figure 3.2: *The structure of the new NHS in England. Source: (Smith and Pollock et al, 2006, p. 8)*...68
Figure 3.3: *Three key elements with strong relationship within a healthcare facility. Source: Chellappa (2009, p. 11)*...78
Figure 3.4: *Professionals and the knowledge base table. Source: Manning and Messner (2008, p. 447)* 79
Figure 3.5: *RIBA Plan of Work (2013)* 80
Figure 3.6: *Construction process. Source: Chartered Institute of Building (CIOB, 2010, p. 24)*...80
Figure 3.7: *The level of involment of professionals within a project. Source: Shah et al. (2008, p. 393) describing Brown (2001)*..81
Figure 3.8: *Healthcare facilities design where BIM applies. Modified from Tompkins et al. (2010)* 83
Figure 3.9: *Adaptable design framework. Source: Allahaim et al (2010)*..............................99
Figure 3.10: *Healthcare facility design framework. Source: Vorel et al. (2009)*....................99
Figure 3.11: *Design framework for community housing. Source: Fien et al. (2007)*...........100
Figure 3.12: *Framework for proper integration of flexibility in conceptual design. Source: Ajah et al., (2005)*...100
Figure 3.13: *Healthcare facility design framework. Source: Kunders (2004)* 101
Figure 3.14: *Steps of flexibility design framework. Source: Shuchi and Drogemuller (2012)* 101
Figure 3.15: *Modular flexibility within an emergency department universal grid system. Source: Taylor et al. (2011, p. 20)* 103
Figure 3.16: *Modular grid system. Source: Zhao and Tseng (2007, p. 730)*........................104
Figure 3.17: *Framework for designing a change-ready healthcare facility developed from literature review sources* 109
Figure 4.1: *Research Methodology adopted Source: Gill and Johnson (2010, p. 9)* 112
Figure 4.2: *Describing qualitative data. Source: Dainty (1998)*..122
Figure 4.3: *Inductive research features. Source: Newell and Bunard, (2011) and Burney, (2008); (Blaikie, 2009); and Koh and Owen, (2000)*..................................126

Figure 4.4: *Deductive research features. Source: Newell and Bunard, (2011) and Burney, (2008); (Blaikie, 2009); and Koh and Owen, (2000)* 127
Figure 4.5: *Organisational structure of data collection methods* 144
Figure 4.6: *Possible errors in data collection method procedures. Source: Fellow and Liu, (2008) quotes Malhotra and Birks (1999)* 148
Figure 5.1: *Background (profession) of participants for both questionnaire survey and interviews* 152
Figure 5.2: *Participant`s years of BIM experience* 152
Figure 5.3: *Questionnaire responses on tools/guidance/software used for space flexibility and space standardisation* 167
Figure 5.4: *Proposed relationship between refurbishment flexibility and standardisation. Source: Ahmad et al. (2011)* 170
Figure 5.5: *Questionnaire responses on the most effective application of space standardisation* 172
Figure 5.6: *Questionnaire responses on the effectiveness of space flexibility at three different places* 173
Figure 5.7: *Strategic application of standardisation, flexibility and BIM during healthcare refurbishment* 185
Figure 6.1: *Profession that most relates to Sample One?* 185
Figure 6.2: *Profession that most relates to Sample Two?* 185
Figure 6.3: *Years of BIM experience within Sample One* 186
Figure 6.4: *Years of BIM experience within Sample Two* 186
Figure 6.5: *Years of healthcare experience from Sample One* 188
Figure 6.6: *Years of healthcare experience within Sample Two* 188
Figure 6.7: *Percentage of BIM applied on live projects within Sample One* 189
Figure 6.8: *Percentage of BIM applied on live projects within Sample Two* 190
Figure 6.9: *Involvement of Sample One respondents within the different building sectors* 191
Figure 6.10: *Involvement of Sample Two respondents within the different building sectors* 191
Figure 6.11: *Opinion of questionnaire survey respondents on degree of effectiveness of the following flexibility concepts from (Sample One)* 198
Figure 6.12: *Opinion of questionnaire survey respondents on degree of effectiveness of the following flexibility concepts from (Sample Two)* 198
Figure 6.13: *Opinion of questionnaire survey respondents on standardisation impeding flexible space opportunities by providing specification that involves the three different categories in (Sample One)* 202
Figure 6.14: *Opinion of the questionnaire survey respondents on standardisation impeding flexible space opportunities by providing specification that involves the three different categories in (Sample Two)* 202
Figure 6.15: *Opinion of the questionnaire survey respondents on the degree of dis (agreement) that BIM tools hinder design innovation and creativity from three different scenarios (Sample One)* 204
Figure 6.16: *Opinion of the questionnaire survey respondents on the degree of dis (agreement) that BIM tools hinder design innovation and creativity from three different scenarios (Sample Two)* 204
Figure 6.17: *Comparability between the two different groups of questionnaire survey respondents (average mean)* 205
Figure 6.18: *Opinion of the questionnaire survey respondents on the effectiveness of using "what if scenarios" with BIM in the design of flexible healthcare spaces from Sample One* 206

Figure 6.19: *Opinion of the questionnaire survey respondents on the effectiveness of using "what if scenarios" with BIM in the design of flexible healthcare spaces from Sample Two* 207
Figure 6.20: *Opinion of the questionnaire survey respondents on the effectiveness of using BIM for analysing and evaluating flexible healthcare space to inform decisions on short-term and long-term basis from (Sample One)*......207
Figure 6.21: *Opinion of the questionnaire survey respondents on the effectiveness of using BIM for analysing and evaluating flexible healthcare space to inform decisions on short-term and long-term basis from (Sample Two)* 208
Figure 6.22: *Opinion of the questionnaire survey respondents on the effectiveness of using BIM for analysing, evaluating and modelling flexible healthcare facility space expanding, contracting, relocating and adapting to changes from (Sample One)*......209
Figure 6.23: *Opinion of the questionnaire survey respondents on the effectiveness of using BIM for analysing, evaluating and modelling flexible healthcare facility space expanding, contracting, relocating and adapting to changes from (Sample Two)*......209
Figure 6.24: *framework for designing a change-ready healthcare facility developed from literature review and questionnaire survey findings*......214
Figure 7.1: *Category of interview findings* 220
Figure 7.2: *UK Government BIM maturity levels. Source UK Construction Strategy Report (2011, p. 96)* 249
Figure 7.3: *Top five key parameters for making informed decisions before selecting a change-ready facility*......256
Figure 7.4: *Framework for designing a change-ready healthcare facility generated from literature, questionnaire survey and interview findings*......259
Figure 8.1: *The Brand`s Six S`s. Source: Taylor et al. (2011) adapted from Brand (2004)* .265
Figure 8.2: A *framework to design a change-ready healthcare facility generated from literature review, questionnaire and interview findings* 293

ACRONYMS AND ABBREVIATIONS

2D	2 Dimensional
3D	3 Dimensional
4D	4 Dimensional
5D	5 Dimensional
ADB	Adaptable DataBase
AEC	Architecture Engineering and Construction
AGC	Associated General Contractors
AHJs	Authorities having Jurisdictions
ASPECT	A Staff and Patient Environment Calibration Toolkit
BBC	British Broadcasting Cooperation
BIM	Building Information Modelling
CABE	Commission of Architecture and the Built Environment
CAFM	Computer-Aided Facility Management
CIM	Capital Investment Manual
CNBR	Co-operative Network for Building Researchers
CIOB	Chartered Institute of Buildings
COBie	Construction and operations Building Information Exchange
CURT	Construction User Roundtable
CQC	Care Quality Commission
D&B	Design and Build
DH	Department of Health
GBXML	Green Building Extensible Markup Language
GC	General Contractor
EBD	Evidence Based Design
HBDN	Healthcare Building Notes
HaCIRIC	Health and Care Infrastructure Research and Innovative Centre
NHS	National Health Service
HTN	Health Technical Notes
IFC	Industry Foundation Classes
IFMA	International Facility Management Association
IPD	Integrated Project Delivery
ISO	International Standard Organisation
MEP	Mechanical Engineering and Plumbing
NBIM	National Building Information Modelling
NICE	National Institute of Healthcare and Clinical Excellence
OGC	Gateway Office of Government Commerce
OJEU	Official Journal of the European Union
PFI	Private Finance Initiative
RFSB	Refurbishment, Flexibility, Standardisation and BIM
RIBA	Royal Institute of British Architects
SHAs	Strategic Healthcare Authorities
STEP	Standard for the Technical Exchange Product Model Data
UK	United Kingdom
VTT	Valtrion Teknillinen Turkimuskeskus (Technical Research Centre)
XML	Extensible Markup Language

LIST OF APPENDIXES

Appendix 1: Paper 1: Space Standardisation and Flexibility on Healthcare Refurbishment……………………………………………………………………………336
Appendix 2: Paper 2: BIM Implementation Plans: A Comparative Analysis……………..351
Appendix 3: Paper 3: Creativity with Building Information Modelling Tools…………....362
Appendix 4: Paper 4: Impact of Space Flexibility and Standardisation on Healthcare Delivery……..………………………………………………………………………373
Appendix 5: Paper 5: Using BIM to Design Flexible Spaces and Apply Design Standards in Healthcare Facilities…………………………………………………………………...401
Appendix 6: Questionnaire survey MS word document…………………………………..422
Appendix 7: Questionnaire survey online version………………………………………...432
Appendix 8: Interview invitation letter……………………………………………………439
Appendix 9: Parameters for design option selection (interviews)………………………...442
Appendix 10: RIBA Plan of Work with BIM Overlay…………………………...….…443
Appendix 11: Definition of terminologies used in this study………………………..…444

1 CHAPTER 1: INTRODUCTION TO THE RESEARCH

1.1 INTRODUCTION

A change-ready healthcare facility can be described as a flexible and standardised facility that can accommodate change when the need arises; it is expected to increase the life span of a facility by adapting to foreseen changes. To achieve quality and cost efficiency in healthcare facilities, the strategic applications of refurbishment, flexibility, standardisation, and Building Information Modelling (BIM) (RFSB) were suggested by this research. Each of these applications contributes explicitly towards the successful design of a change-ready healthcare facility. Refurbishment creates an opportunity to improve the condition of existing buildings; flexibility allows future changes to take place; standardisation is considered as standard specifications of physical space and its elements, it allows the use of define space sizes for compatibility, precision, simplification and bench marking; and BIM supports healthcare delivery through virtual optimisation of future improvisations and improved productivity. Healthcare in the UK is a very important sector; it provides state of the art accommodation that meets the need of patients, visitors, medical professionals and other stakeholders. The UK Government is currently cutting costs within the different sectors of the economy. The figures from the UK National Health Service (NHS) spending are rising. However, the NHS needs to cut cost in their various projects without compromising the quality of services it provides to the public. Hence, more value for money is required to enable the NHS to cut costs while keeping high quality standards.

This study explores different opportunities and strategies for improving healthcare facilities. The combined application of the four processes mentioned above were suggested for improving cost, time and quality control in the design, construction and operation of healthcare buildings. Cost reduction without compromising quality has been a challenge for the NHS in UK, but Bisgaard (2009, p. xii) argued that some researchers believe that "*To cut the rising costs of healthcare, we must be prepared to compromise our quality requirements, but that is not necessarily so! Reducing cost while improving quality is not a contradiction*". With the use of strategic schemes, costs can be reduced while improving quality. The NHS funding is a major issue in the UK`s political realm. As a result, the NHS is required to employ *value adding initiatives* in its service delivery which requires input from building professionals to provide innovative approaches that can delineate and improve the quality of new and existing healthcare facilities. Perhaps, this suggests that healthcare designers, planners and researchers need to collaborate and develop strategies that can improve healthcare facilities. This research focuses on cost reduction and improved project quality through the application of BIM in healthcare facilities. This process requires the understanding of the BIM processes and implementation plans, and identifying what is achievable within a BIM environment. This can be done by distinguishing between BIM reality and BIM fantasy. There are several BIM standards within the public domain. As a result, there is a need for research scholarships to focus on issues around their feasibility, suitability and usability.

Park (2005) described a research as a process of adding new knowledge to the existing. Therefore, this research seeks to achieve new findings through the application of refurbishment, flexibility, standardisation and BIM within a change-ready healthcare facility design process. Currently, there are on-going research studies that focus on: adaptable futures; BIM; standardisation; flexibility; healthcare facilities; BIM and healthcare facilities; flexibility and healthcare facilities. The limitation of contemporary research is that the application of BIM is not currently explored in the design of a flexible healthcare facility. This research suggests innovation through the integration of healthcare refurbishment, flexibility, standardisation and BIM to achieve state of the art healthcare facility designs. This requires an innovative strategy that can create a strategic process of effectively using the four applications in order to reduce the cost of designing, constructing and operating healthcare facilities. Healthcare facility issues being addressed by the UK Government include cost, quality and functionality (BBC, 2010). Each of the four applications can individually contribute towards improving cost effectiveness, time saving and quality in healthcare. Flexibility covers areas of adaptability, convertibility, expandability, reversibility, workability and functionality. See Table 3.1. *Standardisation is not explored in the context of IFC information exchange* to focus the research on the physical space; it is explored for the purpose of this research as bench marks, specifications or quality standards that can successfully improve healthcare delivery. BIM for the purpose of this study is described as a tool, process and information manger that facilitates collaboration between project stakeholders during the delivery of a building. Simple and clear definitions of refurbishment, flexibility and standardisation are given by Oxford Dictionary, (2013):

- refurbishment is the process of renovating or redecorating (especially a building).
- flexibility is the quality of bending easily without breaking, or the ability to be easily modified, or the willingness to change or compromise; and

- standardisation is to cause (something) to conform to a standard, or adopt (something) as ones standard, or determine the property of (something) by comparison with a standard.

Knowledge from literature review was used to develop the first framework in this research. Flexibility frameworks found in existing literature have not explored the use of BIM. Therefore, the proposed framework of this study explored and established the possible application of BIM in healthcare facility design. The application of BIM in the framework focused on modelling alternative design options, analysing and evaluating the different flexible design options; and sharing new findings and knowledge. These features support the applications of flexibility and standardisation in healthcare design. The framework was developed from literature review and further revised through the use of questionnaire survey and interviews (semi-structured) with healthcare design professionals. As a result the revisions were used to present a final framework. A validation was undertaken further through an interview process (semi-structured) with healthcare design professionals, facility managers from the NHS Trust, and the Royal Institute of British Architects (RIBA) BIM working group. Semi-structured interviews were conducted to collect both statistical and in-depth data that this research can analyse.

A framework that supports the design of a change-ready healthcare facility through the use of BIM can reduce cost and improve productivity. Currently there is no framework that combines space flexibility, space standardisation and BIM within a healthcare refurbishment project. The framework focuses on refurbishment projects more closely. Refurbishment projects are currently about half of the construction projects been undertaken within the UK. It was stated by Palgrave, (2011, p. 8) "*the value of all construction work excluding maintenance in the UK in 2000 was in the region of £60 billion. Of this, approximately half was classified as refurbishment work*". It was also stated by Graphisoft, (2012) that "*renovation and refurbishment projects are nearly equal to the volume of new buildings". As* a result, this framework focuses on refurbishment projects but can be applied to new buildings. The framework elaborates and complements the RIBA Plan of Work at the critical design Stages, it can be better managed and implemented with the RIBA procedures while in-cooperating developments such as: considerations for refurbishment and reconfiguration; optimisation of flexibility; maximising standardisation; and implementing BIM. Key features of the framework are outlined below.

- it provides a guide for the combined applications of refurbishment, flexibility, standardisation and BIM. These include:
- ✓ the combined application of flexibility and standardisation;
- ✓ BIM supporting the combined application of flexibility and standardisation; and
- ✓ designing flexible and standardised facilities through BIM support within a refurbished project or new buildings.
- the framework is planned to guide the early use of flexibility concepts in healthcare facility designs;
- it provides guidance and shows the role of the architectural designer when embedding flexibility into healthcare facilities;
- it assumes the project brief is dynamic;
- it works alongside the RIBA Design Stages, with the exception of Technical Design Stages;
- it promotes collaborative project delivery processes;
- it is expected to respond to (known or expected) future changes that could be identified from evidence based design or precedent studies. For example, Lam (2008, p. 43) suggested that there should be 5-6 beds per 1000 people.
- it deals with measurable aspects (project cost, time and quality) rather than non-measurable aspects to simplify BIM integration; and
- creates the basis for developing a BIM plugin that records the decision taken for each design option at each stage of the framework process.

1.2 RESEARCH BACKGROUND

This research is focused on the use of BIM to design standardised and flexible healthcare spaces during refurbishment or new buildings. Space is a vital component in every healthcare facility; it provides the environment for healthcare services to be performed effectively and efficiently. There is a need to introduce standardisation, as it supports staff performance by specifying sizes of spaces, building elements, furniture or equipment that can simplify medical tasks. Continuous use of standardised spaces can lead to acquaintance (Price and Lu, 2012). As a result, it can gradually reduce human error. But the main question that emerges from literature is how healthcare designers manage healthcare spaces that cannot easily be standardised due to the constraints of existing structures, diversity in patient and staff needs and lack of frequent update in healthcare standardisation tools such as Healthcare Building Notes (HBN) and Activity Data Base (ADB). Different healthcare environments, such as Acute, Mental and Community hospitals have different spatial needs. The uses of generic spaces allow more flexible opportunities in the design of healthcare spaces. To achieve flexibility, the use of generic spaces and increased floor to floor height are encouraged according to Kagioglou and Tzortzopoulos (2010). This statement agrees with Wolper (2011) who suggested the use of flexible ceiling heights and generic spaces characterised with similar spaces sizes that can be later re-use for different functions to achieve more flexibility.

Funding the NHS in the UK is a major issue; the UK population is constantly growing and there is a need for healthcare facilities that can adapt to new and advance technology for the purpose of achieving more quality in service delivery. This research focuses on the key factors influencing the implementation of BIM to improve healthcare facilities through cost reduction and performance optimisation. To achieve the benefits of BIM, it has to be implemented first and the challenges associated with BIM have to be explored to make informed decisions whilst implementing it. The application of BIM can be considered to reduce project costs and time in the design, construction and facility management phase. A lot of important considerations are required when applying BIM to live projects. For example, at which phase do companies experience more profit and save more time? What are the tested and trusted BIM standards? Manning and Messner (2008, p. 279) argued that "*The missing element essential for the success of BIM is the conviction of property owners that they are not getting full value from the construction industry...some clients who use BIM successfully may not wish to share their knowledge*". With these identified gaps, there is a need to share successful outcomes with professionals in the Architecture Engineering and Construction (AEC) industry. Distinctive primary data collection was conducted to explore the methods of improving project outcomes with BIM. These include the application of BIM to design for space standardisation and embed flexibility.

1.3 RESEARCH JUSTIFICATION

In an article reported by the British Broadcasting Corporation (BBC, 2006) Bob Dredge, a programme director for financial reform of the NHS stated that *"in terms of productivity, value for money has been reduced*". The BBC (2009) also quoted Melanie Kay; the deputy director of commercial development in the Department of Health (DH) outlined some of the challenges that the NHS faces which is centred on issues of improving quality in service delivery due to vast change in population and technology. BBC (2009) also reported that Haldenby stated that "*the NHS is bleeding to death, and the time to operate is now*". Similarly, Smith (2007) declared that the "*NHS is 'failing patients' despite record funding*". According to the King's Fund and the Institute for Fiscal Studies, the NHS must prepare for shortfalls with the current financial policies. It is also stated by Strohm (2009) that "*funding crisis threatens NHS building schemes*". Purves (2009, p. 3) raised a question; he asked "*Why has the NHS concentrated on time and cost parameters for health building procurement?*" The reasons are based upon the fact that recently the UK Government is considering lowest cost tenders, and the Treasury is beginning to promote "*best value*". He also further described that the Lord Darzi`s review of health services published by the Government stated that health services will be judged based on quality. The application of BIM can contribute in reducing costs and improving the quality of healthcare facilities by virtually optimising the cost and quality of different *design options* before a suitable design is selected for construction. Manning and Messner (2008, p. 447) quoted Dauner (2004) in a study that was conducted in the United States that

> "*If collectively the healthcare industry (owners, planners, designers and contractors) can optimise the current process to effectively reduce cost by even a minimum of one percent, there is a potential to save $100`s of millions in facility capital investment. One percent alone in California`s projected 10 years healthcare facility capital investment would save approximately $300 million*".

The importance of BIM in healthcare is not different from any other AEC Industry, but healthcare facilities are complex due to their multi-tasking capability, capacity and quality of healthcare delivery required by patients. This include the 24 hour round the clock services of healthcare services which makes them heavily serviced with Mechanical, Electrical and Plumbing (MEP) amenities. But the main problem associated with the application of BIM in the AEC is the distinct lack of common standards in its implementation across the industry. The absence of a generalised standard limits the wider adoption of BIM. BIM standards are being produced by different organisation for different purposes. Howard and Bjork (2008, p. 74) argued that *"many standards relevant to BIM exist but it was suggested that there is a lack of a framework into which they could fit*". Reducing project cost and time can be achieved within the different stages of a building`s life cycle while designating high priority to project quality. To achieve the benefits of BIM, it can be used as a decision support tool, a modelling tool, and an activity that supports stakeholder collaboration. It is very important to adopt BIM for the design, construction and facility management of healthcare buildings.

1.3.1 THE NEED FOR REFURBISHMENT IN HEALTHCARE

The UK Construction Strategy (2011, p. 5) observed that "*the public sector has a relatively small new build programme (£4bn) compared to repairs and maintenance (£10bn)".* It was stated by Palgrave, (2011, p. 8) that approximately half of construction work taking place in the UK was classified as refurbishment work. It was also stated by Graphisoft, (2012) that refurbishment works are almost equal the sum of new projects in the UK. EC Harris (2013, p. 4) stated that "*in 1995 around 50% of the estates was built pre 1948,…The trend over the most recent four years saw a radical improvement with more than 35% of the NHS estate now at 17 years old or less*"; from 2008-2012 NHS estates have been improving. The aim of refurbishment is to improve the existing conditions of healthcare buildings. Ali (2010) believed that the collaboration of contractors and sub-contractors with the design team during the analysis process increases the quality of healthcare facilities. With increasing concerns regarding the sustainability of existing facilities and facility whole life cycle costs, researchers and healthcare planners are being encouraged to provide innovative means of improving these facilities. The refurbishment process of healthcare buildings varies; which could depend on the nature of the problem or the culture of responsible organisations such as the NHS trusts. Refurbishment is vital to the development of a facility over time, especially from a sustainability perspective; it involves reconfiguring, recycling, modifying, extending, contracting and re-planning existing spaces to meet performance targets such as carbon reduction and ability of the facility to adapt to changes, and to achieve preferred quality outcomes that will enable the facility to function effectively. These include the need to achieve user essentials and desirable healthcare standards. Refurbishment can also be undertaken to save time and cost. For example, the high running cost of a facility, can lead to refurbishment. It might be cheaper to refurbish it with double glazed windows and revolving doors than to continue operating and maintaining the facility in its current state. Refurbishment is also required to improve interior and exterior functions such as, indoor air quality and natural lighting. Sheth (2010a) categorised the need for healthcare refurbishment into three drivers: user drivers; construction drivers; and future drivers. Appendix 1: Ahmad *et al.*, (2011) have modified the needs for refurbishments to include: space design drivers; building structure drivers, and facility management drivers.

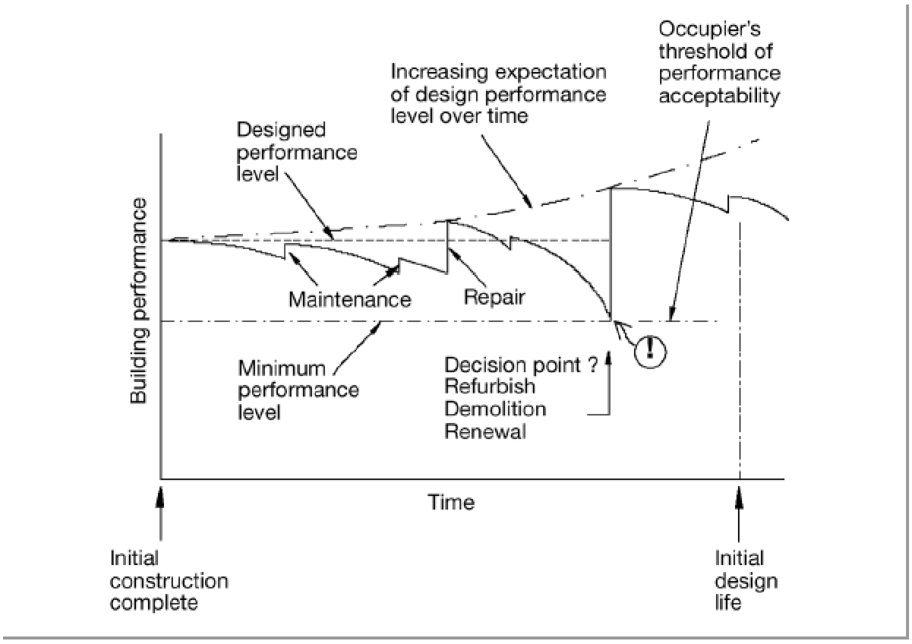


Figure 1.1: *The Life cycle of a building. Source: Palgrave (2011, p. 6)*

Figure 1.1 describes that different building performance levels can be achieved with different improvisations over a building`s life time. Three levels of facility performance are described by Palgrave (2011). These are identified in a hierarchy order starting with the least effective improvisation. These include the process of maintenance, repairs and refurbishment. With the required level of maintenance over the years of facility use, the life span of a building can be increased. Performance of a facility can be more improved with adequate repairs. The process of refurbishment enables a much higher improvement through structural modifications in an existing facility. It can also be noted that during the operational use of a facility, it has to tackle the problems of an ageing and growing population, advancement in treatment and care, and the use of modern technology. The need of healthcare facilities certainly changes over time. In these cases, the facility is expected to respond to changes through the process of adapting, expanding or contracting. Findings from this research were used to present a guide for generating flexible designs through the use of a framework that can guide healthcare designers and planners to design healthcare facilities with cost effectiveness and project quality as the main project goals.

1.3.2 THE NEED FOR FLEXIBILITY IN HEALTHCARE

Flexibility is described in this study as the ability to change or adjust when the need arises. Flexibility can be embedded into a new or existing healthcare building. It is required in healthcare as it allows care to be taken directly to patients through the use of universal spaces, reducing both travelling distance and possible patient handling errors. It also creates an alternative option for a facility to consider when there is change in function, capacity, flow or pattern of system delivery. Flexibility supports buildings to adapt to changes in healthcare. For example, changes caused by a growing and ageing population or due to technological innovation in medical treatment and equipment. Flexibility allows buildings to perform effectively when changes arise, to increase the value of a facility over time. The Department of Health (2010-2015, p. 10) stated that when a facility is empowered by flexibility then "*annual savings of up to £1.8billion are achievable*". Pommer *et al.* (2010, p. 1383) 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.* (2007, p. 155) 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 life span has not reached its peak level. These are mostly caused by changes in demographic, operational running cost, technological hospital demands, operational and functional spaces requiring constant attention over the life span of the facility. See Fig 1.1 above. Repudiating these factors in a given healthcare facility tend to reduce its life span by increasing operational cost causing early re-construction, re-development or large scale refurbishments. Adams (2008, p. 121) imagined that a flexible hospital could be designed today but be used for a different function in the future. Intelligent spaces that can adapt to increase in population and facility capacity are one of the factors that initiate flexibility to take place in the future. Both growth and flexibility require space, but growth is considered as one of the major drivers for flexibility; it requires more space to accommodate changes in demography with increased capacity requirements. While flexibility requires space to be organised and designed to adapt to different activities without compromising productivity or creating unused spaces that could be functional in the near future. Standardisation can allow the continuous application of flexibility. However, they could be at two extreme ends, but are interrelated. The section below addresses the need for standardisation in healthcare.

1.3.3 THE NEED FOR STANDARDISATION IN HEALTHCARE

This study deals with standardisation in the context of size, layout, arrangements, patterns, specifications and standard space requirements of components such as furniture, equipment and services. According to Reiling (2007) standardisation routine or standard size specifications are important; it improves the safety of both patients and staffs. The use of standardised layout can reduce the possibility of errors occurring during healthcare delivery. He also reported that the human brain creates patterns which work subconsciously; standardisation helps these patterns work perfectly over time. Non standardisation leads to thinking consciously which can lead to exhaustion, weariness and human error. Nevertheless, specifications that do not simplify given tasks can hinder the ability to focus on imaginative problem solving. Standardised specifications can easily be analysed and evaluated for possible improvements, but simplification is important (Price and Lu, 2012). When human error is reduced in healthcare delivery, optimum performance can be achieved. The Joint Commission Resources (2004a) stated that in the manufacturing industry, the management creates possible strategies of reducing errors to achieve more productivity by simplifying a process. This can be conducted in a healthcare environment by using successful and appropriate specifications that the average user can easily put to practice. Standardisation creates the ability to always automate an activity due to the continuous use of a procedure. A predictive and simplified process can be achieved within a standardised space reducing fatigue or any possible disruption to optimise the quality of healthcare delivery enabling staff to focus on clinical issues. It can help staff adapt to healthcare delivery by providing standards that are simplified, desired and preferred. Standardisation for the purpose of this research is considered as space layout, sizes, specification or requirement; there is a need to manage this information (Price and Lu, 2012). BIM is used to manage the information used in a given healthcare facility. For the purpose of this research, the application of BIM is suggested to support the use of flexibility and standardisation through integration, management and collaborative analysis of healthcare spaces within a virtual environment to produce effective and efficient spaces that are virtually evaluated before constructed.

This study focuses on refurbished buildings compared to new builds as new healthcare facilities should embed flexibility as a primary objective (Neufville *et al*. 2008). However, an opportunity for the proposed framework to respond to new builds is a bonus to the contribution of this study.

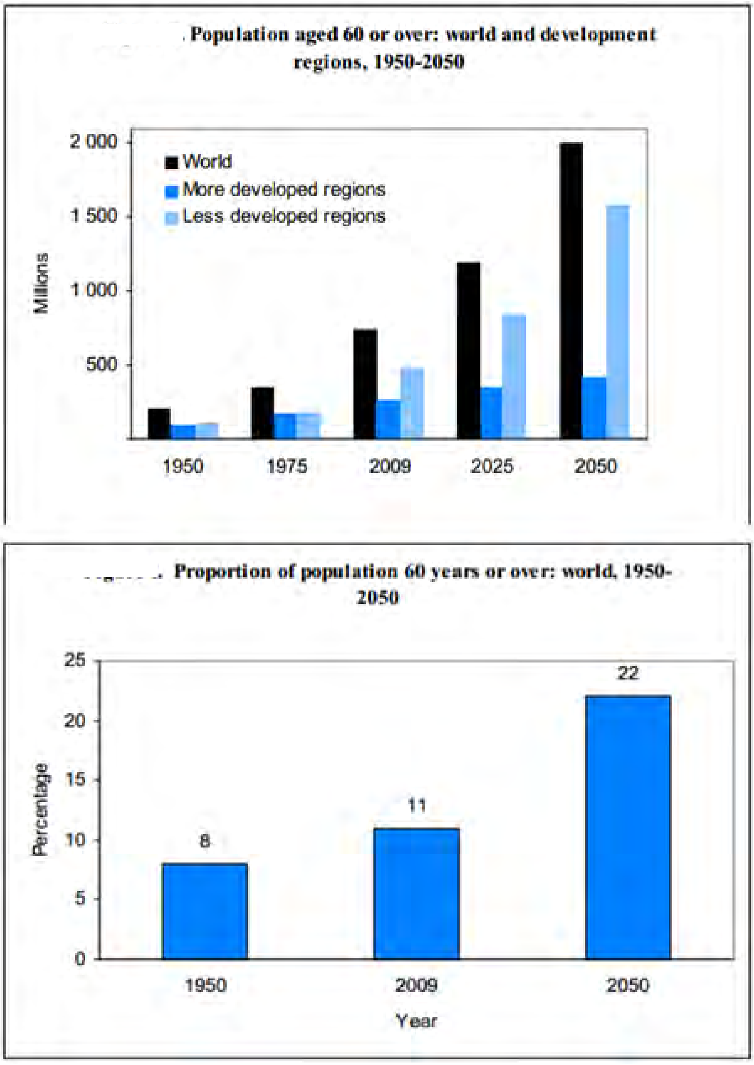
1.3.4 THE NEED FOR BIM IN HEALTHCARE

As previously stated, the NHS must prepare for shortfalls with the current financial policies. In Sullivan (2007, p. 194), Douglas Fitz Patrick, a managing member of Fitzpatrick Engineering Group is quoted as saying "*I don't know how you`d design and build a medical facility without using BIM*". The issue of cost and quality can be achieved through the use of BIM. Over the years, cost reduction and value for money has been the major topic of discussion, especially in the healthcare sector. The Construction User Roundtable (CURT, 2004) stated that when issues of cost and time arise in building projects, building professionals tend to use new methods and tools. Perhaps the use of BIM can be a new approach towards achieving quality in healthcare. BIM is used in the design, construction and facility management of healthcare facilities to reduce costs and save time within a building`s life cycle. It can be used as an information manager, a modelling tool or an activity/process. The issues stated above show that the NHS requires costs savings and time management, the more the time the more the project cost. Hence, there is a need to provide more value for money and increased productivity in NHS projects. BIM is used to produce a virtual model in real time, showing how staffs and patients interact within a facility; this will help to visualise the operational flow of a facility through walk-through simulations. Chellappa (2009, p. 29) described three important features of BIM in healthcare. These include: phasing; prototyping; and application of baseline model. Phasing can be described as the process of forecasting the development of design projects and their schedule from inception to completion. Prototyping with BIM allow different healthcare spaces to be stored and organised throughout the facility`s life cycle. Baseline model shows the connection between a completed construction project and a possible future renovation. Perhaps a baseline model can be used for future design work or a folder for future work analysis. Healthcare facilities are frequently under renovation, extension, alteration or development in the UK. About 50 percent of facilities are undergoing refurbishments (Palgrave, 2011). Some of these refurbishments take place while the facility is operational. BIM can be used to analyse the movement of occupants while the hospital is virtually operational to spot major obstacles during the project execution; it can also be used as a library for healthcare design information. Levy (2009) views the emergence of BIM as a key innovation which will undoubtedly become main stream in architecture, and amaze potential clients. Perhaps clients like the NHS will take full advantage of BIM as the UK Government cuts spending in the different sectors of the country's economy. BIM can support the applications of flexibility and standardisation within a new or refurbished project through the process of organising both flexibility and standardisation data. It can also be used to generate different flexible options that can be tested with 3D simulations to visualise possible changes, solutions, standardised patterns and so on.

1.4 PROBLEM IDENTIFICATION

This research focuses on exploring the designer's role and key factors that could guide healthcare designers and planners when optimising space flexibility and space standardisation during healthcare refurbishment through the application of BIM. World Population Ageing (2009) stated that the ageing and growing world population is expected to double between 2009 and 2050, as presented in Figure 1.2. Key Statistics on the NHS (2010) showed that the UK population is expected to project from an estimated 61.4 million in 2008 to 71.4 million in 2033, and the NHS deals with over 1 million patients every 36 hours. Similarly there are more aging people who need better designed facilities. The NHS net expenditure has increased from £34.7 billion in 1997/1998 to £98.3 billion in 2009/2010, and the planned net expenditure of 2010/2011 is projected at £102.3 billion due to population and technological advancement needed in the NHS. New and refurbished healthcare facilities need to be flexible and adaptable; there are a high number of out-dated hospitals in the UK. This reduces the quality and standard of healthcare facilities, and will make it difficult for staff and medical professionals to conduct their various tasks efficiently and effectively, autonomously affecting the quality of treatment provided to patients by healthcare staff.

The UK BIM mandate addressed in the UK Construction Strategy (2011) shows the need for BIM in future healthcare projects. Arguably, the most common achievement of applying BIM in any project is the opportunity to gain more productivity in working and achieving desired project outcomes. As a result, this study needs to address how BIM can be applied in the proposed framework.


Population aged 60 or over: world and development regions, 1950-2050

Proportion of population 60 years or over: world, 1950-2050

Figure 1.2: *A growing and ageing population. Source: World Population Ageing (2009)*

BBC (2010) described the views of Triggle, who stated that:

- in total, 17% of the NHS estates being used are deemed to be not up to scratch;
- the figure includes 33 hospitals that have at least half of their estates below standard;
- there are more than 100 other sites - mainly Community hospitals and Mental health units that have 50% or more of their estate not up to scratch;
- part of the problem is that a large chunk of the NHS estate, nearly a fifth dates back to before the creation of the NHS in 1948;
- the NHS estates classed as not suitable had design functionality problems; and

- nearly a fifth of facilities in use in England are deemed not up to scratch.

BBC, (2010) quoted Mark Masters, "*the hospital's director of estates and facilities, said it means staff are left to do their best in these circumstances*". Purves (2012, p. 52) stated that "*Government procurement methods must enable future buildings to be flexible shells within which highly serviced work stations can be developed and changed over a short periods of time*". Pommer *et al.* (2010) described that healthcare facilities needs to adapt to future changes in order to function effectively. Brothers *et al.* (2007, p. 155) stated that flexibility should be the cornerstone of the design of healthcare facilities as it allows facilities to grow and expand when the need arises. For example, when it is required to make functional changes within a facility, an upgrade might be necessary. McCullough (2009, p. 57) quoted Eileen Malone (2007) that improving quality, safety and flexibility in healthcare facilities are part of the five Evidence Based Design (EBD) principles defined by Miller (2006, p. 140). He also quotes Mortland that clinical laboratories are changing frequently; most laboratories are expected to accommodate new equipment or technologies frequently. Carthey *et al.* (2010, P. 111) quotes Pressler (2006, p. 53) who stated that a good hospital design should have an adequate amount of flexibility. McCullough (2009, p. 222) noted that future flexibility is important and essential for the long-term viability of healthcare institutions. Pati and Harvey (2010) stated that healthcare facilities more than occasionally need to be adjustable for changes in operations, equipment and management. Sheth *et al.* (2010) also noted that storage space, flexibility and adaptability are used in building flexibility into healthcare facility to respond to future changes; this could help save costs and improve quality. Lam (2008) was of the view that healthcare facilities have life span of 30-60 years, and without design flexibility they could be functionally superseded.

This study presents the problems that need to be addressed within the UK`s healthcare sector. Some of the major problems currently faced by the NHS include: the UK Government policies on national budgets to cut deficits which include the Department of Health and by extension NHS budget cuts/savings. These difficulties resulted in NHS spending cuts. Therefore, the NHS has to deal with a rapid ageing and growing population which requires funds to tackle. All the problems identified and addressed by this research are presented with references from Journals and Conference Papers, Books and UK Government websites. The problems are presented in Table 1.1 Hypothetical solutions are prescribed to address the problems identified.

Table 1.1: *Problem statement*

PROBLEMS	REFERENCES	YEAR	HYPOTHETICAL SOLUTIONS
One fifth of NHS Estates, (20%) predates the NHS.	BBC,	2010	Use of flexible spaces. Use of standardised spaces. Use of BIM. Use of healthcare refurbishment.
NHS estates are underutilised, with unused space the size of London Hyde Park.	EC Harris	2013	
Aging population needs a flexible healthcare space.	Key Statistics on the NHS,	2010	
Growing population needs an adaptable healthcare space. (Changing demography).	Key Statistics on the NHS, Chefurka *et al*.,	2010 2005	
Rapid changing healthcare delivery needs to adapt to the changing technology.	Hei, Reiling, Joint Commission Research, Miller, Chefurka *et al*.,	2008, p. 120 2007 2006 2006:140 2005	
There is a UK Government BIM mandate by 2016.	NBS National BIM Survey,	2012	
There is a UK Government proposal set out that "requires the delivery of £15-20 billion in efficiency savings over the three year period from 2011"	Department of Health,	2010-2015, p. 10	
They stated that "In a report, NHS England warns that by 2020-21 the gap between the budget and rising costs could reach £30bn".	BBC,	2013	
Cost of managing facilities is a times (3 times) the first premium cost of building over 50 years of operation.	Battisto and Allison,	2002, p. 4	
"In terms of productivity, value for money has been reduced" (BBC, 2006) Cost reduction in healthcare facility and more value for money is required.	Purve,	2009	
The Treasury is beginning to promote "best value"; and Lord Darzi's review of health services published by the UK Government stated that health services will be judged based on quality.	BBC,	2006	

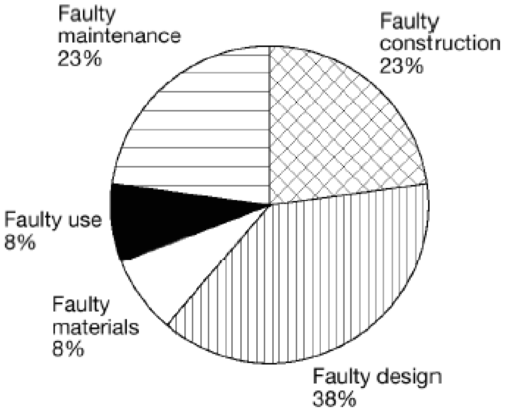


Figure 1.3: *Causes of failure of buildings. Source: Palgrave (2011, p. 13)*

Figure 1.3 shows design fault as the major factor causing building failures. For example, designs with poor ventilation, circulation spaces or unsuitable working spaces. This implies that the design stage is an integral part of the building process. As a result, this research is focused on the design process identified within the RIBA Plan of Work 2007 and 2013. This research also explored the application of refurbishment, flexibility, standardisation and BIM in the Design Stage.

1.5 IMPORTANCE AND PURPOSE OF RESEARCH

The importance of this research will not only be the impact of BIM, flexibility and standardisation in healthcare facilities, but also the lessons learnt. These are carefully presented in chapter 9. This research is important, mainly for cost reduction, increasing the quality of healthcare facilities to respond and produce guidance for healthcare designers and planners to design a change-ready healthcare facility that can adapt to future challenges of modern healthcare delivery.

1.5.1 THE MAIN DRIVERS AND REASON FOR THIS RESEARCH

The main driver for this study is to respond to future challenges of healthcare facilities caused by change in function, flow and capacity. This research is important for professionals who are engaged in the design of healthcare facilities for the following reasons:

- require ways of improving quality in healthcare environment;
- interested in exploring the importance of BIM in healthcare facilities;
- in need of a framework that can suit different companies with different goals and targets;
- need to effectively organise design information; and
- for exploring and identifying methods of producing a change-ready healthcare facility.

1.5.2 THE SCOPE OF THE RESEARCH

This research focuses on the AEC industry professionals such as healthcare designers and planners. Facility managers can also benefit from the conceptual framework designed for adapting future changes. Input from facility mangers is designed to be collected and analysed within the proposed framework for designing a change-ready healthcare facility. Flexibility is effectively embedded into a facility at the early design stages. Flexibility could be active or switched on years into the operational life of a facility. Therefore, it would be important for the facility team to understand *how* and *when* a facility is supposed to respond to changes within the life span of a facility. Nevertheless, this research is centred on guiding healthcare designers and planners. It explores and prescribes guidelines that could enhance the development of healthcare facilities in the UK. Perhaps the NHS could be the main achiever of the successful outcome of this research.

1.6 RESEARCH QUESTIONS

Research questions used sequentially within this research are presented below. The questions were generated from literature review and were further developed through a desktop study to produce a framework that can guide healthcare designers and planners to design a change-ready healthcare facility that responds to future challenges. Specific questions were also used in a questionnaire survey and interviews to further develop the framework in order to reduce cost and improve project quality. Research questions were developed for the four different applications.

1.6.1 REFURBISHMENT IN HEALTHCARE

Healthcare facilities need to be improved due to their rapid changing nature; they could be improved through renovating, decorating, relocating, converting, contracting, expanding or adapting to changes. Refurbishment is an opportunity to enhance the current and existing situation of a facility when the need arises. Refurbishment arises after a robust analysis of an existing project, a decision is made to either abandon or refurbish at a minor, average or major level depending on the feasibility of the analysis conducted. BIM can also be used to reduce design effort during the refurbishment process through the use of existing model information.

Research question 1 category: How can refurbishment increase the value of a facility?

- How can refurbishment allow flexible opportunities in a facility?
- How can healthcare designers and planners combine the application of flexibility and standardisation and BIM within a refurbishment process?
- What is the most effective refurbishment method that can deliver desirable project outcomes?

1.6.2 THE APPLICATION OF FLEXIBILITY IN HEALTHCARE

There is an argument on the relationship between flexibility and cost reduction. Flexibility is understood by Neufville and Scholtes (2011) to reduce the cost of designing healthcare facilities, while it is agreed by many of the interview respondents in chapter 7 to increase the cost of building a facility. There is a need to explore the applicability, benefits and challenges of flexibility to be able to embed it effectively into a healthcare facility. There are also different classifications and approaches towards the application of flexibility. Perhaps there is a need to explore the application of flexibility from precedent studies.

Research question 2 category: How can Flexibility improve the quality of a facility?

- How do designers in-corporate flexibility into a facility?
- What are the most important considerations when embedding flexibility within a facility?
- What is the impact of standardisation on the ability to design flexible spaces?

1.6.3 THE APPLICATION OF STANDARDISATION IN HEALTHCARE

Healthcare facilities need standardised applications, spaces, equipment, furniture and so on to function in a successful, efficient and effective manner that would continue to improve the quality of services, staff and patient experience. Standardisation is explored in this research to reduce cost and increase the value of healthcare facilities.

Research question 3 category: How does standardisation impact healthcare facility design?

- What are the drivers and barriers to achieving standardisation in healthcare?
- What is the most effective standardisation approach when designing a facility?

1.6.4 THE APPLICATION OF BIM IN HEALTHCARE

BIM is suggested to aid the process of cost control when designing facilities, but Eastman *et al.* (2011) stated that BIM is understood differently by different people. Therefore to understand the application of BIM in all sectors including healthcare, certain questions were presented in preliminary questionnaires survey and interviews, and in a further questionnaire and interview that was later conducted to explore practical strategies of improving quality of healthcare facilities through the combined applications of flexibility, standardisation and BIM within a newly built or refurbished project.

Research questions 4 category: how can BIM aid in designing healthcare facilities?

- How can BIM support the process of embedding flexibility within a healthcare facility?
- How can BIM support the use of standardisation within a flexible space?
- Are there any special features of BIM in healthcare?

1.7 AIM AND OBJECTIVES

This research is focused on guiding healthcare designers to identify design roles and best practices for creating flexible and standardised healthcare spaces that could improve healthcare delivery by adapting to changes such as the changing demography and technology advancement in treatment and equipment through the development of a change-ready healthcare facility.

1.7.1 AIM OF THE RESEARCH

The overarching aim of this research is to develop a framework by exploring the key factors that could guide healthcare designers and planners when embedding space flexibility and standardisation within a healthcare refurbishment projects through the application of BIM to achieve a change-ready healthcare facility.

1.7.2 OBJECTIVES OF THE RESEARCH

Six objectives have been identified to achieving the research aim. These are:

1. to understand refurbishment, flexibility, standardisation and the application of BIM within a healthcare environment;
2. to explore the challenges of BIM in the design of a flexible and standardised healthcare facility;
3. to examine a strategic and effective process of applying refurbishment, flexibility, standardisation and BIM in healthcare;
4. to identify how healthcare designers in-corporate flexibility in healthcare facilities effectively with BIM;
5. to develop a framework for designers to produce digital flexible and standardised healthcare refurbishment realities using BIM; and
6. to validate the framework.

Table 1.2 outlines the research objectives used to achieve the aim of this research; the methodology employed for each objective; the research activities undertaken; and the expected research outcomes.

Table 1.2: *Research aim and objectives*

<table>
<tr><td colspan="5">Research aim: To develop a framework by exploring the key factors that could guide healthcare designers and planners when embedding space flexibility and standardisation within a healthcare refurbishment project through the application of BIM to achieve a change-ready healthcare facility.</td></tr>
<tr><th>Objectives</th><th>Research Methodology</th><th>Research Activities</th><th>Research Outcome</th><th>Chronology</th></tr>
<tr><td>To understand and explore:
refurbishment, flexibility, standardisation, and the application of BIM in the AEC industry; and
Explore the need for flexibility, standardisation and BIM, within healthcare refurbishment.</td><td>Robust literature review.
Use of preliminary questionnaire and interviews.
Use of secondary data.</td><td>Establish the context of research.
To identify different flexibility processes.
To explore the impact of flexibility, standardisation and BIM on cost reduction and healthcare refurbishment.</td><td>(First year report)
(Paper 1): Impact of Space Standardisation and Flexibility on Healthcare Refurbishment.</td><td>Feb, 2011
November, 2011.</td></tr>
<tr><td>To explore challenges of BIM in the design of a flexible and standardised healthcare facility. These include:
Selecting a BIM implementation plan.
The impact of BIM tools on design creativity when designing a facility.</td><td>State of the art literature review.
Desktop study,
Questionnaire survey.</td><td>Comparative analysis of different BIM implementation plans.
To generate a framework from literature (desktop study).
To explore the relationship between BIM tools and design creativity.</td><td>(Paper 2): A Comparative Analysis of Building Information Modelling Implementation Plans.
(Second year report)
(Paper 3): Creativity with BIM Tools.</td><td>May, 2012
April, 2012
August, 2012</td></tr>
<tr><td>To examine an effective and strategic process of applying refurbishment, flexibility, standardisation and BIM in healthcare.</td><td>Use of secondary data.</td><td>To explore a connective strategy for integrating refurbishment, flexibility, standardisation and BIM in healthcare.</td><td>(Paper 4): Impact of Space Flexibility and Standardisation on Healthcare delivery.</td><td>Sep, 2013</td></tr>
<tr><td>To identify how health designers effectively in-cooperate flexibility and standardisation in healthcare refurbishment with BIM.</td><td>Questionnaires
Interviews</td><td>To develop the framework from literature review using questionnaires.
Identify the opinion of BIM users on the use of BIM and flexible healthcare facilities.</td><td rowspan="2">(Paper 5): designing virtual flexible healthcare space realities within a BIM environment.</td><td rowspan="2">Sep, 2013.</td></tr>
<tr><td>To develop a framework for designers to produce digital flexible and standardised healthcare refurbishment realities using BIM.</td><td>Interviews.</td><td>Analyse methods of evaluating flexible design options with BIM.</td></tr>
<tr><td>To validate framework.</td><td>Validation using focus group/ interviews.</td><td>Validating the framework.</td><td>PhD thesis.</td><td>Aug, 2013.</td></tr>
</table>

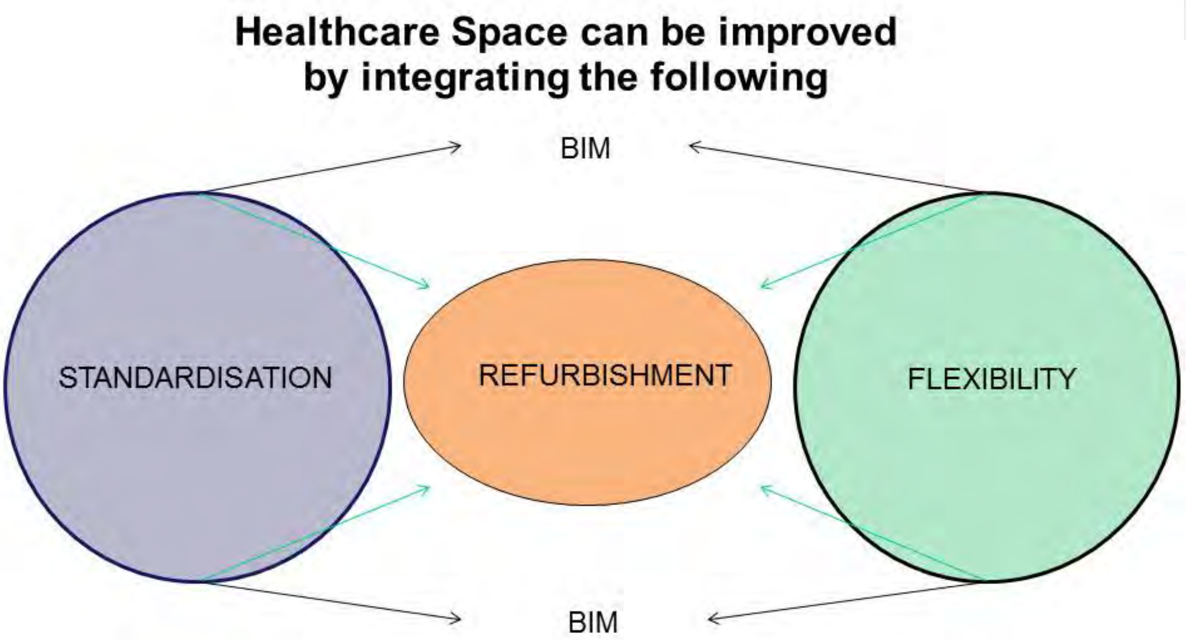


Figure 1.4: *The combined applications of flexibility and standardisation within a refurbishment project through the use of BIM in healthcare*

Figure 1.4 shows a conceptual approach that was generated at the early stages of this research. The strategy was to apply standardisation and flexibility into the refurbishment process through the application of the BIM. The main challenge was to find a relative plan that links all processes coherently; cost reduction and achieving quality were key themes that linked the processes together, but to link them technically, innovative steps towards their various applications were considered. Figure 1.5 presents the overlapping order of the four applications used in developing the framework, and it helps to understand their combined application presented in Figure 1.4.

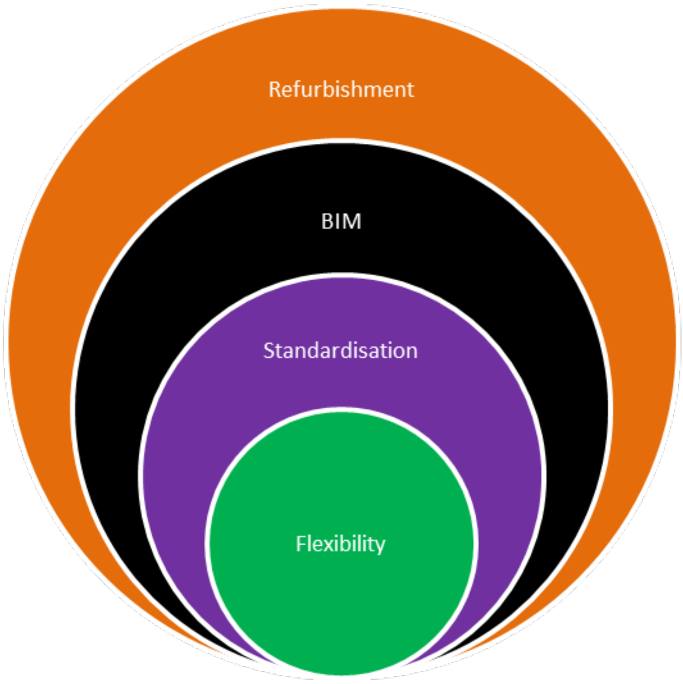


Figure 1.5: *Overlapping of the framework components*

1.7.3 RESEARCH SCOPE, TARGET AND OUTPUT

The research target was to generated one final framework, which went through some iteration. The final one is the only important one. A total of four frameworks were refined: from robust desktop analysis of current literature; from questionnaire survey; from interviews; and from validation interviews. It was important to have the basis of the framework from literature which was further developed through questionnaire survey and interviews to achieve the aim and objectives of this research. Questionnaire surveys and interviews were required as no research has clearly combined refurbishment, flexibility, standardisation, and the application of BIM together for the sole purpose of cost reduction, productivity and improving quality of healthcare facilities. Table 1.3 was used to illustrate the relationship between the objectives and the outputs of this research. Table 1.4 shows summary of peer-reviewed journals and conference papers that have been either published, accepted for publication, drafted or under review. The papers span across the broad topics of healthcare refurbishment, flexibility, standardisation and BIM. Appendix 11 defines some important terminologies used in this study.

Table 1.3: *The relationship between the research objectives and the research tasks*

Process	Research tasks	Objective 1	Objective 2	Objective 3	Objective 4	Objective 5	Objective 6	Conference	Journal	PhD Thesis
Exploration	Establish the context of the research.	x								X
	Identify the different flexibility processes.	x						x		X
	Explore the impact of flexibility, standardisation and BIM on healthcare and cost reduction.	x						x		X
	Comparative analysis of the different BIM implementation plans.		x					x		X
	To explore a connective strategy for BIM, flexibility, standardisation and healthcare refurbishment.		x						x	X
	Generate a framework from literature using desktop study.		x						x	X
	Explore the opinion of BIM users on: tools that could hinder design creativity; and standards that can affect flexibility.			x				x	x	X
Conceptualising	Revise the framework generated from literature review using questionnaire survey.			x					x	X
	Identify how BIM users: Apply BIM with flexibility; Combined the application of standardisation and flexibility.				x				x	X
	Revise the framework generated from literature review and questionnaire survey using interviews.				x				x	X
Application	Analyse methods of evaluating flexible design options with BIM.					x			x	X
	Validating the framework.						x		x	X

Table 1.4: *List of peer-reviewed papers*

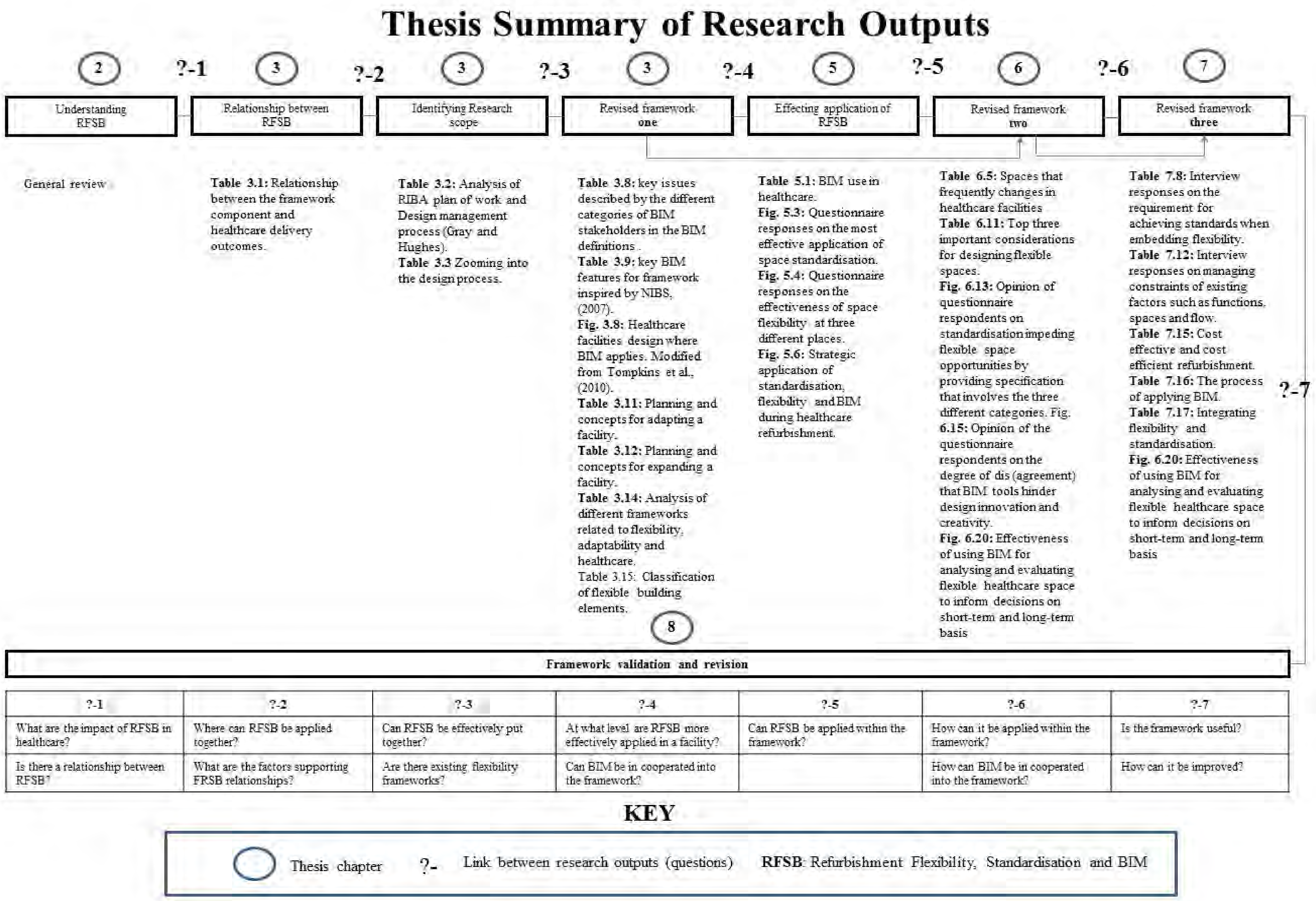
Paper ID	Title	Journal/ Conference	Description	Status
Paper 1 –Appendix	BIM Implementation Plans: A Comparative Analysis	Proceedings of the Association of Researchers in Construction Management (ARCOM) Conference, 2012	A literature review was conducted and 15 different definitions of BIM were encountered. 12 different BIM implementation plans were found in publications by academics, software vendors and Architecture/Engineering/Construction (AEC) industry professionals. Those implementation plans were compared using a matrix which covers the complete building lifecycle.	**Published**
Paper 2 Appendix	Space Standardisation and Flexibility on Healthcare Refurbishment	Proceedings of the Open Building Conference, (2011)	Standardisation can and should be used to improve efficiency and reduce errors, it has been implemented in many manufacturing processes such as the automobile industry, but the question is how will it impact buildings especially existing healthcare spaces? This paper is aimed at identifying the impact of space standardisation and flexibility on healthcare refurbishment.	**Published**
Paper 3 Appendix F	Creativity with Building Information Modelling Tools	First UK BIM Academic Conference, (2012)	A literature review was used to identify the benefits and constraints of BIM tools on design creativity; a questionnaire survey was used to verify its impact. A questionnaire survey was conducted with the top 100 UK architectural firms (group one) and CNBR Yahoo Group (group two).	**Published**
Paper 4 – Appendix	Creativity with Building Information Modelling Tools	International Journal of 3D Information modelling (IJ3DIM)	A literature review was used to identify the benefits and constraints of BIM tools on design creativity; a questionnaire survey was used to verify its impact. A questionnaire survey was conducted with the top 100 UK architectural firms (group one) and CNBR Yahoo Group (group two). ***Conference version.***	**Published**
Paper 5 – Appendix	Impact of Space Flexibility and Standardisation on Healthcare Delivery	Journal of Architecture Engineering and Design Management (AEDM)	An important question emerges relating to healthcare facilities: how does standardisation and flexibility impact healthcare staff workflow and patient care? It is important to apply them simultaneously in the physical space, as they both improve efficiency in healthcare delivery. This paper aims to identify the impact of space standardisation and space flexibility "*space attributes*" on healthcare delivery.	**Accepted**
Paper 6– Appendix	Using BIM to Design Flexible Spaces and Apply Design Standards in Healthcare Facilities	Journal of Engineering Construction and Architecture Management (ECAM)	A questionnaire survey and interview was used to collect primary data on the application of BIM in the design of flexible spaces, BIM users, healthcare architects and planners were selected as the questionnaire respondents. This paper forms the basis to design a change-ready design framework. ***This paper was collaborated with a colleague.***	**Draft**

1.8 OUTLINE RESEARCH METHOD

Exploring success with BIM is a management matter. The process of embedding flexibility into a facility is also a management issue. The project management team makes decision on the application of adaptable future approaches to cut costs and improve the quality of a facility. As a result, their input is required at early design stages. Therefore, management research method is adopted for the purposes of this research. To understand management research Gill and Johnson (2010) suggested seven principles which include: identifying a broad area of interest; selecting a topic and developing a focus; deciding the approach; formulating a plan; collecting information; analysing data; and presenting of findings. The research process is clearly discussed in chapter 4.

To develop the framework, three different frameworks were developed using three different research methods to generate a final framework that is comprehensive. The first framework was developed from (literature review analysis). The impacts of refurbishment, flexibility, standardisation and BIM in healthcare were explored. There was a need to explore existing frameworks, principles and approaches used in designing healthcare facilities. A framework was developed using these findings. The applications of flexibility and standardisation have already been applied in existing frameworks. The second framework was developed through (questionnaire survey with architectural practices). It was important to verify that it was feasible to apply BIM within the framework developed from literature review using statistical data. The three applications are designed to be applied within refurbishment. The first question that was raised is at what level are flexibility, standardisation and BIM more effective during the different scope of works conducted during healthcare refurbishments? The second question; can more applications be used in the design of a change-ready healthcare facility? The third question; what are key considerations when designing flexible spaces with BIM. Questionnaire surveys are fast and easy to collect primary data that this research can analyse at the early study stages. The third framework was a development of the framework generated from both literature review and questionnaire survey; interviews findings from architectural practices were used in the development process in order to provide in-depth data on how the four applications can be managed. Finally a validation (interview was conducted with architectural practices, facility managers and the RIBA). Interviews were conducted in order to verify the usefulness of the framework and provide useful data that can improve it.

……………..



?-1	?-2	?-3	?-4	?-5	?-6	?-7
What are the impact of RFSB in healthcare?	Where can RFSB be applied together?	Can RFSB be effectively put together?	At what level are RFSB more effectively applied in a facility?	Can RFSB be applied within the framework?	How can it be applied within the framework?	Is the framework useful?
Is there a relationship between RFSB?	What are the factors supporting FRSB relationships?	Are there existing flexibility frameworks?	Can BIM be in cooperated into the framework?		How can BIM be in cooperated into the framework?	How can it be improved?

Figure 1.6: Thesis summary of research output

1.9 THESIS STRUCTURE

This section shows academic research work conducted over a three year period. It covers the entire first, second and third year research activities with details such as research aim and objectives, research methods and methodology, literature review, primary data results and conclusions. This section also presents the organisation of the primary data collected for the purpose of this research. These include exploratory preliminary questionnaire and interviews conducted with fellow researchers at the School of Civil and Building Engineering (Research Hub) Loughborough University; main questionnaire surveys and interviews conducted with architectural practitioners and academics from the built environment; and a validation interview that was also conducted with architects, RIBA BIM working group and the NHS Trusts; all within the UK. A brief description of each chapter is presented below.

Chapter 1 introduces the main themes and justifies the logic behind this research. The aims and objectives of this research were clearly described, stating the importance of the research and justification for the research.

Chapter 2 presents an extensive literature review on the application of refurbishment, flexibility, standardisation and BIM in healthcare facilities. The four applications are very broad. Therefore, their definitions, challenges and applications in healthcare were described.

Chapter 3 presents a systematic review of literature for the purpose of developing a framework.

Chapter 4 illustrates the ontological, epistemological and empirical features relevant to this research. This chapter also describes the methodological consideration applied to achieve the aims and objectives of this research.

Chapter 5 describes the findings from three different sources, which include: a preliminary questionnaire, a preliminary interview; and analysis of secondary data (HaCIRIC team). They were used to develop a strategy for combining the four applications.

Chapter 6 shows the findings from a questionnaire survey which was conducted with two different samples which include: the top 100 UK architectural firms, and a Web Based Group. The findings were used to develop the framework previously generated from literature review analysis in chapter 3.

Chapter 7 demonstrates findings from interviewees; Findings from the interviews were used to develop the framework generated from both desktop analyses of literature review and questionnaire survey findings (chapters 3, 5 and 6).

Chapter 8 illustrates the systematic and systemic development of the framework. The validation process and suggestions from the interviewees to further develop the framework.
Chapter 9 discusses the research findings of research methods and questions. The contribution of this research to knowledge was outlined. Areas of future research and limitation of this research were presented.

1.10 CHAPTER SUMMARY

The UK population is growing; there is a need for novel and advance technology to provide state of the art healthcare facilities that can adapt to future changes. This research contributes to knowledge through study on BIM implementation plans and the process of in-cooperating BIM with the combined application of flexibility and standardisation during healthcare refurbishment to successively save cost and improve project productivity. To establish effective standard features of using BIM in saving cost and time in the building procurement process, many questions arise. Such as, which building phase do companies: experience more profit? Saves more time? Saves cost the highest? What BIM standards are tested and trusted?
The main beneficiaries of BIM in the AEC industry are the clients and the facility managers. Nevertheless, all the stakeholders within the industry can benefit from implementing BIM in their projects. This research can conclude that the NHS and facility users could be the main beneficiary of applying BIM in healthcare as the client and key stakeholder in the design, construction and facility management of NHS estates. To improve the use of BIM in the AEC industry, the benefits should be shared among the entire professionals who participated in the entire building procurement process.

2 CHAPTER 2: LITERATURE REVIEW- UNDERSTANDING THE APPLICATION OF RFSB

2.1 REFURBISHMENT

Refurbishment is defined by Palgrave (2011, p. 5) as the process of "*extending the useful life of existing buildings through the adaptation of their basic forms to provide a new or updated version of the original structure*". There are many existing healthcare facilities that are operating below their required standards. BBC (2010) reported that one fifth of NHS facilities were designed and constructed before the NHS was created in 1948. Perhaps a sensible refurbishment appraoch can help improve the current situation of existing healthcare facilities to meet the need of its users. Shah (2012) stated that refurbishment is mostly viewed as a sustainable option, but this is not always the case; the option to refurbish might not be sustainable. Therefore, it is important to achieve value of lowest cost and quality. Payne and May (2009) noted that *homely and comfortable* refurbishment could improve healthcare treatment by 14 percent. The more improved the healthcare spaces, the more productive is the service provided by healthcare staff. Despite the projected productivity expected from refurbishment projects Burton and Kesidou, (2005) reported that in a research they conducted in Greece, it was found that after 10 years of refurbishing office buildings they were still not performing to the required standard. However, an office project is different from a healthcare project, but it is noteworthy to understand that not all refurbishments enables more productiveness; more useful schemes have to be embedded into the refurbishment process. Refurbishment for the purpose of this research is considered an opportunity to improve existing situation of a facility. A question arises, what does a refurbishment process entail? And what is a refurbished space? Perhaps these questions can lead to a simpler and clearer understanding of refurbishment.

2.1.1 REFURBISMENT PROCESS

One fifth of NHS estates were built before the NHS was created 1948. Therefore, there is a need to upgrade existing healthcare facilities. However, some buildings cannot be fully refurbished. For example, listed buildings, the extent of their refurbishment will depend on their listing level grade. Before preparing designs for refurbishment, an appraisal process is usually conducted. It determines whether it is sustainable to refurbish or demolish an existing structure. A refurbishment process includes the process of analysing existing buildings, the designing and construction process. The appraisal process in Figure 2.1 illustrates the sequential steps used to achieve a successful refurbishment project. The exploratory investigations in the appraisal process include the utilisation and analysis of existing and proposed refurbishment design features and components. Their successful analysis enables a facility to be improved, enhanced and increase its value. Palgrave (2011) further described refurbishment to be conducted into four different phases which include: *minor refurbishment* might require certain replacements or redecoration; *major refurbishment* requires the replacement of major building elements such as ceilings or floors; *complete refurbishment* is the process where everything is altered with the exception of the substructure, superstructure and floor structure; and *redevelopment* is the process where only the existing façade and foundation remains in its original position.

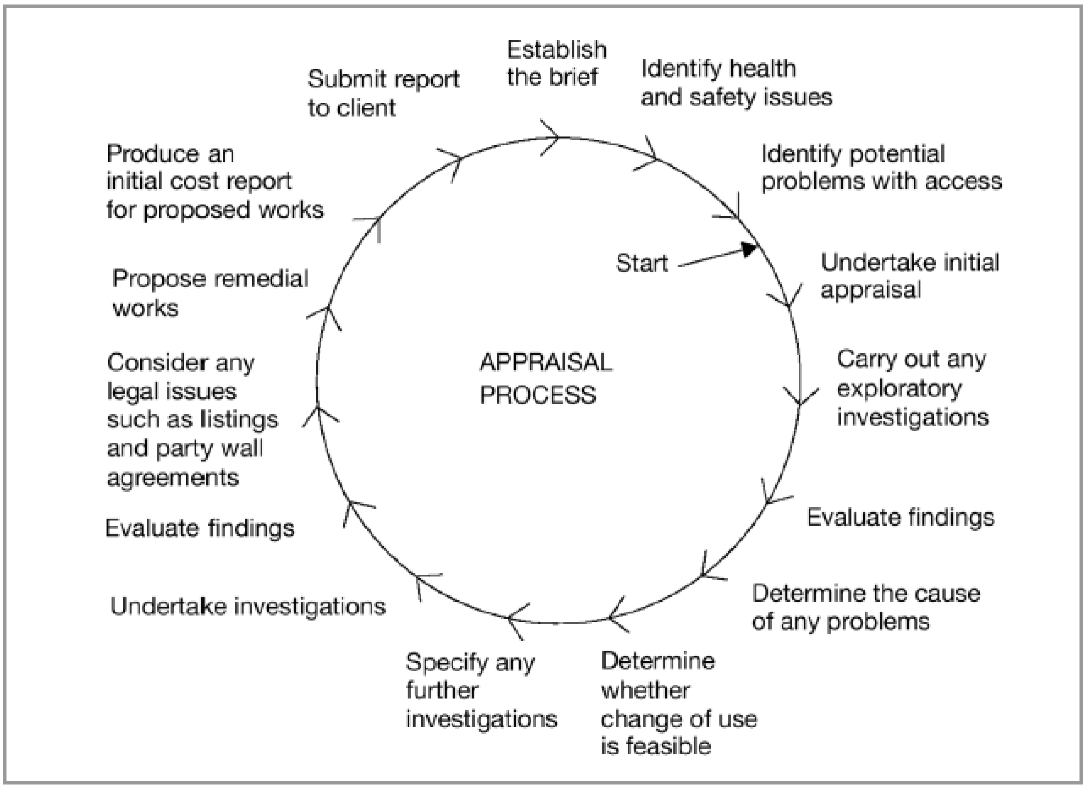


Figure 2.1: *Refurbishment appraisal process. Source: Palgrave, (2011, p. 17)*

To decide the most suitable and appropriated refurbishment process to undergo, there should be a good relationship between the reason for the refurbishment and the chosen refurbishment phase. Some of the essential requirements for refubishment are described by Gorse and

Highfield (2009). They illustrated factors to consider before refurbishing or upgrading a building. Theses include:

- Generally for modern accommodation: many structures are required to be improved. For example, when the status of an area improves, the buildings situated in the area will also be required to match the expected development .
- Availability of buildings` suitability for refurbishment: For example, a refurbishment can be conducted to convert an old industrial building to an accommodation building depending on the nature of the existing structure.
- The quality of buildings and their suitability for refurbishment: This includes structurally stable buildings which do not suit the modern day use.
- Short-term development or time-frame: New accommodation and upgrades can be available within a short time frame, saving time, saves cost and could suit the need of an organisation with a short-term or immediate goals.
- Listed buildings: Some *conservation area legislation;* the Government legislation in the UK determines the character and appearance of some historical areas. Another important factor to consider when proposing a refurbishment is a*rchitectural advantages*. For example, some buildings are refurbished to maintain their architectural character or unique designs from use of materials or building elements to showcase their aesthetical features that are appealing to the public and could be restored for tourist attractions. This also include the structures close to natural or architectural attractions.
- Availability of the existing infrastructure: The re-use of some infrastructures could cut the cost of redesigning the entire structure leading to cost effective refurbishment. Re-using some part of an existing building such as cables, MEP, drainages and so on could be an important factor to consider when proposing for a refurbishment.
- Social advantages: Sometimes the process of building a new building is far too complex compared to the refurbishing process; the easiest and economical process will drive building option type, and would influence the stakeholders decision on wheather to opt for new building or a refurbishment. Some new buildings might go through a lot of legislative protocols, community impact considerations and so on.

while an existing structure might require less protocols to start re-development, but this will depend on the short-term or long-term goals of the project.

- Environmental advantages: One of the key considerations of the building industry today is to explore and reduce carbon emission through sustainable appraoches which include re-using and recycling existing structures where possible; this can be conducted successfully through the process of refurbishing existing buildings.

Shah (2012) categorised the refurbishment process into four groups. These are: Brief; design; construct; and operate. The appraisal process and the need to refurbished are all explored before a design is produced. Decisions are made during the analysis of the brief. It is noteworthy to understand that decision making before and during the refurbishment process is iminent. The knowledge of the project team is important towards establishing the clients needs. Smyth and Pryke (2008, p. 75) stated that "*knowledge is also elicited from various project team members during the construction process*". Boland (1996, p. 38) stated that reengineering steps provide strategies for approaching the design, building and implementation of new processes to achieve effective refurbished medical facilitates. Seven key steps were identified for redesigning healthcare delivery. These are:

- acquire new medical technology and methods expertise;
- design, develop, and implement information systems;
- plan and implement medical facility changes;
- design, develop, and pilot new clinical and management processes;
- design and launch education and training programs;
- transition hospital management, clinical staff, and administrative staff; and
- launch reengineered services

There are different factors to consider before conducting a successful refurbishment project, these factors include environmental issues, Government policies, economical factors, social problems e.t.c. However, it is important to have an idea of the features and qualities of a refurbished space. These are presented below.

2.1.2 A REFURBISHED HEALTHCARE SPACE

The fous on refurbishment is to improve the current conditions of buildings, change functions and meet business needs. An effective and efficient refurbished space would have qualities such as: increased life span; newer opportunities; and an improvement on the existing space. These improvements could be based on the need to adapt to rapidly changing environments, treatments, equipments, etc. With increasing concerns regarding the sustainability of existing facilities and facility whole life thinking and costs involved; researchers and healthcare planners are being encouraged to provide innovative means of improving these facilities. The refurbishment of healthcare buildings varies depending on the nature of the problem and the culture of responsible organisations such as the NHS Trusts.

Refurbishment is vital especially from a sustainability perspective; it frequently involves reconfiguring (recycling, modifying, extending, contracting and re-planning) existing spaces, meeting energy targets (carbon reduction), meeting users' needs to achieve desirable goals of healthcare facilities. Refurbishment can also be undertaken to save time and money. For example: higher operating costs can mean that it is cheaper to refurbish a building (with double glazed windows and revolving doors) than to continue operating and maintaining it in its current state. Refurbishment is required to improve both internal and exterior elements and functions such as indoor air quality and natural lighting. A refurbished space can add new spaces, functions, equipment, furnitures, services, productivity or opportunity to achieve different tasks, a number of additional benefits are usually realised within a refurbished space, but sometimes they come along with complexities such as dealing with existing constraints.

A refurbished healthcare space can be effectively improved through the application of BIM. Chellappa (2009) described that the use of baseline modelling within a BIM environment can be used when refurbishing healthcare facilities to improve the conditions of facilities through the use of existing facility data that was used in its design and constrcution. Baseline modelling is the process of creating a line between what is already built and what will be build in the near future. Figure 2.9 shows a description of baseline modelling. BIM is also used in coordinating existing and proposed information for new design, construction, and facility management. It is important to understand the challenges involved in conducting refurbishment. This involves the process of addressing possible delays or difficulties that could be encountered within the refurbishment process. The challenges of refurbishment are further discussed below.

2.1.3 CHALLENGES OF REFURBISHMENT

The barriers towards achieving a flexible space are numerous. Both refurbishment and flexibility share a similar impediment (uncertainty). Wilkinson and Reed (2006) stated that refurbishment process is mostlly related to uncertainties and changes in an unpredicted manner, this could be due to the presence of occupants while buildings are fully or partially operational. Therefore, uncertainty is the only certainty in healthcare. Burton and Kesidou (2005) noted that refurbishment projects are challenged with achieving required energy performance, waste management, pollution, air quality for workers and possible occupants if facilities are fully or partial operatioanl and the emission of co2 in the atmosphere. There is a required user comfort level that has to be attained, and the incoorporation of desired physical and functional components within a building. Gesler *et al.* (2004) stated that healthcare facility designs are complex buildings. Milburn (2004) stated that in a new or refurbished healthcare facility patients expect modern treatment and advance healthcare delivery. Gorse and Highfield (2009) identified economic challenges of refurbishment which involves different possible scenarios. For example, clients expecting a certain rental income due to a proposed new use, location, attractiveness, quality of accommodation, or demand. Expected capital value; estimated cost of development due to new use proposal, the age of a building or cost of acquiring the site which involves planning permissions and site location etc. Cost of financing the scheme will depends on the availability of financial aids. The availability of funds is one of the most important drivers for any refurbishment or upgrade project. Listed buildings legislation; little refurbishment can be done on listed buildings in the UK which are preserved from the past for the present and future generation. Sometime only sensitive refurbishment is conducted on listed buildings depending on its level grade to be preserved. Other common challenges of healthcare refurbishment include: the constraints that comes along with existing spaces, functions, equipments, furniture flow and so on. Challenges of healthcare refurbishment found through interviews are further discussed in section 7.5.2 of chapter 7.

2.2 FLEXIBILITY

Flexible spaces are encouraged when designing buildings that can adapt to future changes, but Sheely (2008) is of the view that more technological approach should be adopted. The definitions of flexibility in Table 2.1 can be understood from different subject areas, but the central idea is the ability to adapt to changes when required for certain specified purposes.

Table 2.1: *What is flexibility?*

References	Year	Flexibility Definitions
Kala and Thursby	(1994, p. 22)	Defined flexibility in economics as the capability to change or regulate.
Guan	(2008, p. 714)	Defined flexibility in Manufacturing system: 1. Equipment flexibility: Capability to accomplish several tasks without introducing major amendments. 2. Logistic flexibility: Capability of conveying items to different places 3. Operational flexibility: Capability of manufacturing different prototype with different techniques. 4. Technics flexibility: Capability of manufacturing different products without introducing major alterations or amendments. 5. Product flexibility: Capability of manufacturing different products. 6. Path flexibility: Capability of using different techniques for production. 7. Out flexibility: Capability to adopt and achieve various economical product output levels. 8. Expansion flexibility: Capability to expand production. 9. Control and program flexibility: Capability to maintain system productivity with software. 10. Organisational flexibility: Capability of an organisation to withstand either internal or external impediment or interferences.
Rajan *et al.*	(2003, p. 3)	Defined design flexibility as the capability to slightly or entirely redesign or substitute.
Zammor *et al.*	(2011, p. 593)	Described routing flexibility as the capability to use a variety of routes to accomplish a task. Describes manufacturing flexibility as the capability of a productive system reacting to changes taken place inside or outside its surrounding.
Neufville *et al.*	(2008)	Described flexibility as an alternative to future accomplishment, which can be switched on or off when required.
Holt *et al.*	(2008, p. 1)	Defined flexibility "as mobility, compliance, and alternatively as the reciprocal counterpart"
Pati and Harvey	(2009)	Defined flexibility from an architectural point of view, as the ability to expand or adapt.
Cleveland Clinic	(2010)	Defined flexibility as the ability to expand or adapt
Oxford dictionary	(2011)	Defined flexibility as "the willingness to change or compromise...ability to be easily modified"

Flexibility for the purpose of this study is defined as *the ability to change or comply with immediate or future needs of a building*. These changes can occur at short-term, mid-term or long-term. Flexibility could be the aptitude to respond to growth, change in flow or equipment. It is important to explore the processes of embedding flexibility within a building to clearly understand flexibility more closely.

2.2.1 FLEXIBILITY PROCESSES

Finch (2008, p. 9) argued that flexibility was recognised in the early 1960s in the educational sector; four different spaces were identified. These are: *expansible space* that allow opportunity for growth; *convertible space* that can economically adapt to future changes; *versatile space* that can serve different purposes; and *malleable space* that can change instantly using simplified appraoches. Neufville *et al*. (2008) classified flexibility into three different processes:

A. operational flexibility: this is a short-term flexibility that can be subsequently accomplished within a very limited time frame, it can be carried out on daily or weekly basis. For example, a flexible furniture or a flexible ward that is equipped to conveniently accommodate different type of patients within a very short notice;

B. tactical flexibility: this is a long-term type of flexibility that needs time to be attained within the healthcare facilities. An example is a shell space or additional suitable foundations to accommodate growth or change; and

C. Strategic flexibility: a much longer and slower option to adopt, which takes years to implement, this sort of flexibility enable healthcare facilities to increase their life span. An example is buying a neighbouring land to expand facility.

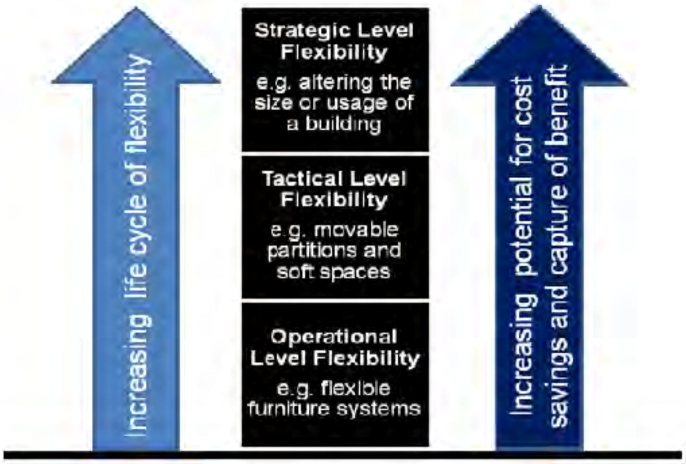


Figure 2.2: *Categorising flexibility. Source: Neufville et al., (2008)*

The three approaches used towards embedding flexibility are related to the short-term, mid-term, and long-term flexibility. Figure 2.2 suggests a possible increase in cost saving and life span of buildings when flexibility is successfully embedded into a facility. However, it is important to explore the features and qualities of a flexible space in order to successfully embed flexibility into a building.

2.2.2 A FLEXIBLE HEALTHCARE SPACE

Flexibility enable changes to take place effectively and efficiently in a rapidly changing healthcare facility. Changes in healthcare are caused by many different factors such as an ageing and growing population, technological innovation in medical treatment and equipment. A building is able to perform effectively over the years if it adapts to changes. Embedding flexible approaches such as universal spaces can help improve healthcare facilities, these spaces have to accomodate changing functions with the ability to relocate instruments and equipment for the purposes of power supply and utility services. Findings from the analysis of the different flexible approaches described by Neufville *et al*. (2008) show that flexibility is at its best when it is *adapting* to changes, the process of adapting requires no structural construction cost. Specific functions can easily change/reposition to adapt to users’ needs. Flexible spaces are designed to flex and change according users’ needs, these spaces address comfort and the way we live our lives. Future designs should take into account the future needs of users` with ergonomic footprint to achieve required and desired building functions. Flexible spaces are simply spaces that change with time for specific purposes, such as adapting to the diversity of people in a given facility such as healthcare staff, patient and visitors. Pati *et al*. (2008) described nine attributes of an adaptable healthcare spaces. These are: categorising and zoning of possible healthcare flexible spaces; patients visibility (distinguishability); grouping staffs into teams to easily deal with healthcare uncertainties; patient closeness to healthcare support at all times; accessibility of functional units; ability of units/departments to exchange functions; and setting flexibility and expandability support system in place. Flexibility can also be achieved through the concept of modularity, partial or fully interstitial spaces and the categorisation and separation of functions.

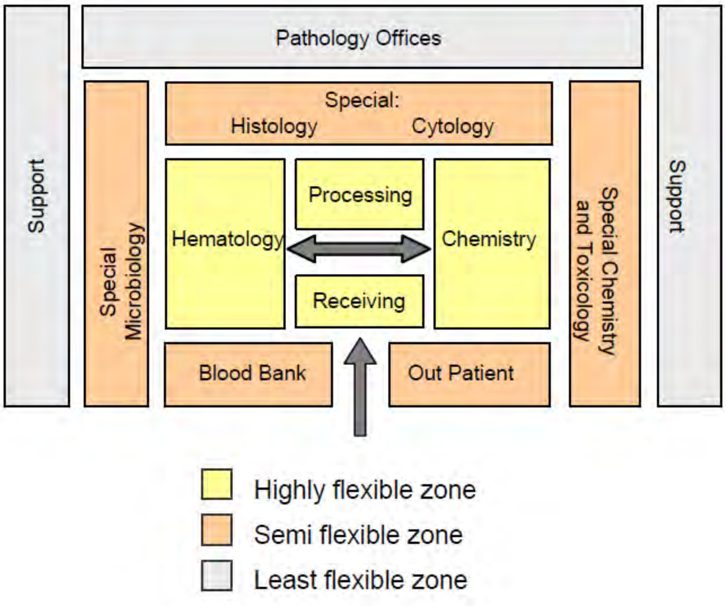


Figure 2.3: *Flexible space concept. Source: Battisto and Allison (2002, p. 40)*

Battisto and Allison (2002, p. 40) described a clincal flexible space in Figure 2.3. The spaces were categorised into three different flexible zones. These are: highly flexible areas which are described as spaces that are accessible to clinical areas to both patient and staff; automated services are centralised to the highly flexible space; while semi-automated and manual services located within the semi-flexible spaces. Offices and support areas are placed within the least flexible space. Perhaps the concept could be applied directly to other type of flexible spaces or can be customised to sort different needs of different spaces. Within a flexible space, the notion of *access* has to be taken into consideration, there should be adequate management in the expected entrance and exit of patients for 12 hours, while the should be some planning for unexpected or emergence entrance and exit for 24 hours round the clock. (Panter, 2011. P. 70). Exploring the challenges of flexibility creates an opportunity to mitigate the problems that comes along with flexibility.

2.2.3 CHALLENGES OF FLEXIBILITY

Flexibility is a broad topic, it falls within the different aspects of life, but in this research flexibility is explored within the context of healthcare facility to accommodate future changes such as advancement in technology or medicine. Lam (2008, p. 43) reported that flexibility is required due to changes and growth which are inevitable. Facility managers expect changes to take place within the life span of a facility (30-60 years). At some point in time, amendments might be required for healthcare facilities to function more effective and resourceful. He also stated that there are different factors that could infuence the need for flexibility. These are:

- high density of fast growing communities;
- special cases (epidemics) which require specific equipments, at specific time and at a specific place;
- changing statutory requirements;
- advancement in medicine, equipment and procurement;
- obsolescence and decline;
- provision of better building performance; and
- social and political issues.

Over the years, many healthcare facilities spaces are becoming obsolete while their life span has not reached its peak level due to variable demographics, cost and availability of technological hospital demands, operational and functional requirements demanding attention over the life span of facility (BBC, 2006). BBC (2010) stated that 17% of the NHS estates are deemed not upto scratch. Repudiating these factors in a given healthcare facility tends to reduce its life span, and increase operational cost while causing early reconstruction, redevelopment or refurbishment. The challenges of flexibility include the indecisive problem of dealing with uncertainty, it is understood that the only certainty in any healthcare facilty is uncertainty. Therefore, to forecast how healthcare facilities will operate and function in the near future is difficult. Perhaps healthcare designers and planners would find it difficult to prescribe solutions due to the lack of information such as the specific time healthcare facilities would grow or contract and at to what extent? They are more challenges apart from the unforeseen and uncertain circumstances as Carthey *et al.* (2010, p. 110) described that some hospitals have bad designs that do not allow further alterations and such are Private Finance Initiative (PFI) structures; possibly due to lack of public partnership. They also quoted RIBA (2005) stating that due to the rigidity and basis of PFI structures contract, they do not allow changes to take place at a later stage. Another difficulty is for healthcare facilities to serve their exact purpose effectively and efficiently. After embedding flexibility; predicting spaces that will not be used immediately but in the near future is complicated. Uncertainty is the greatest challenge of any flexible healthcare facility (Gressel and Hiland, 2008). It is difficult to predict the future, but using previous studies or history, a prediction with some degree of accuracy can be drawn. The UK national statistics shows a constant annual growth. To respond to some future changes healthcare facilities might need to be downsized by offering some spaces to third parties. For example, sub-letting. Pati and Harvey (2009) reported that cost and change management are key barriers towards achieving facility flexibility. Inaccurate future prediction can cause inadequate facility flexibility while it can lead to the creation of obsolete spaces which can consequently lead to underutilised spaces. Neufville *et al*. (2008) reported that "*it is impossible to predict future patient activity with a reasonable degree of accuracy*". Lam, (2008, p. 43) understood that the size of a big hospital depends on the number of beds, he also stated that in Hong Kong there is a standard of five to six beds per 1000 people population in a given area. This simply shows that the higher the population, the higher the number of beds required. Using an exact or most likely projection in population growth, it would be easier to produce the right amount of hospital beds in the near future to accommodate population growth. But identifying accurate populations is difficult. Other barriers of flexibility can be found in appendix 4.

2.3 STANDARDISATION

Standards (component specifications) can be used to manage information exchange within BIM project. This research focuses on standards with regards to healthcare space specificaiton. Standardisation in healthcare is understood in various terms, The UK Government addresses it to focus on procurement methods such as Procure 21 and recently the Procure 21+ procurement framework that 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 Chain*" (NHS, 2011). Standardisation is understood as a dimensional specification, pattern, process, agreed manner or a simplified approach of doing things that an average person can use effectively and efficiently. Joint Commission Resources (2004a) stated that the manufacturing industry improves efficiency and reduces error to a certain degree by applying standards; it permits automation and expectedness of different tasks so that they can be conducted with less exhaustion, breaks, disruptions, or interuptions enabling staff to focus on their related healthcare tasks more productively. Healthcare and manufacturing industry are different but the level of standardisation and improved efficency achieved in manufacturing industry can be appreciated by the healthcare sector. Standardisation can help staff adapt to healthcare delivery by providing work flow delivery processes that are desired and simplified. For the purpose of this research, standardisation was explored in the context of a space and objects specification. Its application in healthcare is discussed explicitly in appendix 1.

2.3.1 STANDARDISATION PROCESSES

Standardisation is applied productively in the automobile industries, phone industries; packaging industries and many other manufacturing industries with an ultimate goal of improving the quality of production of various regular products. In the built environment, there are many factors to consider which are subjective due to different groups of facility users. One factor to consider in healthcare facilities is the rapidly changing nature and needs of healthcare buildings within the built environment making it is difficult to standardise; frequent updates are required within certain time frames. Facilities such as healthcare require specific designs that can respond to the needs of their intent users, while manufacturers request more for customisation. Standardisation can cause *one size fit all*, this could lead to space obsolete within a building. Nevertheless, the application of standardisation in institutions or manufacturing industries is closely related to its application in healthcare buildings. According to Reiling, (2007), standardisation routine is important; it improves the safety of staff and patient. standardisation reduce the possibility of errors occurring during healthcare delivery. A challenge of non-standardisation is that sometimes it does not allow the ease to focus on imaginative problem solving.

Simplification and standardisation helps ease human error. When human error is reduced in healthcare delivery, performance can been achieved. However, it is important to identify that they are challenges towards the application of standardisation. Jakobs, (2000) stated that standardisation design process is attributed to four specific functions. These are: high technical quality; effective solution to the initial prolem; timeliness; and wide adoption. National Intitute of Health and Clinical Excellence (NICE, 2012, P. 11) stated that the process of achieving quality through the use of standards in healthcare include: a comprehensive evidence base study; the existences of independent advisory committees; clinical and patient expert input; transparent process and decision-making; genuine consultation; effective dissemination and implementation; and the process of regular review. Hall and Giglio (2010 p. 541) stated that "*a little standardisation in architectural design brings about huge benefits..standards are important because they harness the ability to* *create, package, and share information, further streamlining the design process*". It was also reported by Rozich *et al.* (2004) that standardisation process increases uniformity of practice and it is worth applying in other sectors to possibly reduce cost and increase safety. McLoughin and Leatherman (2003) reported that the standardisation process drives the design of a healthcare system through the process of balancing available funds with facility quality. Spivak and Brenner (2001, p. 18) are of the view that a standardisation process invloves "*formulating and applying rules for an orderly appraoch to a specific activity*". The National Audit Office (2007, p. 2) stated that "*the OGC published the Common Minum Standards for the procurement of built environment in the public sector which apply to both construction and refurbishment projects*". The standards provide guidance towards improving performance of buildings. Literature shows that standardisation is understood as a standardised process, information management and so on. However, this study focuses on standardisation process in relation to dimensional specifications in healthcare spaces and equipment. One question emerges; what does a standardised physical space entail? The next section below discusses the features of a standardised space.

2.3.2 A STANDARDISED HEALTHCARE SPACE

What is a standardised space? Robbins and Huzair (2011, p. 180) stated that it is understood as an organised space for people, objects and activities that enables certain forms of knowledge and action/social relation to take place such as exchange, movement and flow. Different activities can be conducted in a standardised space including the exchange of functions. It can be described as a controlled spaces in so much that many aspects are entirely defined. Reiling *et al.* (2004) noted that standardisation of workflow reduces reliance on memory and allows people unacquainted with a specific process or product to use it in a safe and efficient manner that improves quality and productivity. Reiling *et al.* (2007) stated that standardisation aids in making a given process more reliable, simple, preferable, desirable, appropriate and achievable. This becomes interesting and serves as incentive when presented as a standard. It could be easier for staff to work within a standardised space due to a continuous similar routine of use; when a nurse comes into a patient`s room, due to familiarity of use, it becomes clear and simple to perform a task. Many elements and functions are standardised according to specific uses. Spivak and Brenner (2001, p. 18) described standardisation to have some particular applications. These include: units of measurement; terminology and symbol representation; product and processes; and the specifications that result to the safety of persons or goods. Within a standardised room: size; shape; layout; size and orientation of windows; location of doors; direction of openings; location of toilets; and the amount of treatment space required for staff to use medical equipment and deliver healthcare services to patients are all a time specified**.** With considerable focus on standardised room spaces, it is vital to acknowledge that room shape, as well as room sizes are important (Price and Lu, 2012). Other important factors to consider when applying standards are described below.

2.3.3 CHALLENGES OF STANDARDISATION

Ehlers and Pawlowski (2006, p. 479) Stated that when dealing with standards there are "*pressing demands for facilitation of information storing, management, and retrieval*". Jakobs (2000) described some considerations when applying standardisation. These are categorised into three groups: *Avoid technological dead ends*; this involves using products that are incompatible, they can cause users to be stocked with ineffective products. *Reduce dependency on vendors* increased competition and lowers the costs attached to any product or process. *Standardising universally* can limit competition capability due to lack of flexibility. With different standards and different vendors, a competitive environment can be encouraged; while users will prefer interoperability between different standards to avoid the use of rigid products. Price and Lu (2012) are of the view that standardisation requires update at certain times. Reiling (2007) describes standardisation to work subconciously; when inadequate standards are used they are hardly challenged. Other challenges of standardisation are presented in chapter 7 from interviews conducted with architectural practices in the UK.

2.4 BIM

The Chartered Institute of Building (2010, p. 30) stated that BIM was

> *First introduced in the 1970s, BIM has become more than just the use of architecture, engineering and construction (AEC) design packages to design buildings and generate three-dimensional images and replicate visual attributes, e.g. colours and textures. Higher level integrated systems are now capable of designing in four dimensions (time dimension added) creating simulations running in real-time.*

Figure 2.4 illustrates the development of design information from the drawing board to BIM. Many features can be used to describe the application of BIM and its adaptation. Professionals are expected to collaborate within the building procurement process to share information and make informed decisions. Different professionals possess different skills and contribute to the entire design and construction project at early stages within a coordinated BIM set up. IFC objects create the basis for BIM development; they allow the use of parametric objects to simplify information exchanged between different stakeholders within a BIM project. Kensek (2009, p. 5) listed three major *dimensions* of BIM which are: 2D/3D coordination, parametric components and interoperability. BIM is also a decision support tool that needs to be implemented in industry before its benefits can be fully achieved. It is important to establish the need of BIM in healthcare projects; clients and others stakeholders have to collaboratively accept the need for BIM. Despites its benefits at the different building procurement levels, professionals in the building industry will have to face the challenges of BIM implementation. The relevance of IFC objects are discussed in detail. Other issues presented include BIM implementation cost, scope, plans, benefits and dimensions.

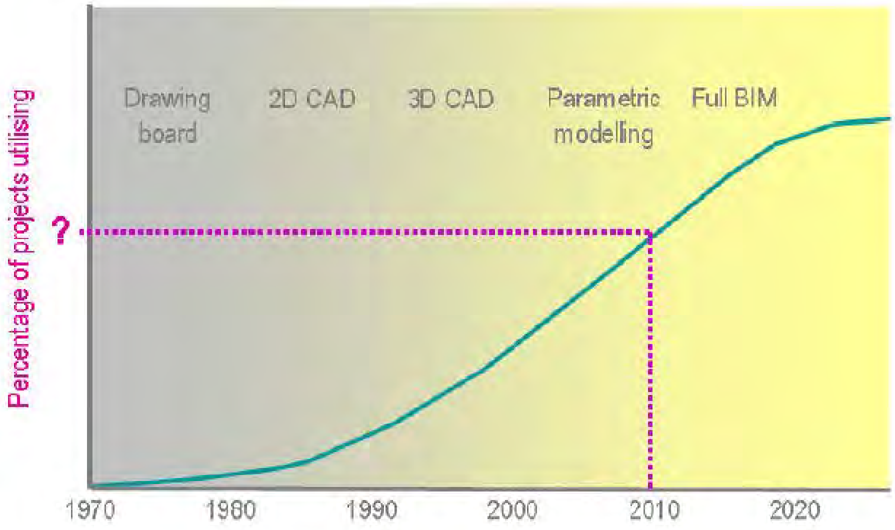


Figure 2.4: *Stages of BIM development. Source: Sheth (2011) quoted Dix, (2009)*

2.4.1 OVERVIEW OF BIM

BIM is not new, it has been around for many years before the *term* was popularised and adopted in the AEC Industry, from a fashionable word to mainstream in the AEC industry. BIM is described to have object features; these object formats help the standardisation format for the purpose of interoperability, and for the ease of sharing information while collaborating with different building professionals. It is important to address that BIM as a *process* is central towards it`s understanding. However, the different understandings of BIM from different stakeholders within the AEC industry are presented below.

2.4.1.1 Different understandings of BIM

What is BIM? Hannon (2007, p. 2) stated that it is defined in quite a lot of ways by many researchers. Eastman *et al*. (2008, p. 1) stated that "*Building Information Modelling (BIM) is one of the most promising developments in the architecture, engineering and construction (AEC) industries*". Thomas *et al*. (2010, p. 170) also stated that when using "*BIM technology, a precise and exact virtual model of a building is assembled digitally, the computer generated model would contain precise geometry and relevant data needed to realise the building when completed*". BIM is widely understood as a technology that enables the production and conversion of traditional 2D building drawings to 3D models, but Hardin (2009, p. 4) described BIM as beyond buying 3D software and modelling but as a process. The aim of BIM is to incorporated, establish and codify paramount practices within the sections of the building industry. Demkin (2008, p. 536) stated that "*according to the National Institute of Building Sciences, a building information model is a legal representation of the physical and functional characteristics of a facility*". It is a multidimensional representation of 2D building drawings with detailed information attached to it. This definition distinguishes 3D model from a BIM model. A BIM model always has information attached to the model for ease of planning, designing and construction. Justin and Schneider (2008, p. 375) stated the the main focus of a "*BIM model is to establish a virtual model of a given project that is attached with additional information*".

Hardin (2009, p. 4) stated that BIM is more than a common 3D modelling software, but a means of adopting and establishing a novel notion of thinking. National Institute of Building Science (NIBS 2007, p. 1) stated that *"BIM stands for new concepts and practices that are so greatly improved by innovative information technologies and business structures that will dramatically reduce the multiple forms of waste and inefficiency in the building industry*". Similarly NIBS, (2007, p. 21) classified BIM as an entity with multiple features; a product describing a building with information attached, an activity to create a BIM model, and also as a business outline that allows schemes of work to be estimated and co-ordinate for improving efficiency.BIM is also viewed as a process that covers the entire life cycle of a building from ineption to completion.

BIM tools are used to create BIM models used in diferent projects. the BIM model contains required information used to fully describe a building in detail. The modelling process allows stakeholders to concentrate on the building as the final product. The BIM model helps foster collaboration between several building professionals working with an integrated approach. Building information management allows information within the building model to be organised, analysed and evaluated. The processed information is shared between the different stakeholders involved. The BIM management process supports the development of a business structure through the use of available information. BIM is also viewed as an activity that allows the modelling and information management process to take place. The technology is used to support the activities taking place within a BIM project. Therefore, BIM is more than the use of technology. Figure 2.5 articulates the mutual relationship between model, modelling and management, and how they are interconnected to each other within a BIM set up. There can be differentiate; BIM as a model is described as a product; BIM modelling is understood as a process; while BIM management is described as the process of collecting , storing, analysis and evaluation conducted through information exchange within a project.

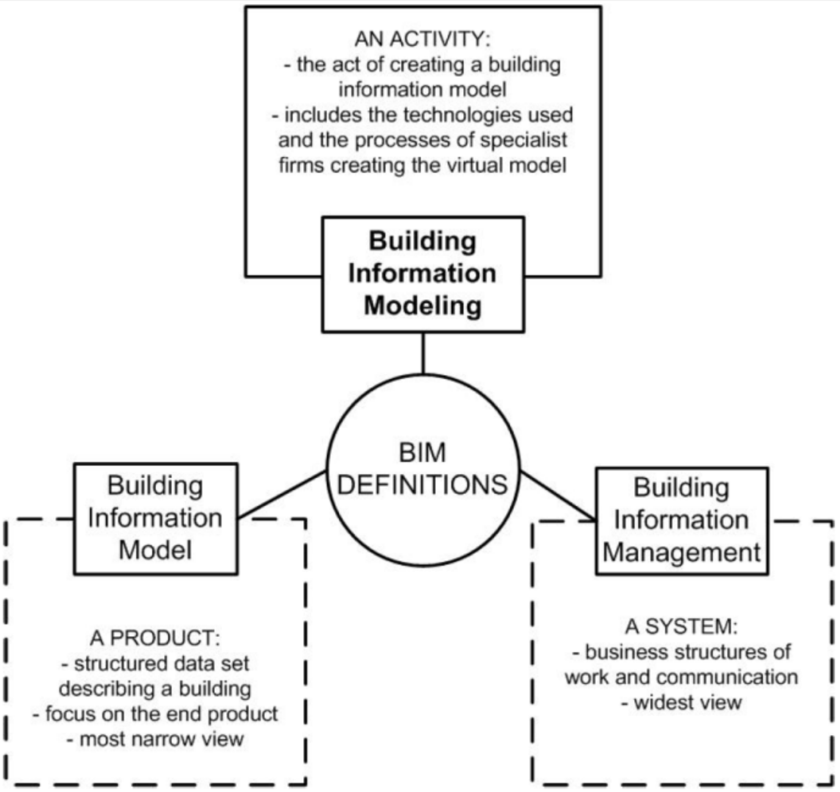


Figure 2.5: *BIM description. Source: (NIBS, 2007, p. 21)*

2.4.1.2 Manifestation of BIM

The expression of BIM was developed from the use of 2D CAD to 3D, 4D, 5D and nD, but the basis of BIM is developed from parametric objects which are used in assigning information to objects; this is the basic difference between the use of 3D CAD and BIM, no information is attached to a basic 3D model. The parametric object creates a geometry that allows the use of information on building element such as doors and windows; non geometric information such as materials, handles, openings and so on are attached to the objects. BIM allows the exportation, modification and linking of different objects within the BIM environment. There is an industry standard used to enable standard information sharing called the Industry Foundation Classes (IFC), Eastman *et al*., (2011) described IFC as "*an international public standard schema for representing building information*" with the use of International Standard Organisation-Standard for the Technical Exchange of Product Model Data (ISO-STEP). They also stated that it "*provides the foundation technologies, tools and methods for developing interoperability tools and standards*" within different industries such as manufacturing and industrial plants.

2.4.1.3 Industry Foundation Classes (IFC) Objects

This study does not focus on BIM standards but space standards. Nevertheless, it is important to acknowledge the impact of BIM standards on information exchange. There is a need to share information within the sequential steps of the framework. Open standards and interoperability are described by BIM Road Map (2011) as features of IFC objects. Mallkawi and Augenbroe (2004) quoted International Alliance for Interoperability (IAI, 2002), that "*The IAI had worldwide chapters with industrial and academic members that jointly contributed to the development of a comprehensive building model, strangely called Industry Foundation Classes (IFC), although its aim is limited to building industry*". Smith *et al.* (2002, p. 1264) are of a similar view that the BuildingSmart who are formerly IAI developed the IFC, which is used to facilitate information sharing between different software use in the AEC industry. The three fundamentals of IFC objects for the first universal simplification are:

1 .IFC Objects, used for generalisation of semantically items within an IFC model;
2. IFC Relationship, used for creating universal relationship of items within IFC model; and
3. IFC Property, used for universal simplification for features of items within the IFC model.

Isikdag (2007, p. 126) stated that *"the IFC is a collection of entities that together form a BIM…the IFC objects allow AEC/facilities management (FM) professionals to share project model and allow each profession to define its own view of the objects contained in that model*". Eastman *et al*. (2011, p. 118) stated that "*IFC models, are composed of the relevant object type and associated geometry, relations and properties*", also of the view that IFC represents the process and activities used in constructing a building through the analysis of geometry, relationships and properties. The IAI now called BuildingSmart considers the entire life cycle of buildings including design, construction and facility management in the AEC industry and promotes specification to standardise the use and exchange of information. Singh (2000, p. 291) also stated that "*the IFC are used to assemble a project model in a neutral computer language that describes building project objects and represents information requirements common throughout all industry processes*". IFC is described by Isikdag and Zlatanova (2009, p. 82) as

> *"The strongest player of the BIM world. IFC is the effort of IAI/BuildingSmart whose goal is to specify a common language for technology to improve the communication, productivity, delivery time, cost and quality throughout the design, construction and maintenance life cycle of buildings*".

They are also of the view that IFC based models simplifies the process for AEC/FM professionals to use a single model, while allowing them to manipulate each object within a BIM process. Hannon (2007) stated that research has shown that data exchange standards (IFC) are improving the exchange of information between different applications and information modelling in 4D planning. BuildingSmart are also making lots of effort to standardise file formats to ease the exchange process during collaboration, but IFC provides a mechanism for interoperability. BIM implementation in the AEC industry is affected by lack of interoperability. Aranda mena *et al*. (2008, p. 14) suggested that due to the nature, size and culture of private and public sectors involved, it will be difficult to assign a standard implementation plan for each firm to work on. Furthermore, Eastman *et al*. (2008) were of the view that there are both technological and sociological barriers to BIM implementation. UK Construction Strategy Report (2011); Succar (2009, p. 363); Aranda mena *et al*. (2008); Eastman *et al*. (2008, 2011); Olatunji (2011); AGC of America (2010); Howard and Bjork

(2008) agrees that interoperability is a major issue relating to BIM in the building industry. Succar (2009, p. 363) noted interoperability as "*the ability of two or more systems or components to exchange information and to use the information that has been exchanged*". Standards should not be mistaken for interoperability; it is note worthy to understand that Boucher *et al*. (2007, p. 141) stated that "*standards only create the opportunity for interoperability and are not equal to interoperability*".

2.4.1.4 Advantages of IFC Objects

Chavez *et al*. (2007, p. 352) stated some advantages of the application of IFC standards in the design, construction and facility management of buildings. These include:

- IFC enable re-use of building information throughout the whole building lifecycle;
- IFC is model-driven and a semantically rich model;
- information can be read and manipulated by any compliant software and thus reducing the "*lock-in*" to proprietary solutions;
- IFC content can be provided by almost all major CAD systems enabling different parties to contribute to the model such as different architects, constructors, structural engineers, etc.
- IFC focuses on the whole building lifecycle and therefore, it is a very integrated dataset for any modification or analyses of buildings. For example, IFC data can be used as an input for energy consumption simulation.

Underwood and Watson (2003, p. 135) described the scope of IFC documents model to have the ability to: manage information about documents; manage reference to documents; and be equally applicable to documents that are paper based or stored electronically. Components that facilitate BIM object sharing and detailing include the Extensible Markup Language (XML). Tatarinov (2002) noted XML is rapidly attracting effective standards for data exchange over the internet and also described it to be used for transferring and storing data. Basically, XML are related to the management of data to ease the transfer process between various parties on the internet. A times these BIM objects are attributed to XML to help manage data transfer.

Green Building XML (GBXML). It is been described by GBXML (2011) to "*facilitate the transfer of building properties stored in 3D building information models (BIM) to* *engineering analysis tools*". GBXML has the support of software vendors like Autodesk, Graphisoft and so on, to reduce time and improve information transfer.

Construction and Operations Building Information Exchange (COBie). This is defined by the UK Construction Strategy Report (2011) as a means for sharing mainly non-graphical data regarding a facility; it is used to share information about a facility without complexity, and it also allows clients to take ownership of information. This is a communication medium; COBie data gathers information relating to the life cycle of buildings. COBie is a subset of IFC. The UK Construction Strategy Report (2011, p. 59-60) also described COBie to "*comprise sheets that document the facility, the level (or sectors), spaces and zones that make up the function of the facility*", and also stated certain questions that are relevant to COBie. These include: what is the design performance of an asset? Such as energy, quality and rentals (sustainable factors); what is the classification of the building types and the area size they cover?; what is the occupancy capacity of a building?; what is the expected operational cost?; and what is the difference between virtual and real time energy cost? They also described that COBie is used for communicating at different levels within the life cycle of the building procurement process. For example, documentation involved during:

- the handover of a facility to the owner/operator;
- the capture of commissioning and survey information;
- the reporting of the designed project ready for rendering;
- the coordination of maintenance records for existing infrastructure;
- the documentation of issues discovered throughout the life cycle;
- the delivery of product data;
- the reporting of design intent at the early design stage; and
- the comparison of briefing requirements against the designed and as built.

2.4.1.5 BIM dimensions

BIM dimensions (D) are also called BIM references, the CIOB (2010, p. 30) illustrated that further work is being conducted to develop "nD" holistic modelling systems (i.e. n dimensions –multi-dimensions). AGC of America (2006, p. 3) stated that "*the extended use of 3D intelligent design (models) has led to references to terms such as 4D (adding time to model) and 5D (adding quantities and cost of material) and on and on*". These BIM references help in attaining the highest level of efficiency in the building industry. Each reference is characterised with a different projection of task; promoting BIM as a strong design, construction and facility manaagement tool. 2D, 3D, 4D and 5D are the only universally accepted BIM dimensions. The extended dimensions are understood and named differently by different individuals or organisations. Some BIM modelling dimensions are:

- 2D drafting (Autodesk, 2003:1; Hardin, 2008, p. 253);
- 3D modelling (Autodesk, 2003:1; Hardin, 2008, p. 253);
- 4D time dimension added (Chartered Institute of Building 2010, p. 30; Hardin, 2008, p. 253);
- 5D adding cost / budget components (Hardin, 2008, p. 253);
- 6D adding facilities management components (Hardin, 2008, p. 253; and UK construction strategy report, 2009; and
- 7D sustainability components (manufacturers, recycled content, embodied carbon and so on) (Hardin, 2008, p. 253).

2.4.2 BIM BENEFITS

Eastman *et al*. (2011); Weygant (2011); Azhar (2011) stated that BIM facilitates the design of accurate virtual building models through collaboration with different stakeholders to improve project productivity. UK Construction Strategy (2011), PAS 1192 and Ahmad *et al*. (2012) supports the notion that electronic data exchange can improve project productivity. Manning and Messner (2008, p. 447) described that jointly if the building professionals in the healthcare sector can work together, they can effectively reduce cost by a minimum of one percent, it will therefore be possible to save $100`s of millions in facility investment for some projects. The benefits of BIM have been described from a general point of view in various sections of this literature review, but this section will categorically classify BIM benefits into different phases of the building process. The identified benefits of BIM are grouped into four different sections. These are: the design, pre-construction and construction and the facility management phase.

2.4.2.1 BIM benefits in the design phase

BIM is used in producing schematics design details and improving the presentation of projects to clients for easier and better decision making, and for a clearer understanding of the nature or scope of work to be conducted. Autodesk (2003, p. 2) stated that BIM is used for the detailed analysis of energy and efficiency, sustainability, cost estimates, schedule and budget information of buildings. BIM is also used in the analysis of building services which could help with clash detections. Timely choices and changes made during the design scope and scheduling can affect the cost and time of construction. However, through the use of BIM tools, these changes can be achieved simply, readily and accurately, reducing the time and costs of project. Olofsson *et al.* (2008, p. 244) also highlighted a few benefits from case studies on BIM implementation in healthcare projects at the conceptual stages which include: quick visualisation; good decision shore up in project development process; precise automatic updating; diminution of man hours for space programs; increased project team communication; and increased confidence of scope of work. John *et al.* (2005, p. 307-328) are of the view that the conceptual design phase includes the clients brief, model and designing building services.

2.4.2.2 BIM benefits in pre-construction and construction phase

The construction process follows the design phase in a traditional procuremnet method while in a D&B method they are conducted side by side. The construction stage involves more professionals compared to the design phase. Additionally, sub-contractors such as mechanical, electrical and plumbing (MEP) participate. Autodesk (2003, p. 1) stated that the use of BIM in the construction phase enables scheduling and work flow coordination, while at the preliminary preconstruction level, it includes cost estimates, virtual construction logistics of cranes and materials on site. The key benefits of the construction phase identified are: 1. the targets and scheduling of construction schemes; 2. scheduling what is constructible; 3. clash detection and reporting; and 4. quality of projects is been analysed and improved by rescheduling projects to improve value. The 4th Dimension is of particular importance as BIM is used in the construction phase to establish and evaluate various construction options. It is been developed by comprehending schedule dates from project plan to model, the evaluation of construction sequence, detection of clashes, identifying construction milestones, understanding and relating the project to owner and contractor can be done more easily using 4D modelling. A 4D model can be obtained by adding schedule data to a 3D building design, introducing time as the 4th dimension. Dawood and sikka (2008, p. 1) stated that "*4D planning is a technique that integrates 3D CAD models with construction actives (schedule) which enables clear visualisation of a construction programme as an animated sequence*".

2.4.2.3 BIM benefits for facility management

Hardin (2009) and Eastman *et al.* (2011) agrees that BIM is used in the operational analysis of a facility within a BIM environment. Issa and Liu (2012) stated that the application of BIM is extended above the design and construction phase which goes into facility management for the purpose of maintenance and maximising the value of a facility. Reddy (2011) described that facility managers will need to maintain an accurate inventory of space. They also stated that Computer-Aided Facility Management (CAFM) and the International Facility Management Association (IFMA) categorised facility management function responsibilities into:

- long-range and annual facility planning
- facility financial forecasting;
- work specifications, installation and space management;
- real estate acquisition and / disposal;
- architectural and engineering planning and design;
- new construction and / renovation;
- maintenance and operational management; and
- telecommunication integration, security, and general administrative services.

2.4.3 INTER-ORGANISATIONAL USE OF BIM

VTT (2006) described Inter-organisation use of BIM as the process of involving one or more organisations in the design, construction and facility management of projects. BIM is been used in four different phases outlined as: 1. use of BIM in one organisation using one application package; 2. use of BIM in one organisation with more than one application package; 3. use of BIM in more than one organisation using one application package; and 4. use of BIM in more than one organisation using more than one application package. Figure 2.6 shows the process of using BIM within an inter-organisational context, while Figure 2.7 gives an example of the inter-organisational use of BIM.

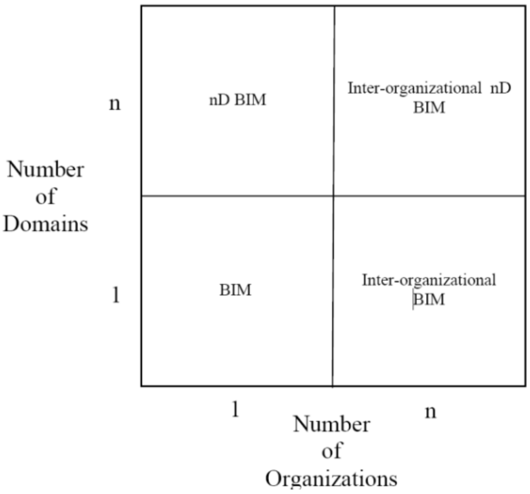


Figure 2.6: *BIM uses at different levels. Source: VTT (2006, p. 33)*

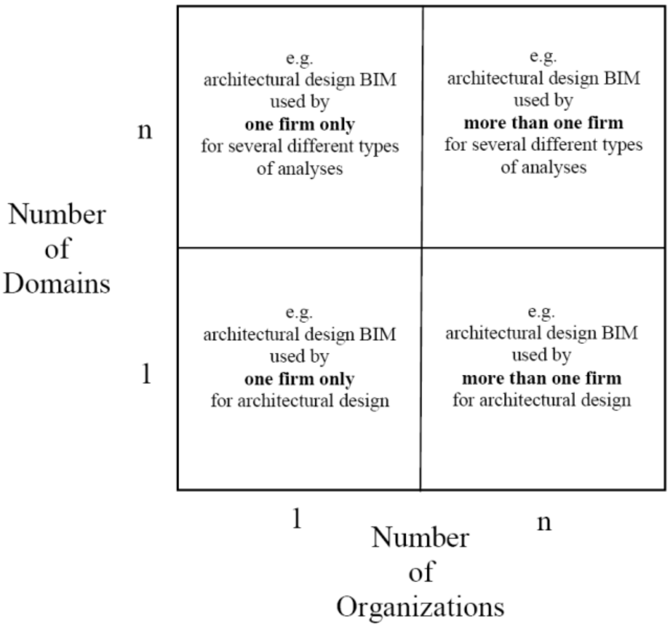


Figure 2.7: *BIM uses with examples. Source: VTT (2006, p. 35)*

They also described that Inter-organisational use of BIM can lead to automational effects, informational effects or transformational effects. The three effects are described as opportunities. These are: *transformational opportunities* that are created with the joint application of BIM, strategic thinking and process innovation; *informational opportunities* are formed by the related use of tactical thinking and BIM through the production of better information for decision making and early identification of design limitations; while the *automational opportunities* are produced through the combined application of operational thinking and BIM. For example, the substitution of manual labour with systematic automation of BIM tools. The benefits of BIM can only be reaped to fruition when it is successfully implemented. Certain factors have to be considered before BIM is successfully implemented.These included the different BIM implementation plans, scopes and costs presented below.

2.4.4 BIM IMPLEMENTATION PLANS

Stebbins (2009) noted that BIM is not a software but a process. He clearly identified BIM as a business decision and the transition to implementing BIM as a management decision. BIM implementation is strongly related to managerial aspect of industries. Most industries have different working styles and culture. AGC of America (2006) stated that each project is special in its own way, and the implementation of BIM on any project should be personalised to the specific needs of the project. Perhaps BIM implementation plans are sensitive. Therefore, it is very important that these plans are well understood, outlined and designed before they are implemented. BIM implementation plans are discussed closely in appendix 2. BIM implementation plan as described by Fisher, (2011) defines the scope of BIM implementation, identifies the process flow for BIM task, defines information exchange, and describes infrastructure needed for support. He also highlighted some importance and value of BIM implementation plans that they provide a better understanding of goals and responsibilities attached to each personnel, teams, department, management and so on. It also helps in creating a workflow that is sequential and binding with expected operations, reducing unknown variables due to scheduling. It also outlines expected training required, resources and the entire process. Some BIM implementation methods are described from literature:

- top-down method;
- bottom –up method;
- slow and drawn out;
- using a selected team;
- using multiple teams;
- use on specific projects;
- use on all projects; and
- entire organisational transformation.

2.4.4.1 BIM implementation scopes

It is however, noted by Jung and Joo (2010) that BIM implementation is classified into three levels: industry; organisational; and project level. The industry level BIM standards such as BS 1192 and PAS 1192 are successfully developed, but the organisational and project level standards are different due to their formats, details and purpose. There are related to managerial corporate strategy issues. In constrast to this, Ashcraft and Sheldon (2008) noted that BIM adoption is divided into three levels. These are: BIM implementation *within an office*, this include the process of selecting software, addressing IT issues, training up and rolling out; BIM implementation *across the design team* include the process of selecting software, addressing IT issues, legal and contractual issues relating to stakeholders involved in the application of BIM. *Across the project delivery team* include procedural scope (design, coordination, estimating, scheduling, submittal review, fabrication, agency review and facility management), legal and contractual issues. Aranda-Mena *et al.* (2008, p. 14-16) stated that implementation of BIM at industry level has three outcomes. These are:

- technical capability: this involves the ability to share information with other consultants and the production of drawings and documents from BIM model;
- operational capabilities: this supports design collaboration, reduces errors and allows the ability to design in 3D environment;
- business capabilities: this includes completing projects with cost control and efficiency. For example, by reducing information errors.

2.4.4.2 BIM implementation cost

There is no specific standardised amount designated to the cost of BIM implementation, nor a clear understanding of how to estimate such cost with a high degree of accuracy. Perhaps it would depend on organisational needs, operational requirement, choice and size of hardware and software etc. As there are various types of BIM implementation levels as discussed above. Therefore, cost and time cannot be precisely measured, but the process can be described in relation to cost and time. AGC of America (2010) described BIM implementation as climbing over a wall, with professionals who are terrified by barriers such as leadership support, software complexity, lack of time and fear of legal issues on one side of the wall, whilst professionals on the other side of the wall confronting these challenges and realising benefits and cost control by implementing BIM and acquiring experience over time. Hardin (2009) referred to BIM implementation in Figure 2.8 as ratio of time against cost. The whole life cycle cost of BIM implementation was described in four stages. The first stage is the *preliminary phase* of implementation, where the cost of implementation begins to accumulate due to the cost associated with feasibility studies. In the second stage, which is the *implementation phase*; it has the highest cost, covering training, purchase of hardware and software etc. The third stage is the phase of *BIM use and development*; this phase is attributed to lower costs as it reviews the progress of BIM implementation and suggest positve feedback to improve the implementaion. With effective response to user feedbacks, cost of implementaion can be reduced. The fourth stage is the phase for *future works and continuous use of BIM*. Cost is furthered reduced to its minimal as all lessons from previous stages are taken into consideration, and no new hardware or software are required. Consequently, this sets both time and cost control to its minimal within the implementation. Cost is a very important factor to consider when implementing BIM, but it is also iminent that project productivity should also be acknowledged. This can be achieved due to improved working conditions such as technological automation of applications and productivity achieved through collaborative BIM working processes.

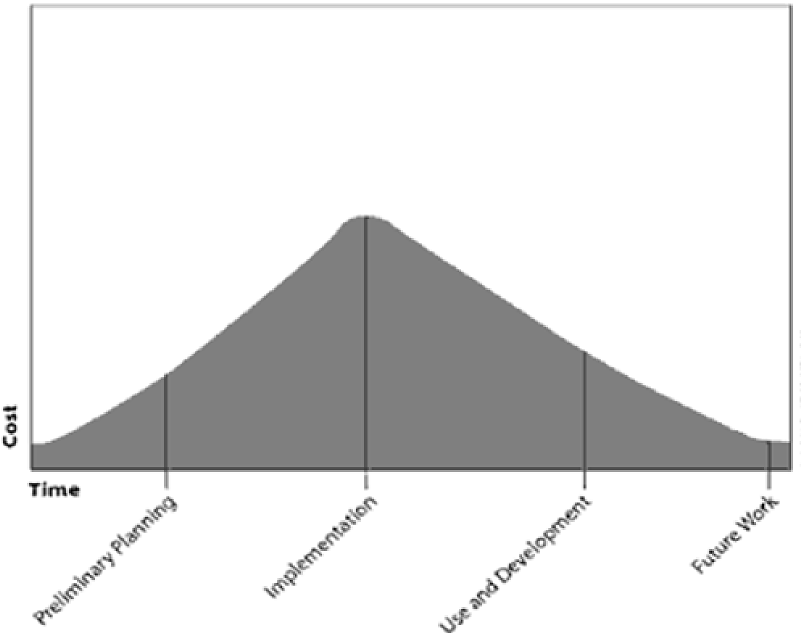


Figure 2.8: *Cost implementation annotation. Source: Hardin (2009)*

2.4.4.3 Challenges of implementing BIM

Hardin (2009, p. 30) stated that the building professionals in companies faces different challenges of adopting BIM at industry level, as it requires setting up a BIM department and training of staff in order to carry out projects tasks using BIM. A couple of BIM myths spreading among professionals in the building industry include:

- BIM is only for large projects with complex geometry (AGC, 2006, p. 2);
- BIM is only for large contractors who can afford the investment (AGC, 2006, p. 2);
- how do they know what BIM standard is? (Howard and Bjork, 2008, p. 275); and
- how do they know which software to choose that would be compatible with their company?

Problems of BIM implementation are classified into different categories from literature review. Each category affects the implementation in a different way. Legal issues slow down the implementation rates, as industries are uncertain about the legal issues relating to BIM. Social issues makes it difficult for industries or BIM users to find a suitable implementation plan to suit their organisational needs and practice culture. Technical issues tends to discourage industries from using BIM, although there are industries such as National Building Information Modelling (NBIM) and BuildingSmart whose sole aim is to improve interoperability making BIM application simple, concise and more convenient. Economic, social, technical and organisational culture constraints are some of the major barriers to BIM use in the building industry as some users need evidence based samples of BIM uses and success before implementing it. A balance between (implementation and running cost) and achieving benefits of implementing BIM is one of the major problems troubling clients. In many industries, the business case for implementing BIM is usually the subject of focus. It is understood that it is difficult to assign certain percentage of benefits on each project conducted with BIM Hardin (2009), hence the justification for the cost of implementation BIM is variable, depending on the size of project in context and the capability of the BIM users. Nevertheless, the benefits of BIM vary from propject to project with different size, project goal and type of organisational management Perhaps this hinders industries and other users to produce an exact cost diagram of BIM implementation cost against BIM benefits.

However, productivity is undoubtedly achieved in BIM projects. Institutional barriers affects BIM implementation as there are limited institutions providing BIM training and awareness. Nevertheless, BIM is currently introduced in the educational curriculums of some institutions around the world. This helps improve the basic learning skills of students, by the time they graduate from their various institutions they would have BIM awareness and training. Consequently, reducing costs, as little or no BIM training might be further required.

Implementation of BIM in industry has been a major issue in the AEC industry; some professionals described it to be expensive, time consuming, and so on, but in a research conducted by Dean (2007) the application of BIM in industry was studied, it was established that approximately 70% of industry participants are using or in view of using BIM, and approximately 75% of survey participant considered employing candidates with BIM knowledge. NBS (2012) showed a growing number of BIM users in the UK, but there is still a small percentage of professionals applying BIM in the AEC industry. Efficiency and quality of BIM is been established and understood globally, yet, the general implementation of BIM use is slower than it is expected. Similarly, they are problems relating to the implementation of BIM, such as lack of documentation that can clearly educate professionals on the application of BIM (AGC of America, 2005). Technical and managerial problems are outlined as the two prime factors hindering BIM implementation. Bernstein and Pittman (2005, p. 13) described technical issues as:

- the production of a well defined construction process model;
- adopting formats that enable design data to be computable; and
- enabling accurate data exchange and integration within a BIM model.

The managerial factors hindering the progressive implementation of BIM revolves around the issues of implementation cost and ease of BIM applicability. Hardin and Bjork (2008) stated that due to lack of standardised established BIM implementation manuals, the management of BIM in a company becomes excessively difficult to establish. Hardin (2009, p. 8) stated that the main challenges of BIM are: organisational implementations; model ownership risks; inter-organisational use of model; interaction of software within the building professionals; and how to work better with building professionals. Manner and Messner (2008, p. 455) noted that the main challenges of BIM is the poor data exchange approaches, limitation of interoperability and lack of parametric concept. There are currently national Government initatives and strategies in place such as the UK Government construction strategy (2011) and PAS 1192 that supports electronic information exchange within the built environment.. Ashcraft (2006, p. 65) described that BIM is viewed with erroneous perception by some firms with regards to limited design benefits. Other problems are related to understanding the concept and application of BIM. Sullivan (2007, p. 194) quoted Boryslawski that "*In the health industry most of the problems occur in MEP construction coordination and about 45 percent to 55 percent of the total cost of hospital projects are in the MEP system...having a fully design-coordinated BIM for MEP will reduce most of the risks associated with healthcare industry projects*". Succar (2006, p. 5-6) noted that there are some set of barriers attributed to BIM implementation in the AEC industry. These are:

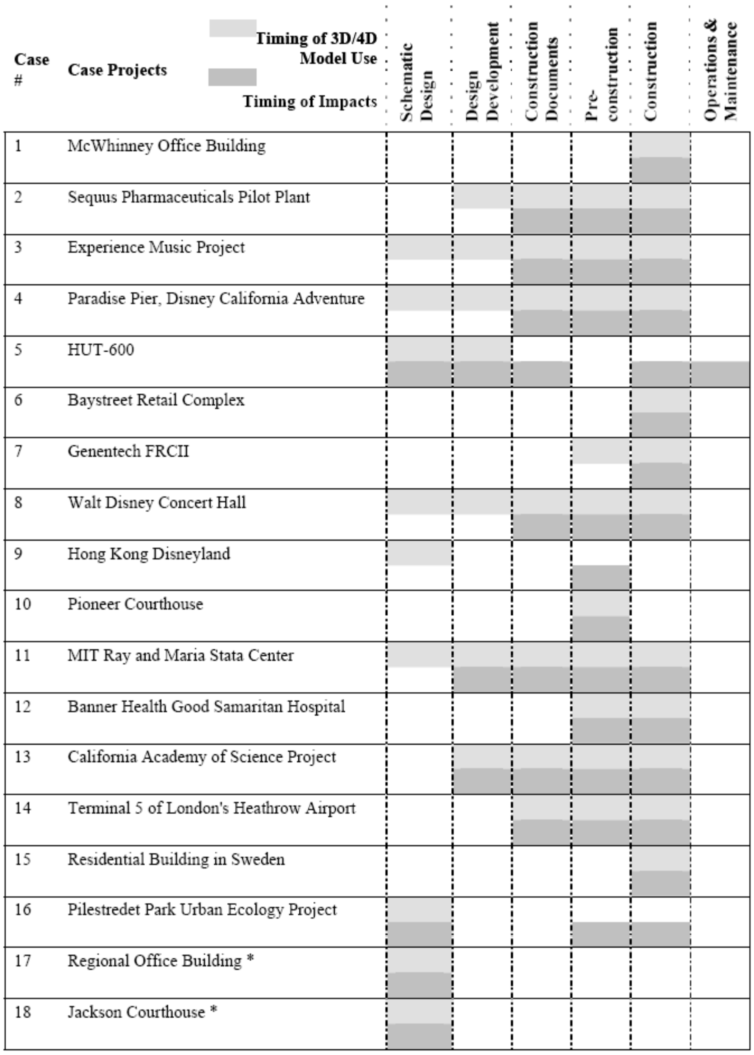
- lack of strategic organisational goals;
- weak managerial commitments;
- lack of communication between management and staff;
- inappropriate hardware (computers) and network infrastructure;
- inadequate training of staff;
- lack of a well crafted implemented trail; and
- lack of adequate process and technical support.

However, despite the challenges of BIM, its implementation can be improved through contractual arrangements and by the Government when theyprovide incentives to companies or individuals applying BIM in their projects at hand.

2.5 DISCUSSION

Flexibility can help design a change-ready healthcare facility by adapting, adjusting or changing to the needs of facility users. This study has found different flexible concepts that can be used to embed flexiiblity, as a result this study identifies different approaches with their specific uses. The benefits of BIM can be simply attributed to project productivity. BIM is used in the different building process stages; based on the outcome of a research conducted by Gao and Fischer (2008, p. 41-42) in Tables 2.2 and 2.3, it clearly shows the impact of BIM benefits at different levels of the building life cycle process. Findings from the research showed that in only a few instances BIM gets involved in the operational phase; out of 32 projects, only five projects were using BIM in the facility management level. Most of the BIM applications were conducted in the design and construction phases, this coincidences with Lee and Gilleard (2002) who noted that research on building maintenance was rarely explored, while the UK Construction Strategy (2011, p. 5) observed that repairs and maintenance (£10bn) are twice new build budgets (£4bn) in some sectors of the AEC industry. Therefore, there is a need for more studies in the field of facility management. But this research explores the design phase, as good designs leads to a cost effective and efficient facility. It was previously stated that in most cases poor building performance are initiated from faulty designs (Palgrave, 2011). Therefore, this specifically led to the decision of exploring the use of BIM in the design phase in order to design more effective and productive healthcare facilities that can respond to known future changes.

Table 2.2: *Application of BIM in different projects. Source: Gao and Fischer (2008, p. 42)*



░ Timing of 3D/4D Model Use
▓ Timing of Impacts

Case #	Case Projects	Schematic Design	Design Development	Construction Documents	Pre-construction	Construction	Operations & Maintenance
1	McWhinney Office Building					░ ▓	
2	Sequus Pharmaceuticals Pilot Plant		░	░ ▓	░ ▓	░ ▓	
3	Experience Music Project	░	░	░ ▓	░ ▓	░ ▓	
4	Paradise Pier, Disney California Adventure	░	░	░ ▓	░ ▓	░ ▓	
5	HUT-600	░ ▓	░ ▓	▓		▓	▓
6	Baystreet Retail Complex					░ ▓	
7	Genentech FRCII				░	░ ▓	
8	Walt Disney Concert Hall	░	░	░ ▓	░ ▓	░ ▓	
9	Hong Kong Disneyland	░			▓		
10	Pioneer Courthouse				░ ▓		
11	MIT Ray and Maria Stata Center	░	░ ▓	░ ▓	░ ▓	░ ▓	
12	Banner Health Good Samaritan Hospital				░ ▓	░ ▓	
13	California Academy of Science Project		░ ▓	░ ▓	░ ▓	░ ▓	
14	Terminal 5 of London's Heathrow Airport			░ ▓	░ ▓	░ ▓	
15	Residential Building in Sweden					░ ▓	
16	Pilestredet Park Urban Ecology Project	░ ▓			▓	▓	
17	Regional Office Building *	░ ▓					
18	Jackson Courthouse *	░ ▓					

Table 2.3: *Application of BIM in different projects. Source: Gao and Fischer (2008, p. 42)*

░ Timing of 3D/4D Model Use

▓ Timing of Benefit

	Case Projects	Schematic Design	Design Development	Construction Documents	Pre-construction	Construction	Operations & Maintenance
19	Samsung LSI Fab Facility					░ ▓	
20	Camino Medical Campus		░ ▓	░ ▓	░ ▓	░ ▓	
21	Fulton Street Transit Center			░ ▓	░ ▓	░ ▓	
22	A Town-planning Project in Finland	░ ▓	░ ▓	░ ▓			
23	Mamselli Low-rise Housing Project	░ ▓	░ ▓	░ ▓		▓	
24	Headquarter Building for NCC-Finland	░ ▓	░ ▓	░ ▓	░ ▓	░ ▓	
25	Tali Apartment Building Project *	░ ▓	░ ▓	░ ▓	░ ▓	░ ▓	
26	Office Building Project in Oulu				░ ▓	░ ▓	
27	Semi-detached Houses in Kerava				░ ▓	░ ▓	
28	Koskelantie 22-24 Residential Renovation	░ ▓	░ ▓	░ ▓	░ ▓	░ ▓	▓
29	Vantaan Silkinkulma Apartment Building	░ ▓	░ ▓	░ ▓	░ ▓	░ ▓	▓
30	Vantann Ankkahovi Apartment Building	░ ▓	░ ▓	░ ▓	░ ▓	░ ▓	▓
31	Pfizer, Scandinavian Headquarter Building	░ ▓	░ ▓	░ ▓	░ ▓		░ ▓
32	Aurora 2 University Building in Joensuu *	░ ▓	░ ▓	░ ▓	░ ▓	░ ▓	

Note (*):

- At the time of writing this report, cases 17 and 18 were still under design development; therefore the impacts of 3D/4D modeling during the downstream phases have not been documented yet.
- At the time of writing this report, cases 25 and 32 were still under construction; therefore the impacts of 3D/4D modeling during the operations and maintenance have not been documented yet.

Despite BIM being centred on the design phase for the purpose of this research, designers have to be creative within the conceptual stage of the design phase. BIM is argured within literature to be promoting creativity to an extent that a designer can be empowered, having limitless opportunities to be creative when conceptualising the design of different buildings through the application of flexible virtual tools that allow imaginative ideas to be realised. On the other hand, it is also argured in literature that BIM affects the ability to be creative when designing facilities due to the limitaiton of information exchange, prametric models, and the need for detailed information at early stages of the design stage.

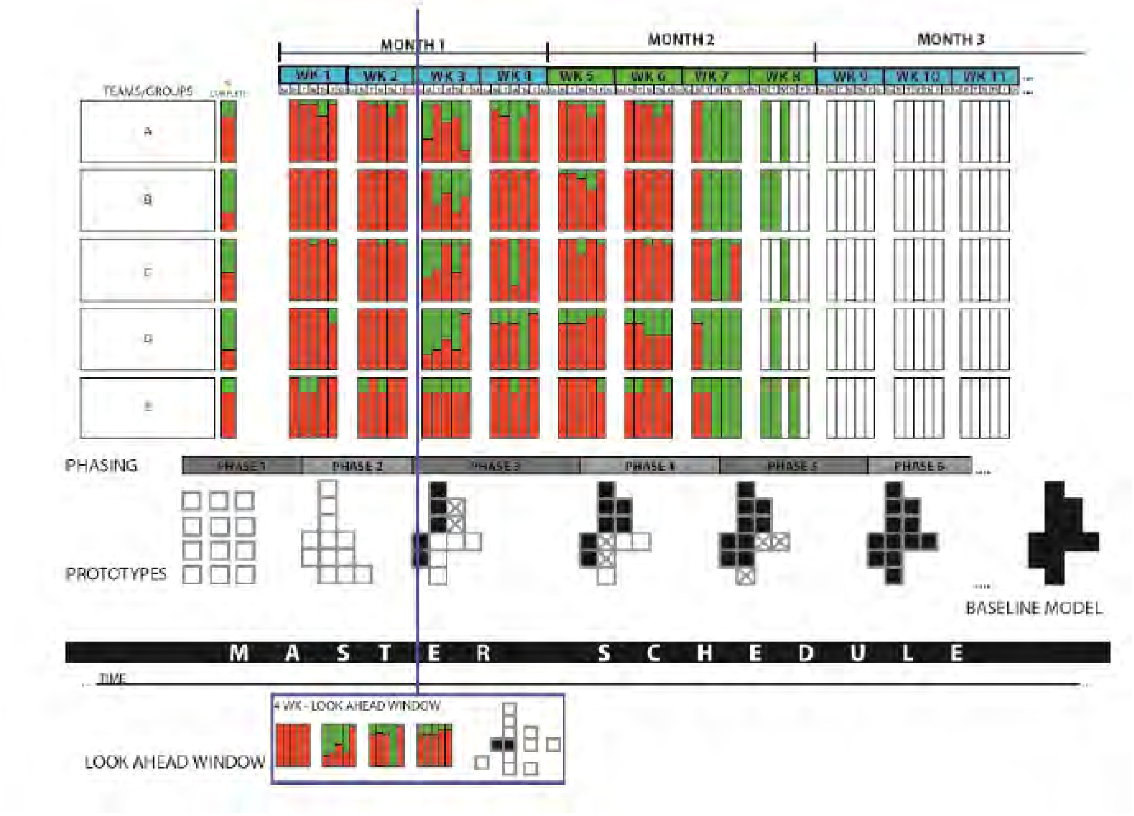


Figure 2.9: *Relationship between phasing, prototyping and baseline model. (Chellappa, 2009, p. 94)*

A good example of the relationship between BIM, standardisation and flexibility during healthcare refurbishment can be seen above. The relationship between the three applications are described in a time-line of a design project. Phasing, prototyping and baseline modelling can be used to inform future redesign projects. phasing allows projects to be conducted in an adequate sequence (standardisaiton). For example, during healthcare refurbishment, facilities can be operational while redevelopments projects are taken place (flexibility). Prototypes reduces the need to re-design, it facilitates design re-use. These prototypes can be applied in a different project. Baseline model provides information of the existing structure, and allows further development (refurbishment) to take place effectively. Phasing can be conducted in this research to avoid clashes or disruptions when a facility is fully or partly operational. The process of prototyping can be associated with design standardisation in healthcare facilities. While a baseline model is viewed as a model that can allow facility mangement and future redevelopment; in order to achieve this collaboration between different stakeholders is iminent to collaborate. As a result, the framework proposed for this study provides an opportunity for early stakeholder engagement to facilitated whole life cycle understanding, including design, construction, facility mangement, post occupancy evaluation and possible refurbishments.

2.6 CHAPTER SUMMARY

To understands the broad topics of refurbishment, flexibility, standardisation and BIM, there is a need to explore their processes and challenges. Refurbishment allows improvements to take place in existing facilities. Flexibility allow changes to take place in existing or new facilities. Standardisation provides specifications (space, furniture, equipment or building elements) that can provide suitable working spaces for the average user. BIM is understood as a process with information exchange between stakeholders. Healthcare is the common factor that links refurbishment, flexibility, standardisation and BIM. They can all contribute towards improving the quality of healthcare facilities. Interoperatability is the ability to exchange information. Standards enable effective information exchange. COBie data is used to support the exchange of non-geometric data of a building during the entire building process; it is a subset of interoperatability. This study concludes that all the four applications (RFSB) used in this research can contribute towards cost reduction and improving project productivity. As a result, their combined application can improve the condition of existing buildings. Each application has its distinct challenges, while their combined applications would have a specific challenge. Due to the changing faces of healthcare facilities. The applications of refurbishment, flexibility, standardisation and BIM in healthcare are furthered explored in the next chapter.

3 CHAPTER 3: LITERATURE REVIEW-EXPLORING THE APPLICATION OF RFSB IN HEALTHCARE PROJECTS

The healthcare sector is an important sector in the built environment; it accommodates medical professionals and their working associates that provide healthcare treatment to the general public. It is important that all necessary measures are taken into consideration when designing and constructing healthcare spaces to improve the quality of healthcare delivery. To improve healthcare service delivery. The relationship between refurbishment, flexibility, standardisation and BIM are explored. Eastman *et al*. (2008; 2011); Succar (2009); Weygant (2011); and Hardin (2009) are of the view that BIM can help reduce project costs. Perhaps BIM can contribute towards NHS effort to achieve the UK Government target of £20 billion savings by April 2015. As a result, Purves (2012, p. 53) stated that the NHS are currently awarding project contracts on lowest cost basis, but there has been a change in the procurement approach by the tresury, with an interest in value, quality and life cycle cost of healthcare facilities. Hence, this addresses the need for designing a change-ready healthcare facility through the use of flexible and standardised approaches within a refurbishment or new project. The application of BIM allows designs to be collabotatively analysed and evaluated virtually at the early stages of the building procurement process in order to optimise design efficiency, increase productivity and the quality of information delivery. Desired quality in healthcare can be set by healthcare bodies such as the NHS.

3.1 HEALTHCARE SECTOR IN THE UK

According to Webster (2002, p. 1) the NHS was established in 1948 as a provider of healthcare services to the general public funded from taxation and provided free at point of delivery to residents with the exception of some services such as prescriptions. Although prescriptions are also provided free to certain category of people within the UK. This idea by Aneurin Bevan was described by Webster (2002, p. 1) as "*the most civilised achievement of modern Government*". Smith and Pollock *et al*. (2006, p. 12) stated that the Department of Health (DH) is responsible for providing and improving health and social services to the people of England. The NHS is fully funded by the tax system of England for its endowment. With this funding, it provides walk in centres, treatment centres, NHS Trusts, primary care (pharmacist, dentist, opticians, and GPs units) and hospitals around the UK.

3.1.1 ORGANISATIONAL STRUCTURE OF THE UK HEALTH SYSTEM

The NHS is grouped into four different and independent bodies within the UK. These are: NHS Scotland; NHS wales; NHS England; and NHS Northern Ireland. The NHS has been criticised, but yet it is one of the most succesful healthcare system in the world due to the quality of healthcare service offered free at the point of use. Despite these issues, there are modern challenges that affect the quality of healthcare delivery. Therefore, there is a need to consistently, unswervingly and unfailingly provide strategies that can develop and improve the current state of healthcare facilities. The NHS Choice, (2012a) describes the three core principles of the NHS. These principles are: that it meets the needs of the public; that it should be free at the point of use; and that it be based on clincal needs not the ability of users to pay for treatment.

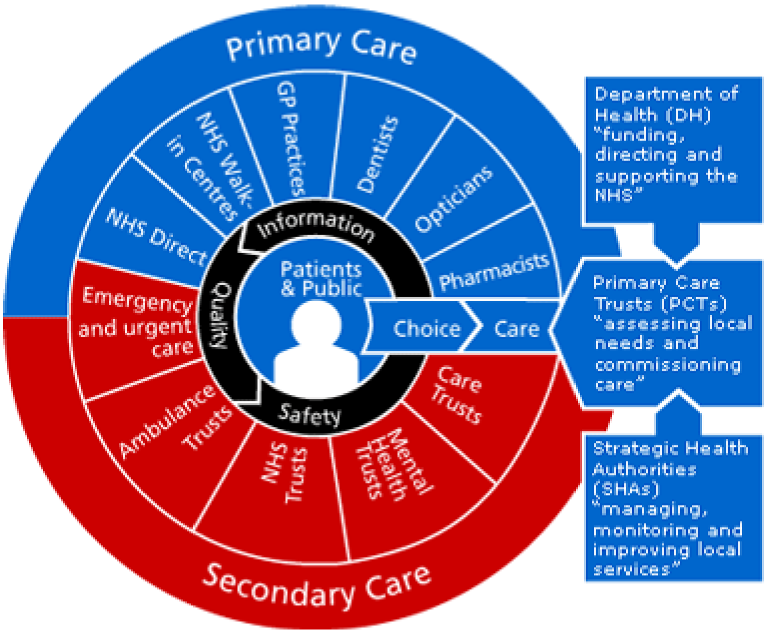


Figure 3.1: *NHS Structure. Source: NHS Choice, (2012b)*

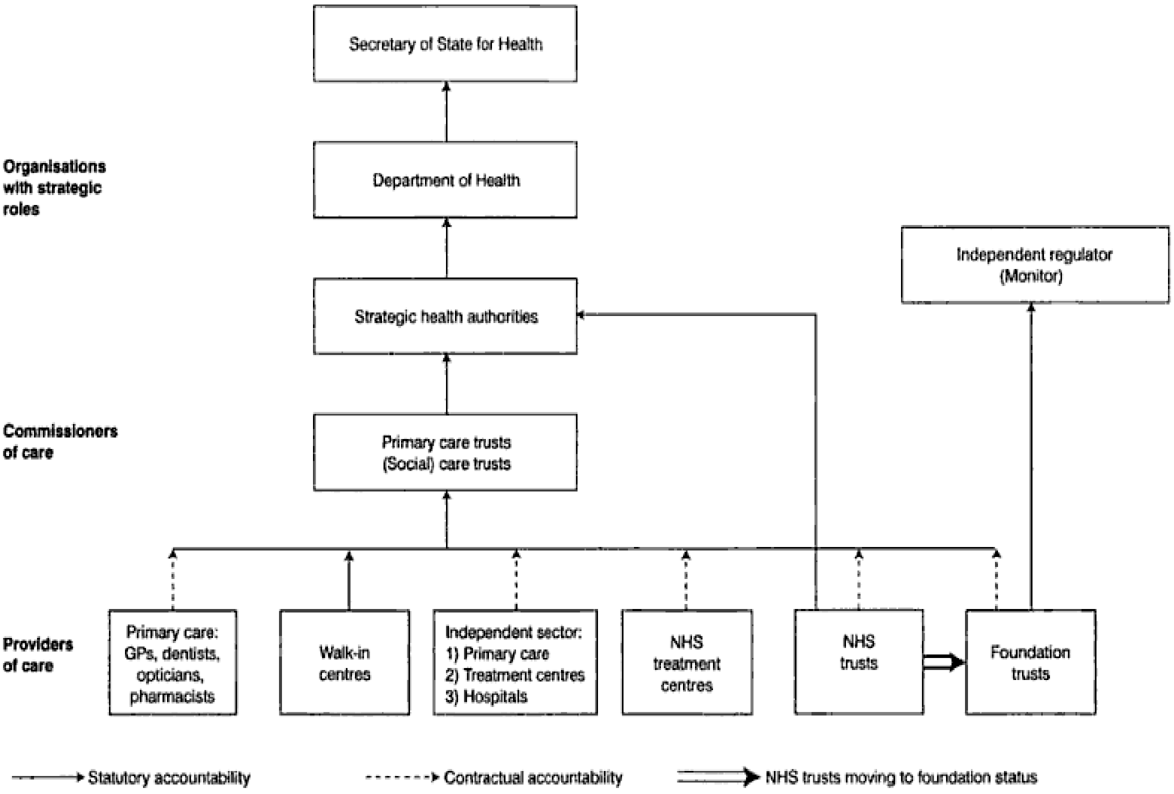


Figure 3.2: *The structure of the new NHS in England. Source: (Smith and Pollock et al, 2006, p. 8)*

The NHS Choice, (2012b) clarified the NHS structure in Figure 3.1, illustrating that the NHS is funded by Department of Health (DH), and it is also managed and monitored by the Strategic Healthcare Authorities (SHAs). It also show the NHS consisting of two major categories of care which are the primary trust and the secondary trust. The primary trust are usually the first contact point for healthcare service to the public. The secondary trust are mostly referral healthcare services known as acute trust; they offer specialist healthcare services, such as surgeries and so on. Figure 3.2 shows a more detailed structure of the hierachial order of the UK healthcare sector presenting the Sectary of State for Health as the top most leading office. Only the DH reports directly to the Secretary of State, all other health authorities reports to the SHAs.

3.1.2 THE UK NHS ESTATES

BBC (2010) stated that one fifth of the NHS estates were built before the NHS was created in 1948, and that 17 percent of the NHS estates are under performing. With the NHS planning to save 50 billion pounds by 2050, it is a very complex task to save cost and improve the quality of NHS estates. The DH, (2009-2010) stated that the main findings for the year 2009-10 are:

- the total size of the NHS estate, measured by its floor area, has grown by around 2 percent to 28.4 million square meters, whereas the total siteland area which includes all buildings, grounds and gardens has decreased by 4 per cent to 7,462 hectares. from 2002/03;
- the percentage of single bedrooms as a proportion of total available beds continues to rise, there has been a significant increase from 22.6 percent to 32.7 per cent. In actual bed numbers, this means that 10,486 more single bedrooms are available for patient use than in 2002/03, a rise from 42,273 to 52,759;
- the NHS have classified 7.3 per cent of all occupied floor area as un-utilised space, declaring it either empty or under-used. This equates to 1,974,983 m2 from the total occupied floor area of 27,053,886 m^2;
- carbon efficiency across the NHS estates have improved by almost one percent during the last year, and is currently 99kg CO2e/m^2; and
- overall, the direct costs of the NHS estates are therefore £6.6 billion which makes it one of the largest costs for the NHS along with staff costs and drugs.

In order to improve the quality of projects the DH (2010) stated that

> *There is no longer a requirement for bidders to complete the Capital Investment Manual (CIM) FB forms; instead they must complete a number of new capital and lifecycle proformas in a new elemental cost format at PITN and FITN stages. These should allow for:*
> *• improved assessment against specifications;*
> *• greater cost and qualitative transparency between bids; and*
> *• more accurate benchmarking against future proposed changes/variations.*

There are some current developments by the NHS in order to save the 50 billion pounds by 2050, but more needs to be done to address the issue of cost and variations within the development of the NHS estates. A total of 50 billion pounds savings will inevitable come from a number of different improvisations in the healthcare sector. The successfully designs of change-ready healthcare facilities using BIM support can promote cost efficiency and project quality to some extent.

3.2 CHANGE-READY HEALTHCARE FACILITIES

To design a change-ready healthcare facility, the application of refurbishment, flexibility, standardisation and BIM can be applied together to create caring environments that can caters for immediate needs. A change-ready healthcare facility is expected to change in order to adapt to future changes, such as an ageing and growing population, change in model of care and advancement in healthcare treatment through the use of modern healthcare equipment. Flexible healthcare spaces have to be provided to accommodate these changes in order to provide more value for money and increase the life span of facilities.

3.2.1 REFURBISHMENT AND CHANGE-READY HEALTHCARE FACILITIES

Refurbishments may include redevelopment, renovation, reorganisation, extension, expanding, contracting or modifications to suit current or future functions. Refurbishment is explored to improve the exisiting conditions of healthcare facilities and to create the basis for change in function. The spaces in healthcare facilities accommodate critical activities that are subjected to rapid changing needs. For example, the introduction of new modern equipments. The application of refurbishment in this research is explored as an opportunity to make buildings more flexible (change-ready) when developing, redesigning, refurbishing or redeveloping. A change-ready healthcare facility is an intelligent building that needs to be carefully designed. The proposal suggested towards achieving future proof designs could affect various parts of an existing healthcare facilities. Nevertheless, during refurbishment Gorse and Highfield (2009) stated that the availability, quality and the process of acquiring planning permission for existing buildings is more feasible compared to new buildings. Milburn (2004) stated that refurbishment supports the installation of modern infrastructure and equipments. The factors stated above can support the design of a change-ready healthcare facility. It is important to appreciate that refurbishment is different from a larger scale maintenance. Refurbishment often involves providing an opportunity to support new activities whereas maintenance is the proces of repairing and maintaining the status quo. Figure 1.1 in chapter 1 shows the different impacts of maintenance and refurbishment on a building`s lifecycle performance.

3.2.2 FLEXIBILITY AND CHANGE-READY HEALTHCARE FACILITIES

Flexibility is the process that enables a change-ready healthcare facility to be adaptable and future proof on a short-term basis, mid-term basis or long-term basis. flexibility creates an opportunity to tackle both immediate and future changes within a facility. The flexibility approaches towards designing a change-ready facility can be achieved through six building elements within a facility. These are described by Brand (1994) as the: site; shell; skin; services; scenery; system; and settings. Yorkon (2010, p. 7) also described strategies that promotes flexibility in a facility. These include:

- use of generic patient contact spaces;
- limiting the number of specialist spaces;
- standardising room sizes and the position of built-in equipment;
- consideration of future engineering sevices requirements at the outset;
- using flexible and adaptable forms of construction;
- developing a modular appraoch to planning and construction; and
- provision of space for future expansion.

Some or all of the features identified above can be incooroperated into a facility to achieve a change-ready healthcare facility, but it depends on the exisitng and proposed features of a facility. There are four flexible spaces described by Finch (2008); these are expansible, convertible, versatile and malleable spaces. These spaces can be used to facilitate the design of a change-ready healthcare facility. This research is focused on known or expected future changes; clients would hardly opt for an improvisation that has little evidence of occurring. Therefore, the framework can easily addressed key functions that can increase the quality and life span of the facility. For example, with more population, more number of beds and subsequent functions should be provided. Another example; with more ageing and growing population, more standardised disabled facilities can improve working conditions.

3.2.3 STANDARDISATION IN CHANGE-READY HEALTHCARE FACILITIES

Standardisation is important especially within a rapidly changing environment. Reiling (2007) stated that standardisation improves the safety of both staff and patient through the process of using simplified and appropriate specifications to prevent or reduce the possibility of errors occurring during healthcare activities. Joint Commission Resources (2004a) stated that standardisation improves efficiency. A predictive, appropriate, suitable, simplified and applicable process can reduce exhaustion, possible disruption or change to optimise the quality of healthcare delivery enabling staff to focus on clinical issues. Jakobs (2000) was of the view that the application of new standards is used to generate effective solutions to initial problems. When spaces are standardised, they are able to relate easily with both patients and staff over a long period of use. Standardisation within spaces allows flexibility to take place. For example, standardise rooms can easily be converted to universal treatment rooms due to similarity in layout, size and shape. Yorkon (2010) stated that flexible spaces are supported by standardised modular designs. For example, the use of similar size spaces for different purposes. For the purpose of this research the applications of flexibility and standardisation are combined and explored collectively.

3.2.4 BIM IN CHANGE-READY HEALTHCARE FACILITIES

One of the key advantages of BIM when designing change-ready healthcare facilities is the ability to generate, analyse and evaluate different flexible design options or scenarios. BIM can be used to support the application of flexibility and standardisation through the integrated and collaborative analysis of different healthcare spaces within a BIM environment to produce effective and efficient spaces that are virtually evaluated before constructed. The benefits of BIM in the AEC industry are unquestionable, it has an impact on pre-design, design, pre-construction, construction, facility management and refurbishment. the benefits of BIM are presented with references in the sections below. BIM can help in cost reduction through the production of designs with lesser errors, mitigating, controlling and reducing the use of excess material and construction labour. The virtual analysis allows optimasation that can increase the quality and efficiency of work to be conducted. BIM is gaining momentum and replacing traditional building procurement process due to its remarkable benefits. Eastman *et al*. (2011) stated that the transformation pattern of BIM application for each organisation will depend on their culture, capability, commitment, and activities. It is described by Autodesk (2003, p. 1) that BIM assists in the:

- design phase- with design, schedule, and budget information;
- construction phase- with quality, schedule and cost information; and
- management phase- with performance, utilisation and financial information.

The Construction User Roundtable (CURT) was founded in 2000 by construction and engineering professional executives representing major cooporations in the US and the world at large. They provide national and international forum for information exchange on construction and improve client owner leadership. CURT, (2004) suggested four key issues to be considered to control time and cost in the AEC Industry. These are: leadership; integration of project structure; information sharing; and BIM.Therefore, it is vital that BIM is considered in any heatlhcare facility project. In addition to this, many design and construction companies are claiming reducing millions in a multi million project through the applciation of BIM. It is stated by Medical Construction and Design (2010) that "*Turners utilisation of BIM and lean construction on Middle Tennessee Medical Centre in Murfreesboro saved project millions*" Turner is claimed to be the US largest builder of healthcare facilities. Digital coordination process was one of the main factors that influence their success of cutting costs. From the analysis of literature review, it can be deduced that the building industry could offer efficiency to the UK NHS through the use of BIM processes. One of the main aims of this research is to reduce costs using BIM while keeping efficiency as a primary concern. There is also a UK construction strategy in 2011 that indicates a BIM mandate 2016 and provides basis for BIM implementation in the UK. IPD facilitates healthcare delivery processes which supports collaboration between different stakeholders involved.

Table 3.1 shows some possible relationships between refurbishment, flexibility, standardisation and BIM; within the 10 healthcare delivery outcomes identified from literature and a questionnaire survey (see appendix 6), five outcomes have been verified from literature sources to have mutual relationships between each other. For example, the applications of refurbishment, flexibility, standardisation and BIM are identified from different literature sources to have the following features:

- saving time and cost;
- ease to use/reuse facility;
- increased operational management;
- increased patient and staff safety; and
- increased whole life cylcle cost effectiveness.

The other five healthcare delivery outcomes within the 10 identified in Table 3.1 were only partially related to each other. A single "x" anotates a partial backing from literature with no found examples, while "xx" annotates a strong backing with clear examples from literature. Findings show some relationship between the applications of refurbishment, flexibility, standardisation and BIM; the four applications above are also represented by 1; 2; 3; and 4 respectively cross referencing in Table 3.1. This research has further explored their combined application within a change-ready healthcare facility design framework. The main challenges were to explore a strategic and effective method of using the four applications. This is explicitly described in chapter 5.

3.2.5 PROCUREMENT DELIVERIES AND CHANGE-READY HEALTHCARE FACILITIES

ProCure 21+ suggest a new framework that will simplify refurbishment and new builds by providing projects to stakeholders with historical evidence of achieving required performance. DH (2010A, p. 12) stated that "*An NHS client may select a (Principal Supply Chain Partners) (PSCP) for a project they wish to undertake without having to go through an (Official Journal of the European Union) (OJEU) procurement requirement*" OJEU is a tender document or template. They also stated that "*the public sector recognised that significant benefits could be realised on capital schemes through collaborative working*". Procurement delivery such as ProCure 21+ have a similar goal with this framework in terms of more collaborative working with close emphasis on refurbishment projects and addressing life cycle inputs. However, they are not precisely aligned. UK Government Construction strategy (2011) addressed the UK Goverment BIM mandate by 2016 to ensure certain projects have at least electronic documents. As a result, this framework had to be BIM compatible. IPD suggests collaboration, where stakeholders and systems share the same project goal through shared risk and reward (Kent *et al*. 2010). Thus in this study, the main goal is to achieve a facility that can respond to known future changes. However, risks and benefits are not shared between the stakeholders in the designed framework. PAS 1192 suggests the exchange of data such as geometry (2D), non-geometry (3D) and documents; this has been achieved in Stage 3 of the framework. The main features of the framework aligning with the UK Government strategies include: collaboration; information management; BIM platform/ BIM ready improvisations; sharing project goal with different stakeholders; life cycle planning by adapting to known future changes.

Table 3.1: *Relationship between the framework component and healthcare delivery outcomes*

Healthcare delivery outcomes	**References**	**Framework design components**			
		Refurbishment……..1	**Flexibility…………..2**	**Standardisation……..3**	**BIM………………..4**
Reduce patient and staff travel	Ahmad………………………………………………………………………..1 Pati *et al*. (2008)…………………………………………………………..…2 Pati *et al*. (2008); Chaudhury *et al*. (2004, p. 11)……………………………......3	x	xx	x	
Saving time or cost	Ahmad………………………………………………………………………..1 Gallant *et al*., (2001); Taylor *et al*., (2011); Slaughter, (2001, p. 209)………...2 Chaudhury *et al*., (2004, p. 11); Price and Lu, (2012, p. 9) quotes Cahnman, (2006); Price and Lu, (2012, p. 8); Gibb, (2001, p. 307)…………………….....3 Healthcare journal, (2011); Hardin, (2009); Eastman *et al*., (2011); and Weygant, (2011)…………………………………………………………..…4	xx	xx	xx	x
Increase staff confidence	Pati *et al*., (2008)……………………………………………………………...2 Pati *et al*., (2008)……………………………………………………………….3		xx	xx	
Facilitates universal space design	Ahmad……………………………………………………………………..…1 Pati *et al*., (2008)……………………………………………………………...2 Reiling, (2007); Taylor et al, (2011)…………………………………………...3	x	xx	xx	
Patient dignity and privacy	Ahmad……………………………………………………………………..…2 Chaudhury *et al*., (2004, p. 3) quotes Bobrow and Thomas, (1994); Burden, (1998); and Morgan and Stewart, (1999)……………………………………......3		xx	x	
Increase staff efficiency	Pati and Harvey, (2011)……………………………………………………........2 Reiling, (2007)…………………………………………………….............……3		xx	xx	
Ease to use / reuse facility	Ahmad…………………………………………………………………...……1 Ahmad………………………………………………………………………....2 Reiling, (2007)…………………………………………………………………..3 Chellappa, (2009, p. 75)……………………………………………………….4	x	x	xx	xx
Increase operational management	Palgrave, (2011)……………………………………………………………....1 Pati *et al*., (2008); Slaughter, (2010, p. 209)………………….……………......2 Joint commission resources (2004)……………………………..............…......3 Eastman *et al*., (2011)……………………………………………………..…4	x	xx	xx	xx
Increase patient and staff safety	Pommer *et al*., (2010, p. 1383)……………………………………………...…1 Chaudhury *et al*., (2004, p. 4) quoted Bobrow and Thomas,(2000); Gallant and Lanning, (2001); Hill-Rom, (2002); Spear, (1997)………………………….......2 Reiling, (2007); Price and Lu, (2012) Malone *et al*., (2007)…………………....3 Chellappa, (2009, p. 31); Sullivan, (2007)…………………………….…….......4	x	xx	xx	x
Increase whole life cycle cost effectiveness	Cleveland clinic, (2010)…………………………………………………….......1 Eastman *et al*., (2011)……………………………………………………...…...2 Price and Lu, (2012)…………………………………………….............…......3 Palgrave, (2011)……………………………………………………………......4	xx	xx	xx	xx

X: Indicates relationship. **XX:** Indicates strong relationship
1: Refurbishment; **2:** Flexibility; **3:** Standardisation; **4:** BIM

3.3 CHANGE-READY HEALTHCARE FACILITY DESIGN

The Joint Commission Resources (2009, p. ix) stated that "*the environment of care is made up of three basic components: buildings, equipment, and people*". These three design components can be achieved through the application of six key factors for designing healthcare facilities. These are: enhancing patient and staff safety; user satisfaction; identifying and addressing the needs of the community; incorporating changes in technology; environmental considerations; and improving medical travel. A change-ready healthcare facility can support the future needs of modern healthcare delivery. Perhaps a robust design is key to achieving an effective healthcare facility.

3.3.1 SPECIAL NEEDS OF HEALTHCARE FACILITIES

What are quality standards in healthcare design? According to Purves (2009, p. 12) "*space utilisation, functionality, suitability, energy efficiency, statutory standards (compliance) and physical condition*" are used to define quality standards in the evaluation of design quality. The issues addressed above show that functionality and cost are very important factors to consider when designing healthcare facilities. Apart from the designer and builder inputs, there are both Governmental and private bodies involved in the design and construction of healthcare facilities. The Commission of Architecture and the Built Environment (CABE) is a public body that was established in 1999 by the UK Government. It is was the Governemnt`s adviser on the built environment. They offer advice to the building project stakeholders to achieve quality and works directly with designers, planners and clients. CABE was merged into the Design Council in 2011. CABE (2006) stated that it provides service to the NHS, it also support projects with technical advices/guidance at early project stages. It also offers design review service at a later stage of the design process for planning submission purposes. A Staff and Patient Environment Calibration Toolkit (ASPECT) is used to enhance healthcare building designs by reviewing the quality of staff and patient environment designed. They produce criteria that enables measurement, and assessment of design quality in order to improve the productivity of healthcare facilities. It is stated by Miller (2006, p. 6-28) that the features of facility design include:

- performing a proactive risk assessment;
- assessing the needs of the community;
- designing to maximize staff efficiency;

- planning for new technology (technological change);
- communicating requirements to contractors;
- focusing on staff safety and prepared for emergencies;
- incorporating designs that encourage healing and enhances positive patient outcomes;
- using the establish architectural standard guidelines for the design and construction of healthcare facilities;
- creating workable schedules;
- managing the nuts and bolts for the design and construction process with an emphasis on joint commission requirements;
- monitoring controls for infection, air quality in clinical areas, patient safety, debris and dust containment (short-term and long-term), and noise; and
- working with the Authorities Having Jurisdiction (AHJs) during construction.

3.3.2 NEEDS OF A FLEXIBLE HEALTHCARE FACILITY

One of the needs of healthcare facilities include the need to design flexible healthcare facilities that can adapt to future needs of facility users. There are other special needs, but this research focuses on the need to generate flexible designs Neufville (2008). Purves (2012, p. 52) stated that

> "*a completely different approach to building design is required for the next wave of primary care buildings. They must be buildings that are flexible, can incorporate the demands of a knowledge-based economy and respond to the rapid changing demands for information technology*".

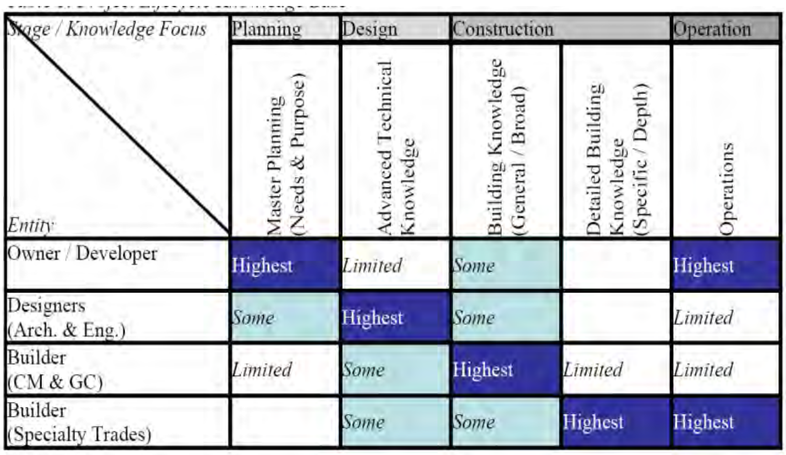
To save cost in healthcare facilities, an approach towards future changes is required. Changes in any facility can increase its operational cost or reduces its quality. Perhaps, flexibility is an option or a means of achieving a subsequent response towards future changes. Flexibility has a place in healthcare facility design, it can be used as an impelling factor that can facilitate and support healthcare facilities to function properly over time. Flexibility also helps to explore effective whole life cycle targets without compromising efficiency or performance. The changing nature of healthcare facilities leaves staff with more elderly people to care for, a growing population, vast change in technology and modern care, change in specifications, new Government policies on sustainability such as green building requirements and reduction in carbon emission. Flexibility is required to help accommodate predictable changes in legislations, population density and technology without the total demolition of buildings. Changes occur drastically and impulsively in hospital designs; there is a need to respond to change and technology in the short-term or long-term. Pressler (2008, p. 53) stated that a ”*good design should provide an adequate amount of flexibility*” to allow healthcare facility to progress effectively over the time of their usage. A question that emerges is what defines a good design? Figure 3.3 describes three key elements with strong relationships within a healthcare setup. These can be described as functional space, diagnostic treatment and equipment/tools (Chellappa, 2009, p. 11).

Figure 3.3: *Three key elements with strong relationship within a healthcare facility. Source: Chellappa (2009, p. 11)*

Figure 3.3 is address three components. These are diagnostic/treatment; functional space; and tools/equipment within a healthcare environment. Healthcare delivery treatment/diagnostics usually takes place within a healthcare functional space using healthcare tools/equipment.

3.3.3 FACILITY PROCUREMENT PROCESSS

The design, construction and management of different facilities are conducted by different building professionals in the AEC industriy. In a basic interpretation of professionals in the building industry, which is not necessarily the case, the design professionals produce the design; the builders build, while the facility managers manages the operation and maintenance of a facility. Figure 3.4 highlights areas and levels of proficiency of the building industry professional at the different stages of the building procurement process.



Stage / Knowledge Focus	Planning	Design	Construction		Operation
Entity	Master Planning (Needs & Purpose)	Advanced Technical Knowledge	Building Knowledge (General / Broad)	Detailed Building Knowledge (Specific / Depth)	Operations
Owner / Developer	Highest	*Limited*	*Some*		Highest
Designers (Arch. & Eng.)	*Some*	Highest	*Some*		*Limited*
Builder (CM & GC)	*Limited*	*Some*	Highest	*Limited*	*Limited*
Builder (Specialty Trades)		*Some*	*Some*	Highest	Highest

Figure 3.4: *Professionals and the knowledge base table. Source: Manning and Messner (2008, p. 447)*

The design process is jointly conducted by the owner and appropriate building professionals. The process starts with the Strategic Definition, Design Brief extending to Schematic Design or Concept Design which forms the basis of the design process. Figure 3.4 describes the entire Plan of Work by the Royal Institute of British Architects (RIBA, 2013). The whole building process covers both the design and construction phase. Wang and Schnabel (2008, p. 69) agrees with Miller (2006, p. 2) that the design process of most projects can be organised into six distinctive phases. These are: Planning, including Master Planning; Schematic Design; Detailed Design; Construction Documentation; Construction, involving the process of converting all design document to contractors manuals; and Commissioning while ensuring all architectural specification are taken into account before the handing over of a given property. The design process described by Miller (2006) was not adopted as the RIBA Plan of Work 2013 illustrated in Figure 3.5 is nationally accepted in the UK.

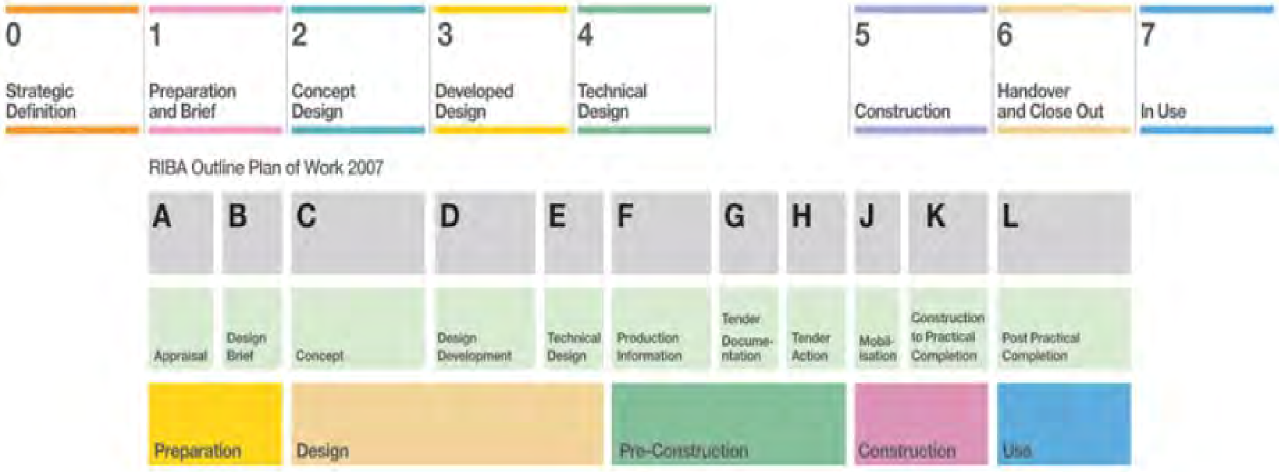


Figure 3.5: *RIBA Plan of Work (2013)*

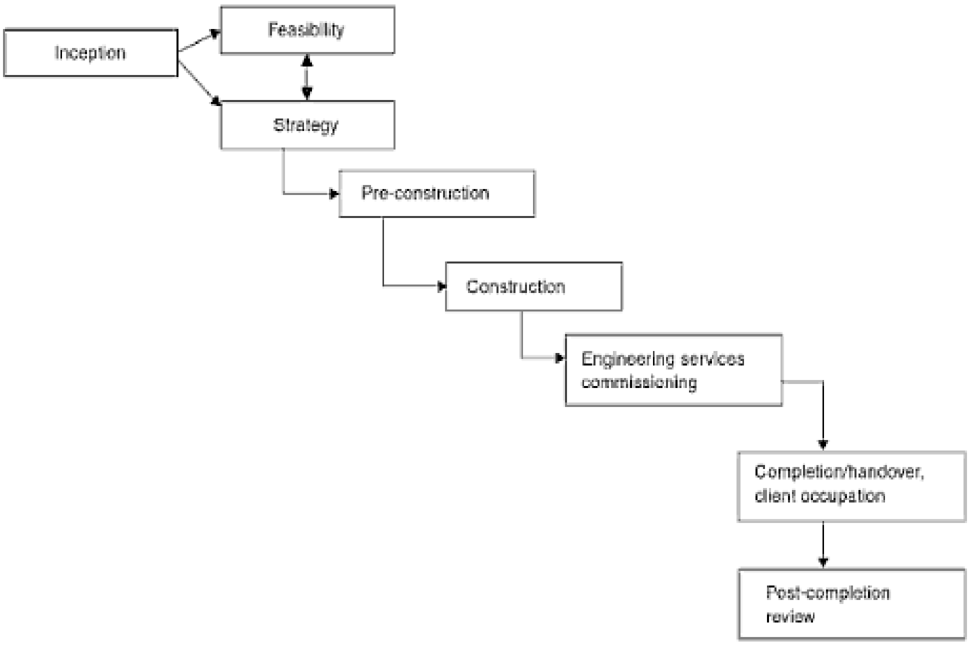


Figure 3.6: *Construction process. Source: Chartered Institute of Building (CIOB, 2010, p. 24)*

The Chartered Institute of Building (CIOB, 2010) described the construction process in Figure 3.6. This research focuses on the design process more closely. Figure 1.1 in chapter 1 illustrated that faulty designs are major causes of building failures. Designs can be optimised using BIM tools to analyse and evaluate facility performances with some degree of accuracy.

BIM has an impact on both business and social outcomes within the AEC industry. The operational phase of a building takes a huge percentage of the entire project cost within some years of use. Chadhury *et al*. (2004, p. 2) quoted Bobrow and Thomas (2000); Paatela (2000); Berry (1974) stated that "*in general, operating cost accounts for over 70 percent of the hospital`s overall cost and are usually the same as capital costs within the first three years of construction*".

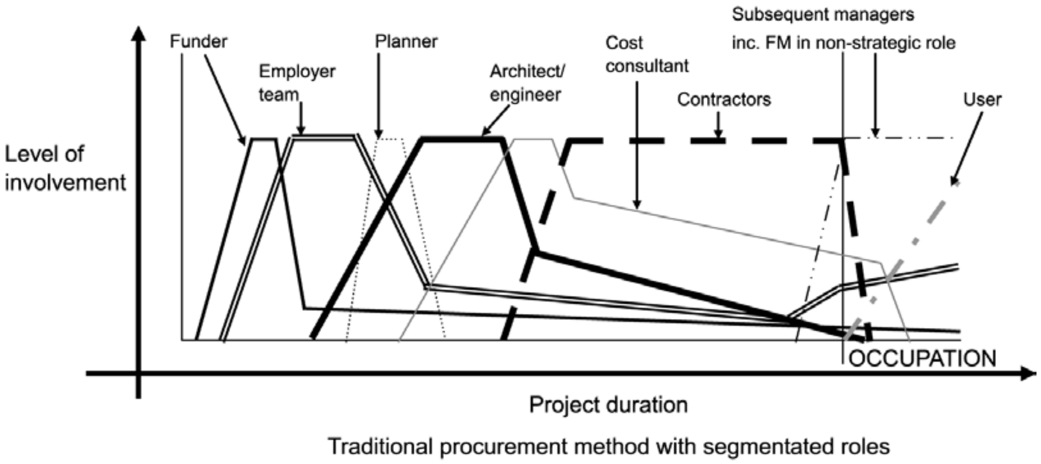


Figure 3.7: *The level of involment of professionals within a project. Source: Shah et al. (2008, p. 393) describing Brown (2001)*

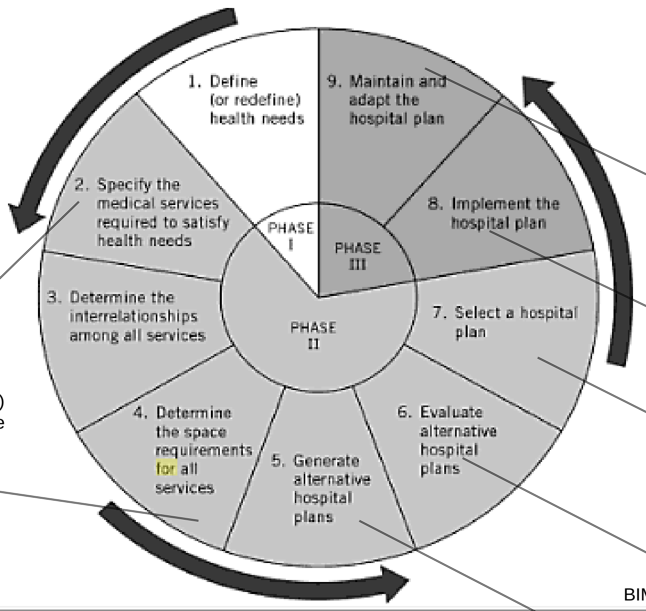
Shah, *et al*. (2008, p. 393) describes Brown (2001) in Figure 3.7. The effective involvement of different professionals is crucial, but when bad decisions are made during the design and construction stage, the outcome can be clearly percieved during the operational phase of a facility. The amount of decision making required during the design process is a lot. The traditional procurement method enables professionals to make individual decisions at their specialised project phases, while procurement methods such as Integrated Project Delivery (IPD), and the Design and Build (D&B) appraoches enable proefessionals the opportunity to make informed and joint decisions at early project stages. IPD is the agreement of stakeholders, sturctures and practices to improve project outcome. D&B is a process in the construction industry where the design and construction team are contracted in a single group. However both processes supports collaborative working schemes. The *McLeamy Curve* describes one of the differences between IPD and traditional approaches, it shows that cost of design changes *increases* after the Schematic Design Stage under the IPD process while it *increases* after Design Development Stage in the traditional design process. Design effort and effect is higher in the trational method. Despite, the construction professionals conducting the utmost tasks during the building procurement process, design faults are the major causes of facility failures and these faults reflect in a facility when it is occupied and operational (Palgrave, 2011, p. 13).

3.3.4 PROCESS OF DESIGNING A HEALTHCARE FACILITY

Tompkins *et al*. (2010) described the healthcare facility design process in Figure 3.8 to be divided into three phases; the first phase requires the identification of the healthcare facility needs and integration of all features that would be designed into the facility. In phase two, specific service that could help fulfil hospital needs are identified. The relationships between different spaces are developed before space specifications are determined. The space requirement for all services identified are expected to allow different plans to be generated and evaluated. Selecting the most suitable and appropriate plan to be implemented requires the combined decision making from the different stakeholders invloved. Phase three is the stage where the design is implemented and maintained. BIM can be used in the entire process to achieve desired project outcomes and mitigate unnecessary waste of time and cost through information management, analysis and evaluation of different flexible design options, and the virtual optimisation of building performance before the construction takes place. Further studies answered questions such as:

- who is responsible for the flexible designs?;
- how to embed flexibility with BIM support?;
- how are flexible healthcare facilities set to accommodate future unforeseen circumstances?;
- what factors determine the need for flexibility in healthcare facilities? and
- how to avoid unnecessary use of redundant spaces?

Figure 3.8 shows the hospital plan and where BIM applies in the context of this research. Within the nine steps identified by Tompkins *et al*. (2010), step two is where all the hospital requirements are specified, this information needs to be organised and managed properly by checking current updates in standards and to share information with other stakeholders involved to make joint and informed decisions. Step four is relevant to step two, but space specification is vital to the process of design re-use. BIM tools can be used to store space specifications, they can be saved as a BIM object which could be prototyped and used in a different project. In step five, alternative hospital plans are generated. The use of *What if scenarios* with BIM can aid the process with different design options, while BIM can also be used to analyse and evaluate the various design options generated. BIM visualisation can be used to illustrate the selected hospital plan in step seven for final review with all the stakeholders involved; the illustration will show exactly what all the stakeholders will expect at the end of the project. The exact illustration is generated from a model which has precise and detailed information that allows the production of a schedule construction sequence to practically implement the virtual hospital plan stated in step eight. When real live information is attached to the BIM model, the performance of a facility can be analysed to simplify the tasks of the facility managers.



Virtual analysis can be conducted to manage the operational performance of a buildings to some extent.

A virtual selected hospital plan can be precisely implemented.

BIM visualisation can be used to select a plan based on informed decision.

BIM can be used to analyse and evaluate design options.

"What if scenarios" can be used to generate different plans.

Using BIM (information sharing) specified requirements can be shared within a BIM platform.

Tompkins et al, (2010)

Figure 3.8: *Healthcare facilities design where BIM applies. Modified from Tompkins et al. (2010)*

3.3.5 CHALLENGES OF HEALTHCARE FACILITIES

There is a need for all professional stakeholders involved in the design of healthcare facilities to clearly understand the plan and its implementation procedures to enable opportunities for joint decisions that could improve and support adjustments prospects, opportunities and parameters relating to cost and quality of the design, while the safety of patient and staff remains paramount to the planning and designing process. Despite the opportunities for modern innovation in healthcare, safety should always be considered as a primary concern. Purves (2002) stated that architecturally, the challenges of a healthcare facility are: to reduce cost of desiging and and managing facilities through energy consumption and life cycle cost management at the early design stages through the; *use of standards*; *planning for flexibility* (functionality); increasing value for money through the effective design of quality spaces and standardisation of components with uniques designs and choice of materials (sustainability); and the production of adequate circulation and wayfinding (accessibility) strategies within a healthcare facility. EC Harris (2012) stated that healthcare facilities face the staggering challenge of designing efficient facilities to avoid the creation of underutilised spaces. They are also of the view that healthcare facilities should be fully standardised to improve the efficiency of healthcare delivery. Herztlinger (2006) stated that innovation in healthcare is difficult due to the different stakeholders involved, lack of funding, contraints caused by regulators, and among others are technology, need of different customers and accountability. Fottler *et al*. (2000) stated that future healthcare designs have to incooperate healing environments to improve patient care. Healing environments may include the introduction of nature to patients or the production of homelike environments. Reiling *et al*. (2008) stated that safety is essential in healthcare facilities, and it can be achieved through: automating where possible; designing to prevent adverse events; design for scability, adaptability, and flexibility; place accessibility information close to users; improve patients visibility to staff; minimise staff pressure; minimise patient transfer; involve patient in their care; reduce noise; and standardise.

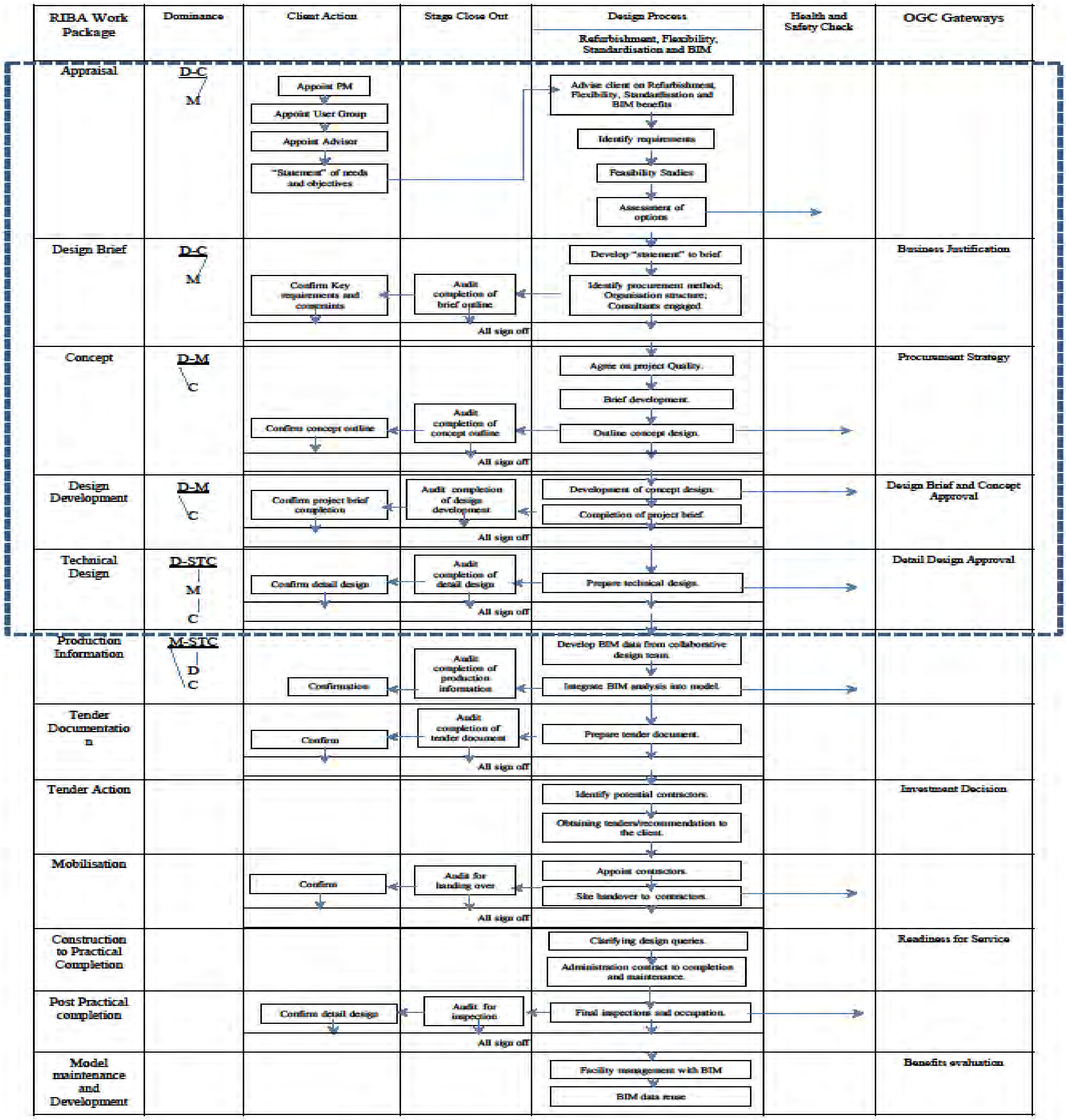
3.3.6 PROPOSED AREA OF RESEARCH FOCUS

The RIBA Plan of Work with BIM Overlay was analysed together with the design management process described by Gray and Hughes (2001) to present the scope of work for this research. The proposed framework was designed in-line with RIBA Plan of Work as it is universally agreed and accepted by majority of the architectural designers in the UK. Table 3.2 and Table 3.3 below shows the entire building procurement process and highlights the focus of this research. It consists of seven columns, these are the RIBA Plan of Work Stages; key features identified include: the most important professionals within each building procurement stage with *dominance*; the required *client action* at each key stages; the stage close out; the main *design process*; the health and safety checks at each key stages; and the Office of Government Commerce (OGC) Gateways. It is an independent body of the UK treasury. It was responsible for improving procurement efficiency. This research focuses only on the design process. The reason behind the decision to select the design process was based on the objectives of this research to produce guidelines for healthcare designers and planners to achieve a change-ready healthcare facility. The application of refurbishment, flexibility, standardisation and BIM are all categorised under the design process column.

Tables 3.2 and 3.3 were developed from literature review. The design management described by Gray and Hughes (2001) was used to described the focus of this research as it provides indepth analysis of the design process. However, the design stages where replaced with the RIBA Plan of Work Stages (2007) and the BIM Overlay presented in appendix 10 was also used to tabulate Table 3.2. The RIBA Plan of Work is nationally accepted in the UK compared that of Gray and Hughes (2001). However, other features such as dominant professionals and client action within the design process were mentioned due to their importance in this study.

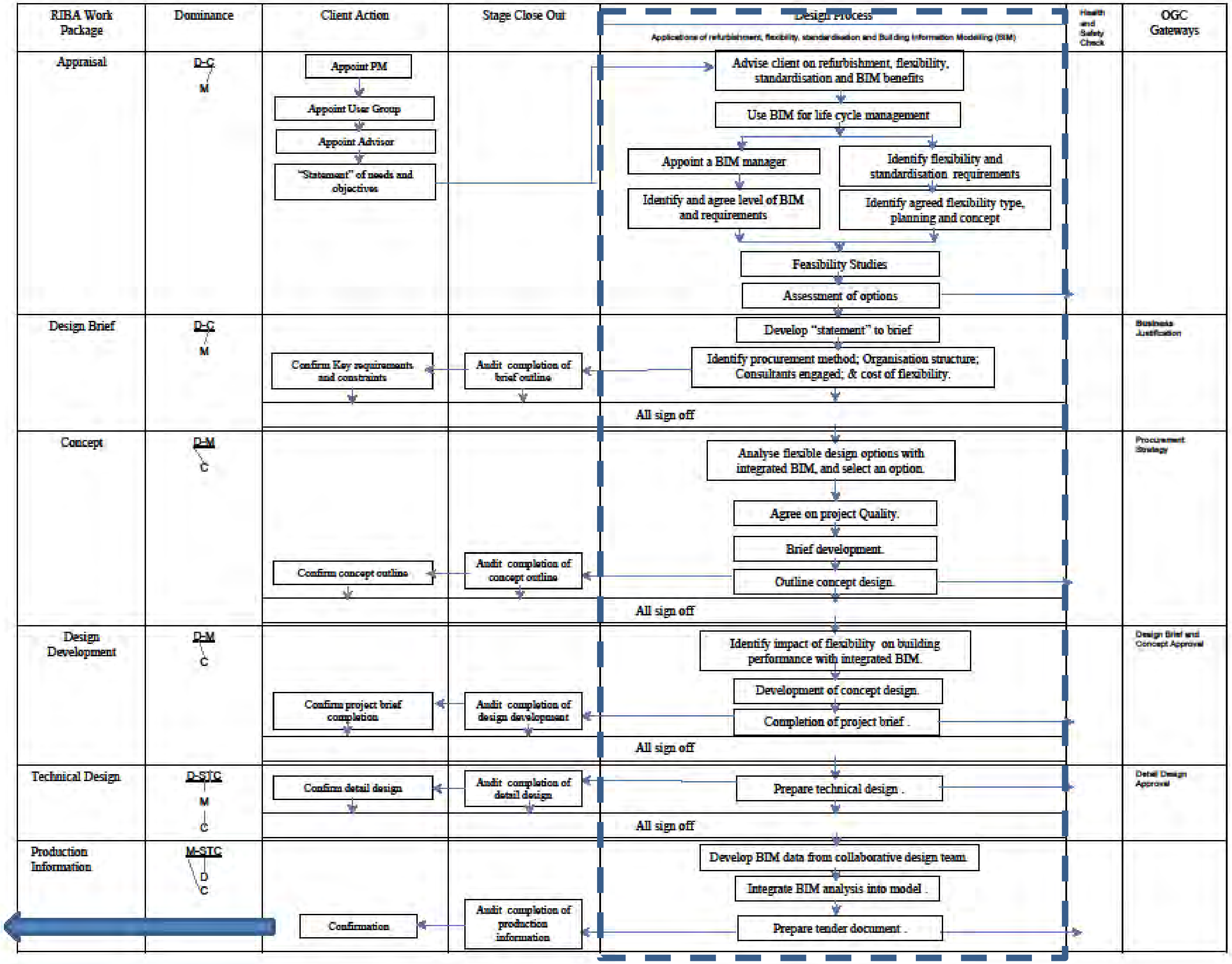
The RIBA Plan of Work 2007 was used during the literature review analysis and when presenting the questionnaire surveys to possible respondents. During the interviews the RIBA Plan of Work 2013 was available. This research improved the framework based on the new changes. The key difference between the RIBA Plan of Work 2007 and 2013 is the introduction of the New Stage (Strategic Definition Stage 0); it is defined by RIBA (2013) as "*a new stage in which a project is strategically appraised and defined before a detailed brief is created..certain activities in Stage 0 are derived from the former (RIBA Outline Plan of Work 2007) Stage A- Appraisal*". However, the new RIBA Stages overlaps at some stages (see Figure 3.5). As a result, the boundaries of the framework tasks were adjusted.

Table 3.2: *Scope of research focus within the building delivery process. adapted from Gray and Hughes (2001) and the RIBA Plan of Work (2007).*



RIBA Work Package	Dominance	Client Action	Stage Close Out	Design Process Refurbishment, Flexibility, Standardisation and BIM	Health and Safety Check	OGC Gateways
Appraisal	D-C M	Appoint PM Appoint User Group Appoint Advisor "Statement" of needs and objectives		Advise client on Refurbishment, Flexibility, Standardisation and BIM benefits Identify requirements Feasibility Studies Assessment of options		
Design Brief	D-C M	Confirm Key requirements and constraints	Audit completion of brief outline All sign off	Develop "statement" to brief Identify procurement method; Organisation structure; Consultants engaged		Business Justification
Concept	D-M C	Confirm concept outline	Audit completion of concept outline All sign off	Agree on project Quality. Brief development. Outline concept design.		Procurement Strategy
Design Development	D-M C	Confirm project brief completion	Audit completion of design development All sign off	Development of concept design. Completion of project brief.		Design Brief and Concept Approval
Technical Design	D-STC M C	Confirm detail design	Audit completion of detail design All sign off	Prepare technical design.		Detail Design Approval
Production Information	M-STC D C	Confirmation	Audit completion of production information	Develop BIM data from collaborative design team. Integrate BIM analysis into model.		
Tender Documentation		Confirm	Audit completion of tender document All sign off	Prepare tender document.		
Tender Action				Identify potential contractors. Obtaining tenders/recommendation to the client.		Investment Decision
Mobilisation		Confirm	Audit for handing over All sign off	Appoint contractors. Site handover to contractors.		
Construction to Practical Completion				Clarifying design queries. Administration contract to completion and maintenance.		Readiness for Service
Post Practical completion		Confirm detail design	Audit for inspection All sign off	Final inspections and occupation.		
Model maintenance and Development				Facility management with BIM BIM data reuse		Benefits evaluation

Table 3.3: *Narrowing the research focus within the Design Stages adapted from Gray and Hughes (2001) and the RIBA Plan of Work (2007).*



RIBA Work Package	Dominance	Client Action	Stage Close Out	Design Process Applications of refurbishment, flexibility, standardisation and Building Information Modelling (BIM)	Health and Safety Check	OGC Gateways
Appraisal	D-C M	Appoint PM Appoint User Group Appoint Advisor "Statement" of needs and objectives		Advise client on refurbishment, flexibility, standardisation and BIM benefits Use BIM for life cycle management Appoint a BIM manager Identify and agree level of BIM and requirements Identify flexibility and standardisation requirements Identify agreed flexibility type, planning and concept Feasibility Studies Assessment of options		
Design Brief	D-C M	Confirm Key requirements and constraints	Audit completion of brief outline	Develop "statement" to brief Identify procurement method; Organisation structure; Consultants engaged; & cost of flexibility. All sign off		Business Justification
Concept	D-M C	Confirm concept outline	Audit completion of concept outline	Analyse flexible design options with integrated BIM, and select an option. Agree on project Quality. Brief development. Outline concept design. All sign off		Procurement Strategy
Design Development	D-M C	Confirm project brief completion	Audit completion of design development	Identify impact of flexibility on building performance with integrated BIM. Development of concept design. Completion of project brief . All sign off		Design Brief and Concept Approval
Technical Design	D-STC M C	Confirm detail design	Audit completion of detail design	Prepare technical design . All sign off		Detail Design Approval
Production Information	M-STC D C	Confirmation	Audit completion of production information	Develop BIM data from collaborative design team. Integrate BIM analysis into model . Prepare tender document .		

3.4 DISCUSSION OF THE ANALYSED LITERATURE USED FOR DESIGNING THE FRAMEWORK

Literature was analysed through a desktop study to develop a change-ready healthcare facility. This section provides detail inputs used to facilitated the development of the framework. This study explored BIM capabilities from the different definitions, different flexibility frameworks, application of standards within flexible spaces and exploring concepts and planning strategies for flexbility. These analyses were conducted to derive a framework that could be supported by BIM. Currently there is no flexibility framework that is supported by BIM. Literature review was used to develop a new framework that can be further developed with more deatailed information from questionnaire survey and interviews. There are existing frameworks but however they do not support the application of BIM.

3.4.1 EXPLORING BIM CAPABILITIES FROM DIFFERENT DEFINTIONS

Eastman *et al*. (2011) observed that BIM is defined and understood differently. BIM is attributed to a process, information, use of technology, modelling and management. Therefore, to explore the understandings of BIM, it is important to identify the different categories of stakeholders involved in the use of BIM within the AEC industry. Information from the different categories were analysed and evaluated to explore the different understandings and views of BIM from different stakeholder. BuildingSMART alliance (2008) noted that it is important to involve different stakeholders involved in the different phases of the building life cycle and interested in introducing, extracting, updating or adjusting information for specific purposes. To narrow down the focus of the research, Eastman *et al*. (2011) identified general stakeholders relevant in the field of BIM. Table 3.4 present the three categories of BIM stakeholders used for the purpose of this research; *other stakeholders category* was the only named group by Eastman *et al*. (2011) not included; they fall under the external category of AEC stakeholders, while academicians, AEC organisations and software groups are considered internal organisation of the AEC stakeholders. Tables 3.5, 3.6 and 3.7 were used to show views of different stakeholders within the AEC industry. themes were taken from the different definitions and understandings of BIM. Themes were later grouped under a larger umbrella in order to understand the basics of BIM.

Table 3.4: *List of identified BIM stakeholders*

Academicians	**Software and Hardware vendors**	**AEC Industry and other organisations**
Weygant (2011)	Bentley (2011)	NIBS (2010)
Eastman *at al*. (2011)	BuildingSmart (2011)	NIBS (2007, p. 49)
Thomas *et al*. (2010)	Nemetschek (2010)	VTT (2006)
Hardin (2009, p. 4)	Graphisoft (2003)	AGC (2005)
Smith and Tardiff (2009, p. XI)	Autodesk (2003)	State of Ohio (2010)
Howard *et al*. (2007)		
Sweet and Schneier (2009, p. 375)		
Howard and Björk (2008)		
Azhar *et al*. (2007, p. 2)		
Riskus (2007)		
Succar *et al*. (2007)		
Messner *et al*. (2010		

3.4.1.1 DEFINITIONS OF BIM FROM ACADEMICIANS

Definitions from academic sources are presented in Table 3.5 as they provide basis for all hypothetical and theoretical applications of inventories before they are put into practice. They are also equipped with the competency to criticise at all stages, covering the entire life cycle of the application of BIM in the building procurement process.

Table 3.5: *Definition of BIM by academicians*

References	***BIM Definitions by Academics***
Weygant (2011, p. vii)	"BIM is a technology that has improved the way structures are designed and built"…"A technology that allows relevant graphical and topical information related to the built environment to be stored in a relational database for access and management".
Eastman *et al.* (2011)	Described BIM as "not just a technology but a process" and also "BIM as vast as a multi-disciplinary design, analysis, construction and facility management technology, as well as the harbinger of dramatic process change" Described National Building Information Modelling Standards (NBIMS) who categorised BIM into three groups, 1. As a product, 2. As an IT-enabled, open standards-based deliverable and a collaborative process, and 3. As a facility lifecycle management requirement.
Thomas *et al.*, (2010, p. 170)	Stated that when using BIM technology, an accurate virtual model of a building is constructed digital when completed which contains precise geometry and relevant data needed to realise the building.
Hardin (2009, p. 4)	Described BIM as a process. Defined BIM as a means of adopting and establishing a new notion of thinking.
Conradi (2009, p. 227)	Described BIM according to US General Services Administration (GSA) as a development and use of a multi feature information model that goes beyond documenting a building to excite the realisation of construction and operation. Also quotes Howard *et al.* (2007) that the main objective of BIM is to provide a specific building model that can be used by most professionals in the building industry.
Smith and Tardiff (2009, p. xi)	Noted BIM as utilising Computer Aided Design (CAD) technology in a way that will ultimately tie all the components of a building together as objects embedded with information.
Howard and Björk (2008)	Defined BIM as a process.
Brown *et al.* (2008:3)	Stated that Riskus, (2007) described BIM as "the use of virtual building information models to develop building design solutions, design documentation, and to analyse construction process".
Sweet and Schneier (2009, p. 375)	Defined BIM as a virtual model with additional information attached to it.
Azhar *et al.* (2007, p. 12)	Stated that "a building information model characterises the geometry, spatial relationships, geographic information, quantities and properties of building elements, cost estimates, material inventories and project schedule".
Succar *et al.* (2007)	Defined BIM as "a set of interacting policies, processes and technologies producing a methodology to manage the essential building design and project data in digital format throughout the building's life-cycle".

3.4.1.2 DEFINITIONS OF BIM FROM AEC INDUSTRY AND OTHER ORGANISATIONS

AEC organisations were grouped into five different categorises by Eastman *et al*. (2011). These are: Designer/Engineer organisation; building organisation; and sub-contractor organisation; owner organisation; and outside organisations. All the organisations are inter-related with each other with the exception of the outside organisations that include people of the community, insurance companies, financial groups and Government agencies. Therefore, information from outside organisation`s category will not be used for this analysis. Table 3.6 presents definition from the AEC industries.

Table 3.6: *Definition of BIM by AEC industry or other organisation*

References	***BIM Definition by Building Industry (other Organisation)***
BIM Journal (2011)	“BIM is a business process supported by technology”.
BuildingSmart (2011)	“BIM is a digital representation of physical and functional characteristics of a facility. As such it serves as a shared knowledge resource for information about a facility forming a reliable basis for decisions during its lifecycle from inception onward”.
NIBS (2010)	Note BIM as a” tetra gram process: design, procure, assemble and operate”.
NIBS (2007, p. 49)	Described BIM as an entity with multiple features: • A product describing a facility (information building) • As a process to create a common exchange platform (information management) • A system that allows a building to be realised (building model)
VTT (2006, p. 25)	Defined BIM in 3 context; • Strategic thinking + BIMs =Transformational opportunities • Tactical thinking + BIMs = Informational opportunities • Operational thinking + BIMs = Automational opportunities
AGC (2005)	Stated that a “building information model, is a data-rich, object oriented, smart and parametric digital representation of a facility, enabling details which can be extracted, analysed to aid decision making and delivery of a facility”.
State of Ohio (2010)	Stated that “The term BIM may be used as a noun to describe a single model or multiple models used in the aggregate. The term BIM may also be as a verb in the context of Building Information Modelling or Management, the process of creating, maintaining and querying the model”
Messner et al., (2010, p. 1) quotes (NBIMS)	Described BIM as “ A basic premise of BIM is collaboration by different stakeholders at different phases of the life cycle of a facility to insert, extract, update or modify information in the BIM to support and report the roles of the stakeholders”

3.4.1.3 DEFINITIONS OF BIM FROM SOFTWARE AND HARDWARE VENDORS

Software and hardware vendors are the category that produces the technology required to implement and use BIM in the building procurement process. This category was selected as they have a tremendous impact on BIM; they are responsible for designing the BIM platform; they provide the technology and applications for multiple professionals in the building industry to collaborate within a single project. Software and hardware vendors are the manufacturers having the knowledge for providing hardware and software, while the building industry have the practical experience. Therefore, information from this category was used in the comparison and description of BIM and its implementation plans. Table 3.7 presents definitions from software and hardware vendors.

Table 3.7: *Definitions of BIM by software and hardware vendors*

References	***BIM Definitions by Software and Hardware Vendors***
Bentley (2011)	Defined BIM as a new way of approaching the design and documenting of building projects, the entire life cycle information is considered (design, build and operations) defining and simulating building delivery and operations using integrated tools.
Nemetschek`sVectorworks (2010)	Described BIM as to be classified into two. These are: Big BIM known as integrated Project Delivery (IPD): This is a business model for design, execution and delivery of buildings by a collaborative and integrated team composed of key project participants. Little BIM: A design process in which the 2D plan, 3D model and all associated design and construction information are linked in a single digital representation.
Graphisoft (2003, p. 5)	Defined BIM as a technology that offers users simulation, collaboration, auditability and maintainability.
Autodesk (2002, p. 1)	Defined BIM as an information technology in the building industry that facilitate the creation and operation, management and collaboration for digital database to be captured, preserved and used for building construction.

Table 3.8 shows keywords extracted from the BIM definitions from different stakeholders that include: academics; software vendors; and AEC industry and other organisations presented above. The keywords are not identified precisely in all definitions, but can be categorised under the same group due to similarity in meaning. The number of times the keywords were mentioned was registered in a tally format. As a result, findings show that each of the seven keywords was mentioned at least once by one of the stakeholders within each category identified by Eastman *et al.* (2011). The purpose of identifying keywords was to have a thorough study and understanding of BIM in the AEC Industry.

Table 3.8: *Keywords described by the different categories of BIM stakeholders in the BIM definitions stated above*

KEYWORDS	**Keyword tally from stakeholders definitions**		
	Academics	**Software vendors**	**Building industry**
1. Information	VIII	III	V
2. Information /management	IV	II	V
3. Modelling	V	I	I
4. Process	VII	II	III
5. Technology	V	IV	III
6. Collaboration	I	III	I
7. Analyse / Evaluate	V	III	IV

From the keywords extracted from the different definitions of BIM in Table 3.8. BIM for the purpose of this research is defined as "*The process of using information technology for the life cycle of a building through analysis, evaluation, sharing, modelling, collaboration, operation and management of a virtually building model*".

Table 3.9: *Key BIM features used to develop the framework for designing a change-ready healthcare facility, inspired by NIBS, (2007)*

Building Information Modelling (BIM)		
Building Modelling Tools	Building Process	Information Management
Automation	Thinking	Information preservation
Modelling	Scheduling	Collaboration
Simulation	Analysis/evaluation	Organising information
Presentation	Organising	Information sharing
"Developing a business case for the use of BIM"		

Possible BIM applications for the design of a change-ready healthcare facility include: modelling different design options to provide alternative design possibilities that could save cost and increase design quality; and the process of analysing and evaluating the different design options. Table 3.8 illustrates seven keywords within the definitions of BIM derived from the three different categories. The seven keywords were used to generate key features of BIM. The application of BIM can be described to have three key capabilities that can be used to support the framework design of a change-ready healthcare facility presented in Table 3.9. These are:

*"**BIM as a tool (technology); BIM as a process (people); and BIM as an information manager (prospect)**".*

Information management can be an outcome of the combined application of BIM as a tool and a process; there is a need to use BIM as a tool for managing information, while the information needs to be shared with different stakeholders involved in the process of executing a building project to achieve quality and cost reduction. BIM as a tool can also support standardisation and the process of facility re-use; once a standardised specification is attached to a space, the design can be replicated in a different facility to provide a similar function. BIM application can be used to store information, allow design duplication and re-use with ease. Prototyping is useful in new or refurbishment projects. To develop a standardised prototype model that can easily be reused Chellappa (2009, p. 57) described four processs of prototyping a project using BIM which include: *setting parameters* for a desired area. For example, identifying the allowable or minimum clear floor area; *obtaining components* (objects), such as wash hand basins, furniture etc; *setting parameters for clearances*: this is the process of identifying the allowable working area required around a component; and *setting schedule parameters*. For example, a specified area classified by appropriate and recommended guidelines. It is possible to re-use design in a BIM environment in many different ways, as there are different BIM tools with different capabilities.

3.4.2 EXPLORING CONCEPTS AND PLANNING APPRAOCHES FOR FLEXIBILITY

Planning involves thinking, organising and conceptualising in order to introduce flexibility, while the concepts are strategies used to find solutions to easily embed flexibility. Flexibility has been explored and understood to allow opportunities for expansion, contraction, relocation, conversion, and adaptation to future changes in a healthcare facility. Flexibility for the purpose of this research is centred on expandability, convertibility and adaptability; in most cases a healthcare facility is either expanding or adapting to changes. EC Harris (2013) have identified that the NHS estates have a large portion of underutilised spaces. These spaces amount to almost the size of the London Hyde Park. Therefore, there might be a need to convert these spaces to reduce the cost of maintaining them. The flexibility considerations, requirements and building systems that can be considered when embedding flexibility are identified by Carthey *et al*. (2010, p. 109) in Table 3.10. These include space expanding, converting and adapting to changes.

Table 3.10: *Flexibility considerations, requirements and building systems. Source: Carthey et al., (2010, p. 109)*

Focus	**Managerial considerations**	**Functional requirement**	**Building system**
Micro	**Operational** *Easy to reconfigure, low impact on time and cost e.g furniture and interior spaces.*	**Adaptability** *Ability to adapt existing space to operational change e.g workplace practices.*	**Tertiary** *5-10 years lifespan, no structural implications e.g furniture.*
	Tactical *Involves commitment of capital expenditure, changes not easy to undo (e.g design of operating theatres, provision of interstitial floors)*	**Convertibility** *Ability to convert rooms to different functions*	**Secondary** *15-50 years lifespan, e.g, walls and ceilings, building services capacity*
Macro	**Strategic** *Substantial increase in the lifetime of the infrastructure (e.g long term expansion plans, future conversion to other functions)*	**Expandability** *Ability to expand (or contract) the building envelop and increase/decrease capacity for specific hospital functions*	**Primary** *50-100 years lifespan,* *e.g, building shell*
Source	(Neufville, Lee. & Scholtes, 2008)	(Pati, *et al*., 2008)	(Kendall, 2005b)

Tables 3.11 and 3.12 shows the planning and concepts approaches towards achieving adaptability and expandability within a healthcare facility. Carthey *et al*. (2010) described that flexibility can be divided into three functional requirements which are adaptability, convertibility and expandability. These requirements are used for the purpose of this research to achieve a change-ready healthcare facility. In-between expandability and adaptability, the application of convertibility can emerge. Therefore, a mid-term flexibility can be described as a space converting for a different function. Carthey *et al*. (2010) suggested that there are two

key features of flexibility that facilitates long-term and short-term flexibility. Table 3.10 shows the key focus of flexibility being at *micro* level (adaptability, short-term) and *macro* level (expandability- long-term). Adaptability is defined by the Oxford dictionary as ability "*to be modified for a new purpose or to adjust to new conditions*" Therefore, when a space adjusts, exchanges, readjusts, dismantle, disconnects or alters in any way to respond to new functions, it can be argued that a space is changing to adapt to new changes, functions or flows.

Table 3.11: *Planning and concepts for adapting a facility*

Flexible Space Design (Adaptability)					
Planning	**References**	**Dates**	**Concepts**	**References**	**Dates**
1. Application of standard modules.	Cleveland Clinic Pati *et al*. Taylor *et al*.	(2010) (2008) (2011)	1. Use of building components that can be reconfigured. Such as flexible services.	Cleveland Clinic Chefurka *et al*. Taylor *et al*. Jeng	(2010) (2006) (2011) (2009, p. 684)
2. Maximising Open spaces. Share spaces if possible.	Cleveland Clinic Chefurka *et al*. Neufville *et al*.	(2010) (2006) (2008)	2. Use of open planning.	Cleveland Clinic Chefurka *et al*. Neufville *et al*. Taylor *et al*.	(2010) (2006) (2008) (2011)
3. Allocating soft spaces where more functions could be needed.	Cleveland Clinic.	(2010)	3. Use of zoning building system. Use of standardised grid. Universal room concept. (Spaces to inter-change Functions).	Cleveland Clinic Pati *et al*. Chefurka *et al*. Gallant *et al*. Taylor *et al*.	(2010) (2008) (2006) (2001) (2011)
4. Designing spaces to accommodate changes.	Cleveland Clinic Neufville *et al*. Pati *et al*.	(2010) (2008) (2008)	4. Use of size structural bays for flexibility.	Cleveland Clinic	(2010)
5. Using portable and flexible equipment or furniture.	Cleveland Clinic Chefurka *et al*. Neufville *et al*.	(2010) (2006) (2008)	5. Use of similar floor to floor height that will allow flexibility.	Cleveland Clinic Chefurka *et al*.	(2010) (2006)

Table 3.12: *Planning and concepts for expanding a facility*

Flexible Space Design (Expanding)					
Planning	**References**	**Dates**	**Concepts**	**References**	**Dates**
1. Creating circulation spaces for growth.	Cleveland Clinic Chefurka *et al.*	(2010) (2006)	1. Use of multi-purpose foundations.	Cleveland Clinic Neufville *et al.*	(2010) (2008)
2. Placing spaces likely to expand on exterior walls.	Cleveland Clinic Chefurka *et al.* Joint Commission Resources	(2010) (2005) (2006, p. 21).	2. Use of vacant /soft spaces to expand.	Cleveland Clinic Chefurka *et al.* Neufville *et al.* Joint Commission Resources Taylor *et al.*	(2010) (2006) (2008) (2006, p. 21). (2011)
3. Grouping and laying out services likely to expand.	Cleveland Clinic Pati *et al.*	(2010) (2008)	3. Allow space for vertical or horizontal expansion.	Chefurka *et al.* Neufville *et al.*	(2006) (2008)
4. Identifying immovable spaces.	Cleveland Clinic Chefurka *et al.*	(2010) (2006)	4. Categorisation and separation of functions.	Pati *et al.*	(2008).
5. Designing to minimise disruption when expanding facility.	Cleveland Clinic Chefurka *et al.*	(2010) (2006)	5. Use of generic spaces.	Kagioglou and Tzortzopoulos	(2010)
6. Thinking through building life cycle: short-term, mid-term and long-term.	Cleveland Clinic				

3.4.3 EXPLORING PROCESSES OF EMBEDDING FLEXIBILITY IN A DESIGN

To embed flexibility, project goals have to be set. Uncertainties have to be identified at early project stages. Allahaim *et al.* (2010) stated that one or two of the flexibility options identified within Table 3.13 can be used to embed flexibility into a facility, and the flexibility scheme should considered spatial, structural and service systems. This research considered all the flexibility options which include: *expand or contract*; *switching option*; and *growth*. The other flexibility options: *defer* and *abandon we*re also considered when developing a change-ready healthcare facility framework; they flexibility options can be used to support the planning strategies to embed flexibility. However, Taylor *et al.* (2011) illustrated that the British architect Frank Duffy identified six S`s that can be considered when designing a flexible and adaptable design framework. Battisto and Allison (2002) and Taylor *et al.* (2011) complemented the theory structured by Brand (2004). These are: site, shell, structure, services, system and space.

Table 3.13: *Flexibility options to consider for facility flexibility. Source: Allahaim et al. (2010) quoted Guma (2008) and Mun (2006)*

Option	Description	Examples
Defer	To wait before taking an action until more is known or timing is expected to be more positive.	When to introduce a new product or replace an existing piece of equipment.
Expand or contract	To increase or decrease the scale of an operation in response to demand	Adding or subtracting to a service offering, or the right to increase or decrease the scale of a development.
Abandon	To discontinue an operation and shut down the assets	Discontinuation of a research project, or product / services line.
A compounds option	To commit investment in stages giving rise to a series of valuation and abandonment options.	Staging of research and development projects or financial commitments to a new venture.
A switching option	The right to change from one product type to another.	The ability to select mode of operation (e.g heater that burns gas or oil). Switching between modes is action.
A growth option	An option acquired through investing in the creation of future growth opportunities.	New technologies or infrastructure.

3.4.4 EXPLORING DIFFERENT FLEXIBILITY FRAMEWORKS

Frameworks presented in Figures 3.9; 3.10; 3.11; 3.12; and 3.13 were developed by different sources. These include: Allahaim *et al*. (2010); Vorel *et al*. (2009); Fien *et al*. (2007); Ajah *et al*. (2005); and Kunders (2004). All the framework`s identified above are related to the built environment, healthcare facility design, flexibility and adaptability. This research has analysed and evaluated these frameworks in Table 3.14. Five key factors had appeared the most. These include: to identify needs and requirement; identify uncertainties, cost analysis; analysis and evaluation; and also design development activities. These factors have appeared in at least three different frameworks identified above.

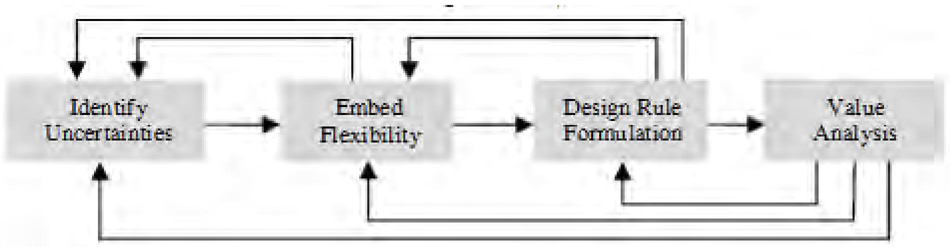


Figure 3.9: *Adaptable design framework. Source: Allahaim et al (2010)*

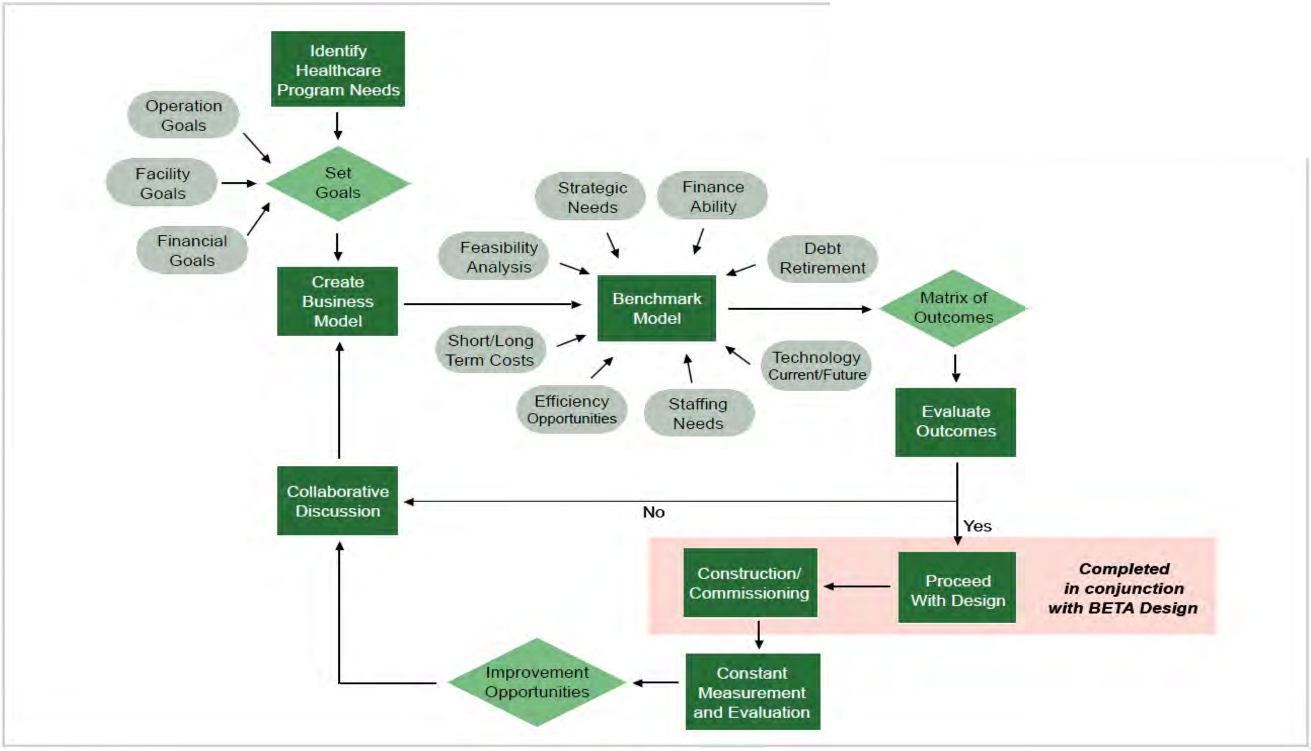


Figure 3.10: *Healthcare facility design framework. Source: Vorel et al. (2009)*

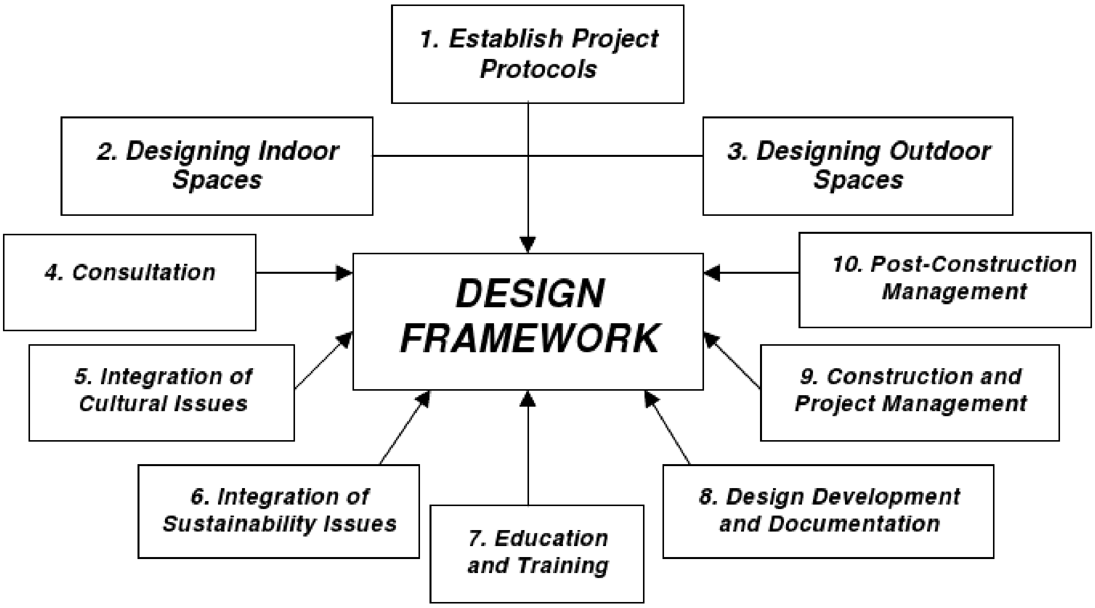


Figure 3.11: *Design framework for community housing. Source: Fien et al. (2007)*

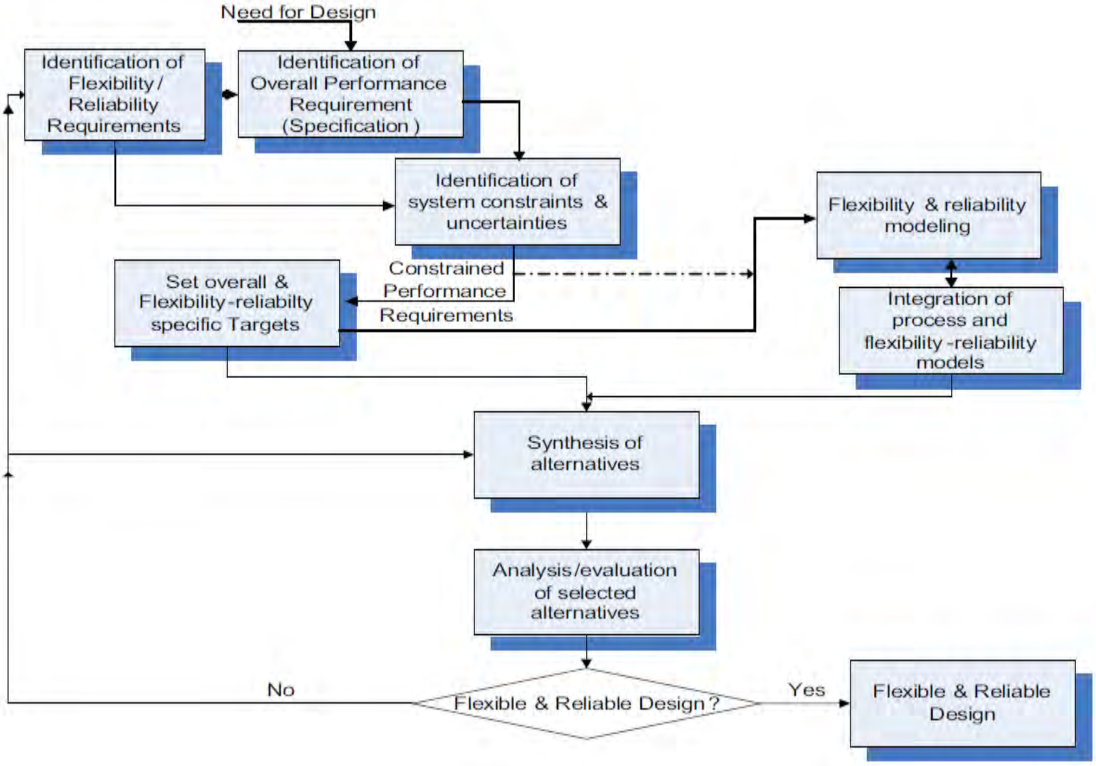


Figure 3.12: *Framework for proper integration of flexibility in conceptual design. Source: Ajah et al., (2005)*

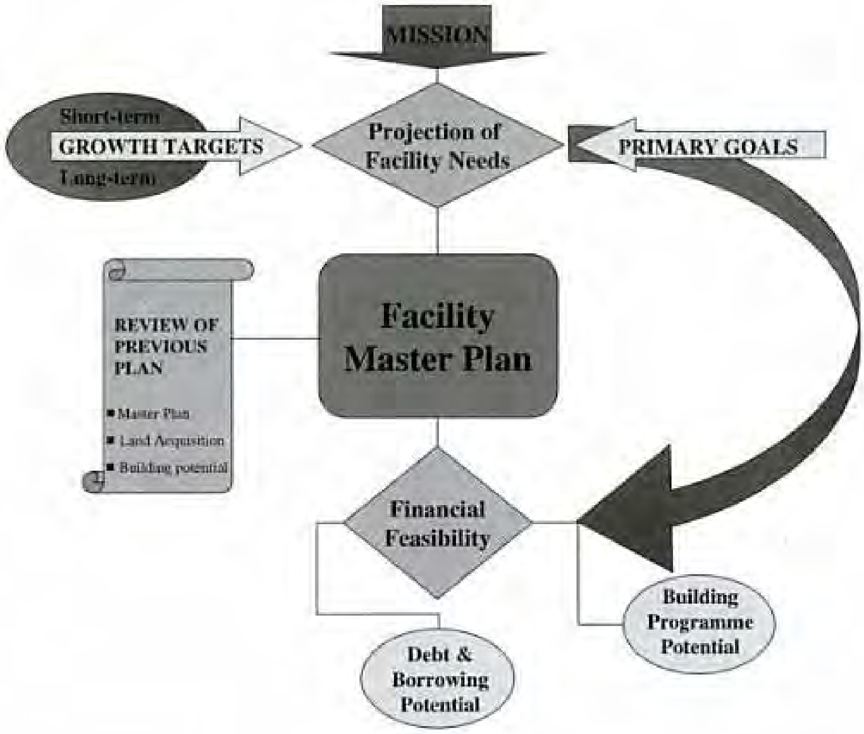


Figure 3.13: *Healthcare facility design framework. Source: Kunders (2004)*

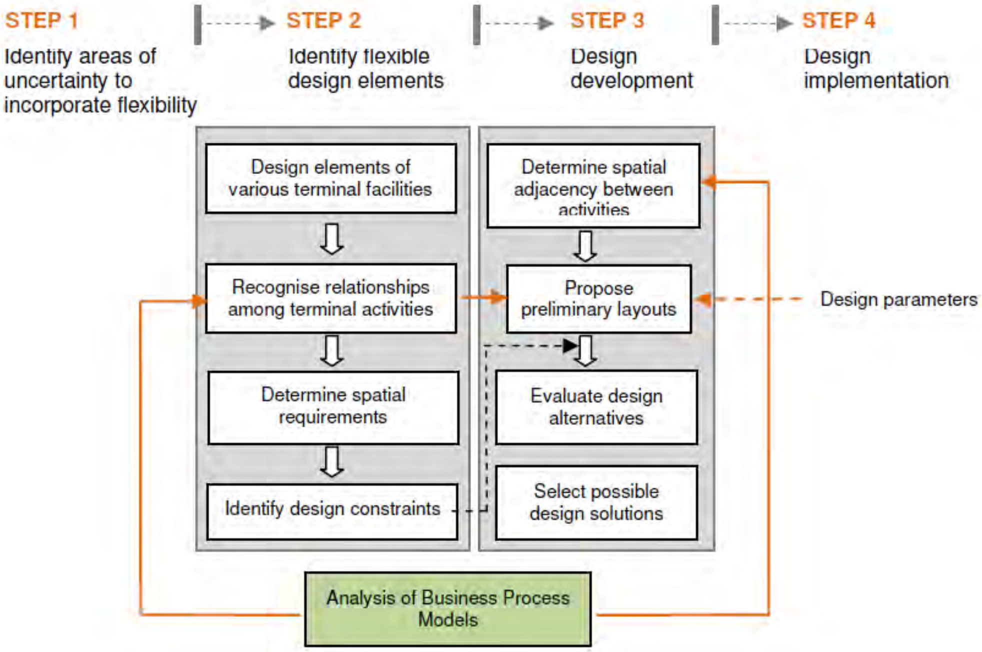


Figure 3.14: *Steps of flexibility design framework. Source: Shuchi and Drogemuller (2012)*

Table 3.14: *Analysis of different frameworks related to flexibility, adaptability and healthcare facilities*

Design framework Reference	Design Framework Features					
	Identify needs /requirements	Identify uncertainties	Cost analysis/ Business model	Analysis and Evaluation	Design development	BIM input
Allahaim (2010)	-	✓	✓	✓	-	-
Vorel (2009)	✓	✓	✓	✓	-	-
Ajah *et al*. (2005)	✓	✓	✓	✓	✓	-
Kunders (2004)	✓	-	-	✓	-	-
Fien *et al*. (2007)	✓	-	-	-	✓	-
Shuchi and Drogemuller (2012)	✓	✓	✓	✓	✓	-

The design framework features identified in Table 3.14 have appeared in at least three different frameworks. These features are used to develop the framework generated from literature review findings. Disadvantage of the analysed frameworks were that the use of BIM was not employed, while it is a UK mandate by 2016. However, despite the features of the frameworks identified, there is a need to input BIM strategies into the proposed framework due to the mandate.

3.4.5 EXPLORING STANDARDS WITHIN FLEXIBLE DESIGNS

The design of flexible and standardised healthcare spaces can be used to improve cost control and project quality. Flexibility and standardisation can be combined and supported by BIM in architectural designs. There are a lot of technical issues involved in their applications. For example, in the application of architectural design and standardisation. Gibb (2001, p. 312) stated that within the four different design categories designed by Fox and Cockerham (2000) which are:

1. bespoke designs: These are designs that their set up requires no specification with the exception of loose parts and materials;
2. hybrid designs: These are the combination of bespoke design and designs with standard sub- assemblies;
3. custom designs: These designs are integrated with standardised components up to assembly level; and
4. standard designs: these are designs with standards components and standardised connections.

There are different levels of standardisations in architecture designs, but this study explores standardisation in the context of size specifications. However, Fox and Cockerham (2000) argued that within architects, the application of standardisation in architectural designs would be difficult to adapt into the custom design (category three) and standards design (category four). This implies, that it is difficult to standardised some designs to a higher level due to the different needs of different people, cost of custom specification, the need to update standards when required and the difficulty in selecting the appropriate standard from the existing and available standards. Regardless of the constraints of standardisation, it is important in simplifying product and process and also attaching value and quality. Perhaps with the application of standardisation, it will be easier to re-use designs and reduce cost by mitigating the process of redesigning facilities with similar functions.

Saving cost with the application of BIM, flexibility and standardisation can be achieved through the use of universal spaces (see Table 3.1 in chapter 3). Taylor *et al*. (2011) agrees with Yorkon (2010), and Zhao and Tseng (2007, p. 730) that modular design approach helps with the design of universal spaces. The use of similar space sizes for different space functions allows different functions to take place in similar spaces. This is clearly described in Figure 3.15 and 3.16. Unit space B is a multiple of unit A; functions assigned to unit B can be used in unit A spaces due to similarity in sizes (modular design approach). The use of similar space sizes for similar function was also acknowledged by Yorkon, (2010). This creates an opportunity for functions to swap location. In times of demand, different functions can be allocated to possible vacant spaces, to achieve more productivity when changes occur in the future.

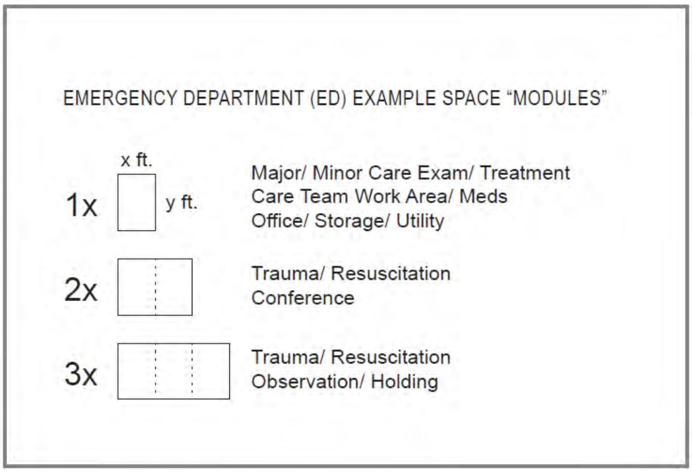


Figure 3.15: *Modular flexibility within an emergency department universal grid system. Source: Taylor et al. (2011, p. 20)*

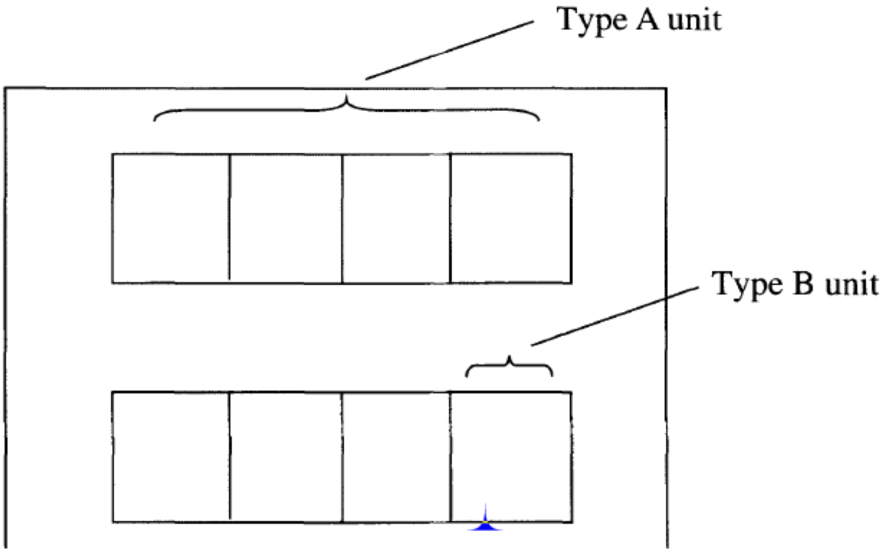
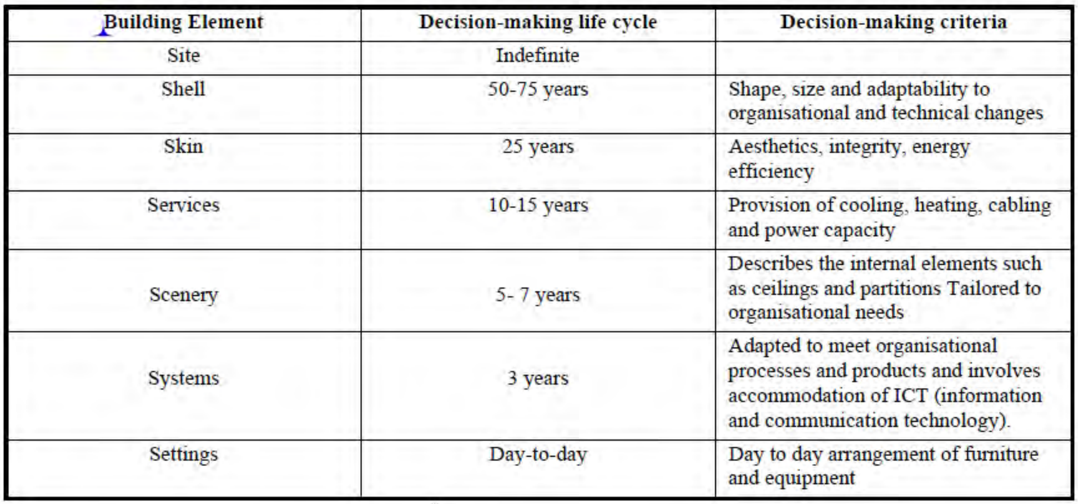


Figure 3.16: *Modular grid system. Source: Zhao and Tseng (2007, p. 730)*

The divisions used in Figure 3.15 can be applied to administrative or treatment spaces. The multiple use of four B units make up one A unit as shown in Figure 3.16. Using the modular concept, space functions can be changed, but there are factors that could affect a possible transfer of functions despite the use of similar layouts, size and shape. These include: the type of material used for finishing, the size of the doors, amount of window opening required for the different space functions e.t.c. In Table 3.15, Finch (2009, p. 10) quoted Myerson *et al.* (1997), they identified seven components that can be used to develop a flexible building system. These building elements are: site; shell; skin; services; scenery; system; and settings. The site cannot be changed, but the other six building elements could be made flexible to allow other funcitons to take place. Each functional space may require specific functional needs. Therefore, there is a need to modify some components to allow changes to take place. The functions of the different building elements are clearly described in Table 3.16. Among the six "S"s Identifed by Brand, (1994) system and settings are categorised under (short-term flexibility goals); service and scenery (short-term flexibility goals); skin and shell are used to address (long-term flexibility goals).

Table 3.15: *Classification of flexible building elements. Source: Finch (2009, p. 10)*



Building Element	Decision-making life cycle	Decision-making criteria
Site	Indefinite	
Shell	50-75 years	Shape, size and adaptability to organisational and technical changes
Skin	25 years	Aesthetics, integrity, energy efficiency
Services	10-15 years	Provision of cooling, heating, cabling and power capacity
Scenery	5- 7 years	Describes the internal elements such as ceilings and partitions Tailored to organisational needs
Systems	3 years	Adapted to meet organisational processes and products and involves accommodation of ICT (information and communication technology).
Settings	Day-to-day	Day to day arrangement of furniture and equipment

Table 3.16: *Analysis of different flexible building elements, modified from Carthey et al. (2010); Brand (1994); and Taylor et al. (2011)*

Building element	**Time frame**	**Managerial Consideration**	**Functional ability**	**Standards supporting flexibility (example)**
Systems/ Settings	Short-term	Operational	Adapt	Flexible and sstandardised curtain walls
Services/ Scenery	Mid-term	Tactical	Convert	Similar space standards
Shell /Skin	Long-term	Strategic	Expand	Standardised modular units

3.5 APPROACHES TOWARDS THE DEVELOPMENT OF A FRAMEWORK FROM ANALYSED LITERATURE

The use of refurbishment, flexibility, standardisation and BIM are broad in their applications. Guidelines were identified from the analysis of literature review in order to develop the framework for designing a change-ready healthcare facility. Section 3.4 addresses the findings from literature review. These findings are summarised in Table 3.17. These include findings from existing frameworks showed the lack of BIM use, the need to identify project needs and to conduct a feasibility study, to identify possible constraints and selecting an appropriate plan through a series of analysis and evaluations. See section 3.4.4.

Among many researchers, It was also suggested by Allahaim *et al.* (2010) that it is important to identify possible flexible options that can be used to embed flexibility. These are presented in section 3.4.3. In order to embed flexibility, strategic planning can help in responding to future changes using conceptual schemes; literature review findings presented in Table 3.11 and 3.12 suggested a number of planning and conceptual schemes that can be used to facilitate the process of building flexibility into healthcare facilities.

Identifying the different types of building elements that can be adjusted in order to embed flexibility were identified by Taylor *et al.* (2011); Brand (1994); and Carthey *et al.* (2010). See section 3.4.5. Six key factors were identified. These are shell, skin, services, scenery, system and setting. For the purpose of this research, the following are considered as drivers for different flexibility time frames. Shell and skin are considered for long-term flexibility; services and scenery for mid-term flexibility; and system and setting for short- term flexibility.

Exploring BIM capabilities from the different group of stakeholders identified by Eastman *et al.* (2011) are presented in this study. See section 3.4.1. BIM for the purpose of this study was understood as the process of optimising a building`s life cycle through analysis, evaluation, sharing, collaboration, operation and management of a virtual building model. BIM is also understood as the combination of a tool (technology), process (people) and information management (prospect). These findings were grouped and applied into the framework for designing a change-ready healthcare facility. Deductive reasoning was used to integrate the findings to appropriate sections of the framework. For example, *selecting an appropriate plan* should come after rigorous analysis has taken place.

Table 3.17: *Literature review findings supporting the framework guidelines for designing a change-ready healthcare facility*

Guidelines	Literature review Findings	Description of Figures and Tables
Identify needs and feasibility studies	Table 3.14:	Analysis of different frameworks related to flexibility, adaptability and healthcare facilities.
Identify possible constraints		
Identify the possible flexible options	Table 3.13:	Flexibility options to consider facility flexibility. Source: Allahaim *et al.* (2010) quotes Guma (2008) and Mun (2006).
Identify type of flexible building element to adjust	Table 3.16:	Analysis of different flexible building elements, modified from Carthey *et al.* (2010); Brand (1994); and Taylor *et al.* (2011).
Identify flexible concepts and planning sequence	Table 3.11:	Planning and concepts for adapting a facility.
	Table 3.12:	Planning and concepts for expanding a facility.
Use BIM as a tool, process and information manager	Table 3.5:	Definition of BIM by academicians.
	Table 3.6:	Definition of BIM by AEC industry or other organisations.
	Table 3.7:	Definition of BIM by software and hardware vendors.
	Table 3.8:	Keywords described by the different categories of BIM stakeholders in the BIM definitions stated above.
	Table 3.9:	Key BIM features used to design the framework for designing a change-ready healthcare facility, inspired by NIBS (2007).
Select an appropriate plan	Table 3.14:	Analysis of different frameworks related to flexibility, adaptability and healthcare facilities.

In Figure 3.17 alphabetical designations were made from letter A to K to ease the process of identifying sources of information used in the framework. These are described as follows:

A- presents the RIBA Plan of Work 2007;

B- presents additional statements on the Design Stages addressed from the RIBA Plan of Work 2007;

C- shows the design tasks flow supported by the application of flexibility, standardisation and BIM. At this point, the strategy to apply flexibility, standardisation and BIM within refurbishment projects was yet to be discovered. As a result, only three applications were considered;

D- to identify needs and conduct feasibility studies were found from the analysis of different frameworks. See Table 3.14. It was the first tasks conducted in most of the analysed frameworks from different literature sources;

E- assessing of options identified from the feasibility study conducted above is the process of making strategic decision at early designs stages;

F- identifying possible constraints was also found from the analysis of the different frameworks analysed and presented in Table 3.14. This task was conducted at the early stages of the frameworks developed;

G- the process of identifying a flexibility approach is described in Table 3.13. This involved making early decisions on long-term, mid-term or short-term schemes. A clearer description of the flexibility approaches is presented in Table 3.16. This task needs to take place at the early stages of the design process. However, this approach is considered after project needs have been established.

H- After selecting the time-frame of the flexibility, the conceptual approaches are identified. Table 3.11 and 3.12 presents possible conceptual approaches from different literature sources for different time frames selected from G above. As a result, this task should take place after task G.

I- After conceptualising the flexibility approach, the planning process takes places Cleveland Clinic (2010). (See Table 3.11 and 3.12).

J- The analysis of the different frameworks identified in Table 3.14 showed that there is no provision for the application of BIM in the available analysed frameworks found from literature. However, section 3.4.1 shows the analysis of the definition of BIM. Findings showed that BIM is the combination of using BIM tools, collaborating with different stakeholders and managing information. These three features were used to strategies the application of BIM in the framework. BIM tools can be used to collect information, design and edit projects while collaborating, analysing and evaluating different design options. At this stage (when the framework developed from literature review was generated) the application of BIM to help design, analyse and evaluate flexible design options was not verified with professionals from the AEC industry. However, this was conducted at a later stage; and

K- Selecting an option is the last tasks conducted in the frameworks analysed in Table 3.14. As a result, this task is presented at the end of the framework design tasks.

The RIBA Stages are linked sequentially; this framework works parallel to it. In Figure 3.17, using the additional information in (B), literature review findings in: D and E are grouped under the Appraisal Stage; G in the Design Brief Stage; H and I in the Concept Stage; J in the Development Stage.

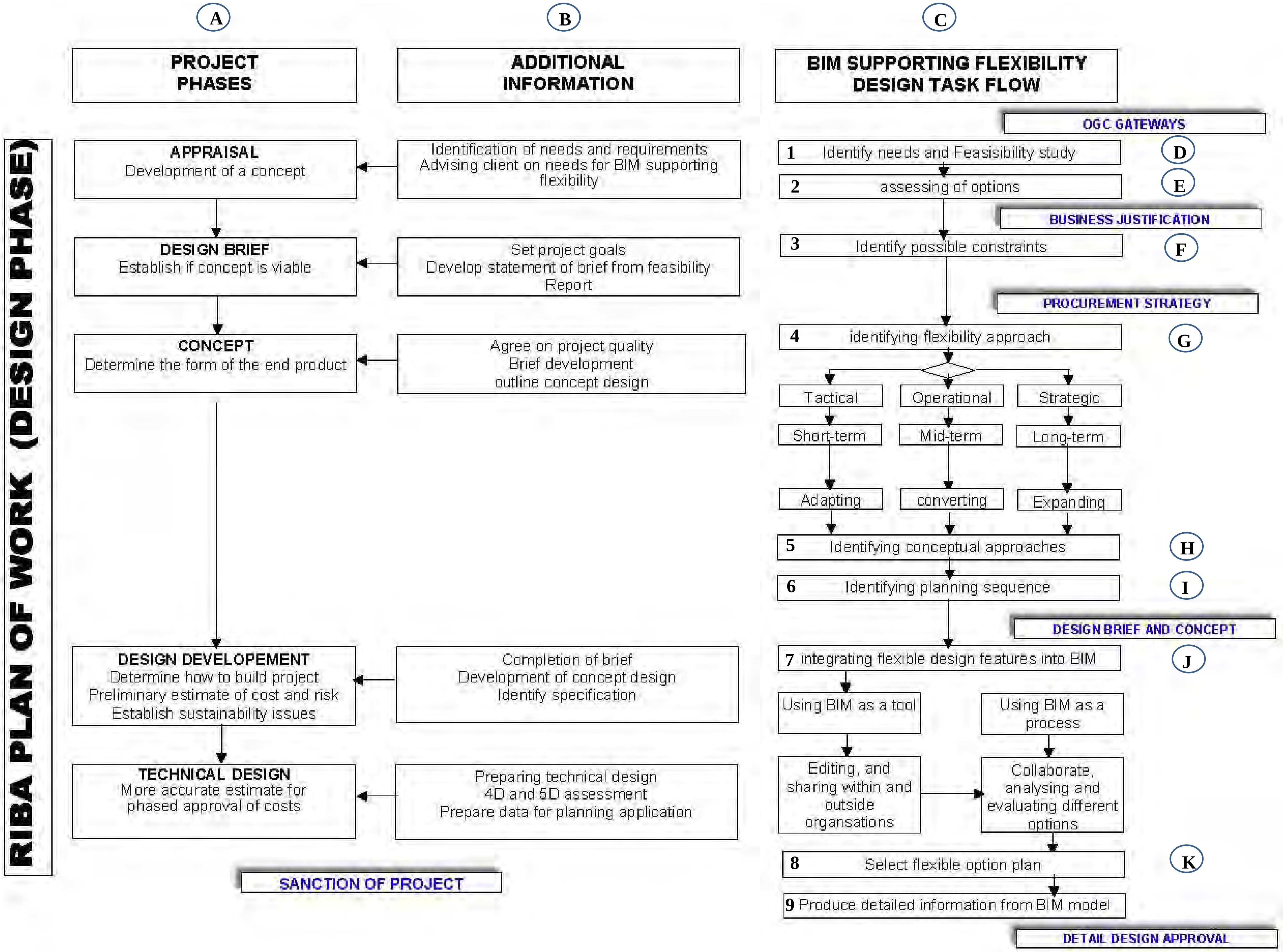


Figure 3.17: *Framework for designing a change-ready healthcare facility developed from literature review sources*

3.6 CHAPTER SUMMARY

The applications of refurbisment, flexibility, standardisation and BIM are broad with lots of benefits, challenges, risks, and practices in the AEC industry. There is a need to narrow down these four broad areas of study; their applications spread across a wide range of disciplines. Flexibility and standardisation can also be applied to improve project outcome. Table 3.17 presents the literature sources used to develop the framework; key guidelines used for designing a change-ready healthcare facility are also presented. Figure 3.17 illustrates the relationship between the RIBA Plan of Work, (2007) and the change-ready design delivery process. This is the first change-ready (flexibility) framework that incooperates BIM support in order to improve the cost and design productivity. Seven key steps were identified, but this study further explored more steps to develop the framework. There is a need to explore when and how to apply the framework? Therefore, a further questionnaire survey and interview was conducted to improve the framework design.

4 CHAPTER 4: RESEARCH DESIGN AND METHODOLOGY

4.1 INTRODUCTION

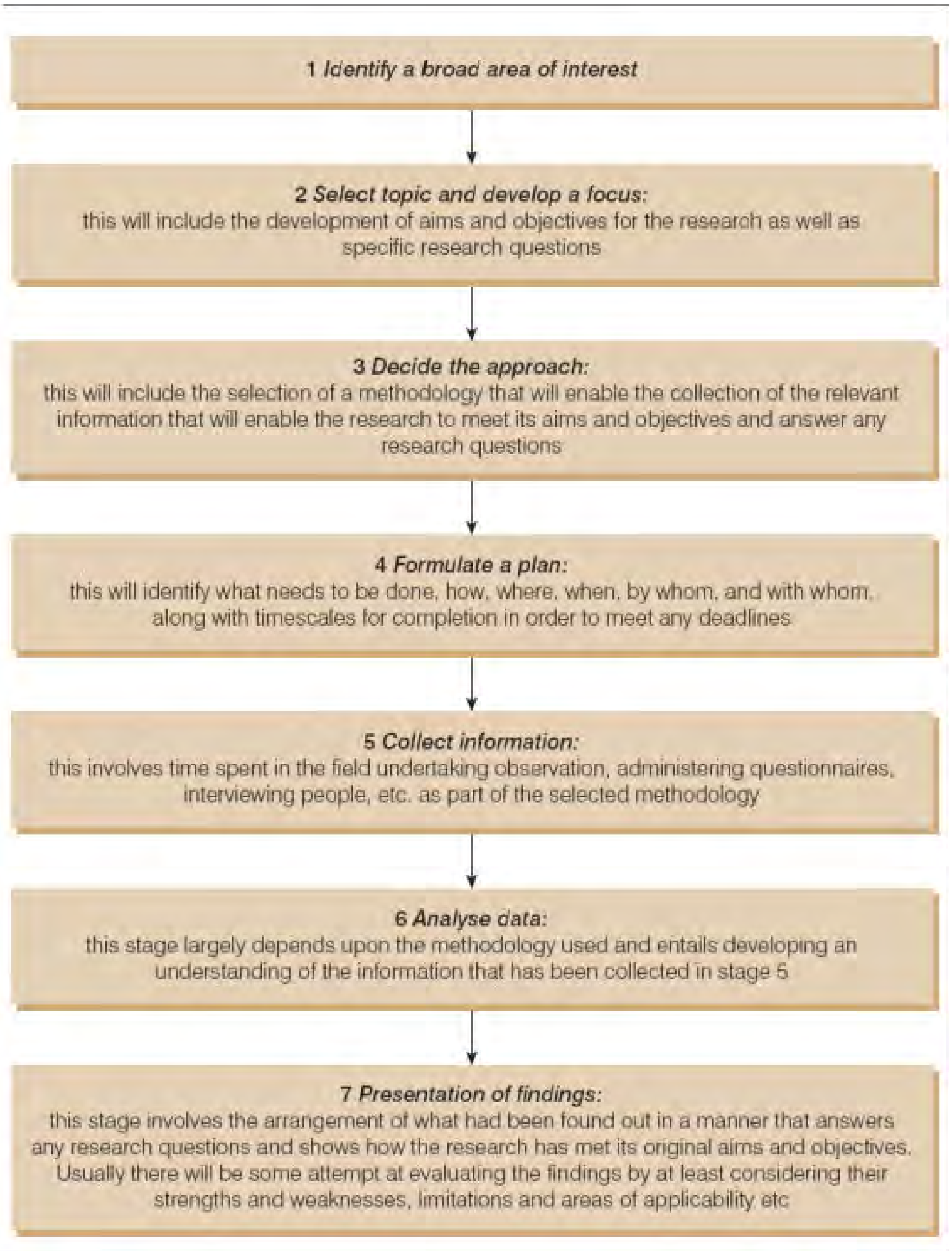
Knight *et al*. (2008, p. 3) described research methodology as "*far more than the methods adopted in a particular study and encompasses the rationale and the philosophical assumptions that underlie a particular study*". Methodology can also be described as the entire research procedure, process, strategy, approach, application, paradigm and method used to achieve desired research outcomes within a systematic pattern that is widely accepted to guide researchers when conducting research studies. Methodology is applied within a study or discipline to generate findings or constructive frameworks that can provide added knowledge (theoretical and practical) that is beneficial and valuable.

Naoum (2007) stated that research is a systematic and systemic process of analysis that can be used for the purpose of adding new knowledge to existing studies through suitable and appropriate methods/techniques/approaches to produce factual outcomes that are binding, usable, consistent and reliable. Blaxter *et al*. (2006, p. 8) quoted (Marshall and Rossman 1999, p. 26; Punch 2005, p. 40) who noted research process to be categorised into the pre-empirical stage and the empirical stage. The pre-empirical stage explores questions, research area, topic and context; while the empirical stage includes the design, data collection, data analysis and answered questions. They also stated that there are different categories of research proceedings. However, for the purpose of this research, five categorises are identified to show all the research proceeding relevant and considered for the purpose of this study. These are:

- research application;
- research paradigms;
- research strategy
- research approach; and
- research methods.

In a broader approach, this research is a "*management research*". It is described in the context of organisations and how managerial schemes are used to solve problems (Bryman and Bell, 2007). To achieve the benefits of BIM in any project, BIM has to be implemented first. The application of BIM in the AEC industry requires both managerial implementation and organisation use. Figure 4.1 shows the research plan sequence described by Howard and

Sharp (1983), it was recently reviewed by Gill and Johnson (2010). The research plan was used to sequentially execute this research.



1 *Identify a broad area of interest*

2 *Select topic and develop a focus:*
this will include the development of aims and objectives for the research as well as specific research questions

3 *Decide the approach:*
this will include the selection of a methodology that will enable the collection of the relevant information that will enable the research to meet its aims and objectives and answer any research questions

4 *Formulate a plan:*
this will identify what needs to be done, how, where, when, by whom, and with whom, along with timescales for completion in order to meet any deadlines

5 *Collect information:*
this involves time spent in the field undertaking observation, administering questionnaires, interviewing people, etc. as part of the selected methodology

6 *Analyse data:*
this stage largely depends upon the methodology used and entails developing an understanding of the information that has been collected in stage 5

7 *Presentation of findings:*
this stage involves the arrangement of what had been found out in a manner that answers any research questions and shows how the research has met its original aims and objectives. Usually there will be some attempt at evaluating the findings by at least considering their strengths and weaknesses, limitations and areas of applicability etc

Figure 4.1: *Research Methodology adopted Source: Gill and Johnson (2010, p. 9)*

4.2 RESEARCH APPLICATION

It is important to understand the different research applications. These are categorised as pure research or applied research? Goddard and Melville (2004) were of the view that pure research and applied research are varied based on the intent of the conducted research, while Drenth *et al*. (1998, p.6) were of the view that they are can be differentiated using the origin of the research problem. But both research methods can be used to conduct a research and add new knowledge to existing literature.

4.2.1 PURE RESEARCH

Pure research in most cases is conducted to add knowledge to existing literature for the exclusive purposes of attaining knowledge. Goddard and Melville (2004, p. 3) stated that pure research is *"research performed for the single goal of gaining knowledge, or"…*for gaining knowledge for knowledge`s sake. *"Any practical useful outcomes of the research are simply a bonus*". Drenth *et al*. (1998, p. 6) described that in "*pure scientific research, the research problem arises in, or in connection with, theoretical questions or previous research*". Kumar, (2005) stated that pure research involves advance development, testing and authenticating theories and hypothesis that may not be situated within the present and future scenarios.

4.2.2 APPLIED RESEARCH

Goddard and Melville (2004, P. 3) stated that applied research "*is performed to solve a specific practical problem. Here the practically usefulness outcome is the goal of the research, and any outcomes of theoretical significance are the bonus*". Drenth *et al*. (1998, p. 6) described that "*applied research is grounded in problems in practices*". Kumar, (2005) characterised applied research as a process that involves the application of existing and established theory that deals with practical endeavours. Perhaps applied research can be understood as a research that deals with practical problems where outcomes are situated around existing concepts or theories that are subjected to present or future developments.

4.2.3 RESEARCH APPLICATION ADOPTED

Both applied and pure research method were applied for the purpose of this research. There is a need for both theoretical and practical inputs to support healthcare facility designs. Applied research is required in this study in order to identify best practices that can be used to guide healthcare designers and planners to design effective flexible healthcare spaces that can adapt to the rapidly changing nature of healthcare facilities while keeping cost and quality as a primary concern. Hence, applied research was conducted to provide practical guidelines that could benefit the design team to effectively and efficiently facilitate the application of BIM in healthcare facility design. While pure research is required for the purposes of conducting a PhD; there is a need to add new knowledge to existing literature.

4.3 RESEARCH OBJECTIVE

Research objectives are used to describe the basic features supporting a given study. This involves the process of specifying key features that describes the research aim in context. It also involves defining what to expect from a certain research. Kumar (2005) stated that there are four different objectives of a study that can be consider when conducting research. These are categorised and identified as descriptive, explanatory, correlation, and exploratory. These research objectives are briefly discussed below.

4.3.1 DESCRIPTIVE

Monsen and Horn (2008, p. 5) described descriptive research as "*an effective way to obtain information used in devising hypothesis and proposing associations*". They also stated that descriptive research cannot be used to test or verify any study as it only describes the existing situation as it is. It is strongly related to qualitative research which is subjective and interpretive in nature; describing the understandings of the describer. A descriptive research explains the study in its relevant context, such as time, place, and culture. As a result, different researchers can describe a similar research in many different ways depending on the context of their relevant backgrounds.

4.3.2 CORRELATION

Jackson (2012, p. 148) described correlational research or method as a "*type of non-experimental method that describes the relationship between two measured variables*". This is a research that allows the possibility of assessing and evaluating two variables within a specified study. Correlation research is centred on two or more studies; a single study cannot therefore be analysed through correlation studies. A study that does not require an extensive analysis of relationships between variables is not suitable for this research tactic.

4.3.3 EXPLORATORY

Exploratory research is described by Fitzpatrick and Wallace (2006, p. 187) as a study that "*investigate little known phenomena for which a library search fails to reveal any significant examples of prior research*". It can be used to find, justify and explore new findings or phenomena that are useful to mankind. Therefore, it is not limited to the application of one paradigm. In exploratory research, a richer, deeper and greater insight is explored within a study to generate new knowledge.

4.3.4 EXPLANATORY

McNabb (2008, p. 100) quoted White (1999, p. 44) who described explanatory study as a research that attempts "*to build theories that explain and predict natural and social events... The ultimate goal of explanatory research is the control of natural and social events*" and is also of the view that explanatory and descriptive research are strongly related to qualitative research which allows subjective applications when conducting a given study. Events are explained in the understandings of the researcher. Explanatory research is more detailed compared to descriptive research. Explanatory research is used to clarify, simplify, elucidate and explain relationships within a study.

4.3.5 RESEARCH OBJECTIVE ADOPTED

For the purpose of this study, an exploratory research was adopted. The combined application of flexibility and standardisation with BIM during healthcare refurbishment is a new research. The research conducted in this study is original and innovative; no literature was found specifically on the design of healthcare spaces with close relations to the four applications. The relationships, possibilities, potentials and opportunities within their studies can be explored to develop guidance that can support healthcare designers and planners to design change-ready healthcare facilities. Perhaps new insights can also be explored within the studies of refurbishment, flexibility, standardisation and BIM to reduce cost and improve project quality.

4.4 RESEARCH PARADIGM

Fellows and Liu (2005) defined research paradigm as a theoretical outline or structure that guides how research is viewed and approached by individuals. These are theories or hypothesis; they define how people view the world differently and how it influences personal behaviour of specific individuals. However, research paradigm can be described as a structure that is used to create theories. Bryman and Bell (2007, p. 25) quoted the definition of paradigm from Bryman (1988a, p. 4) as "*a cluster of beliefs and dictates which for scientists in a particular discipline influence what should be studied, how research should be done [and] how result should be interpreted*". Guba and Lincoln (1994, p. 107) noted that "*a Paradigm may be viewed as a set of basic beliefs*". They also stated that research paradigms can respond to three principle questions. These are:

- methodological question: this is the question asked by individuals; how does a researcher goes about a research, and what are the processes used from inception to completion;
- ontological question: this is the question individuals ask to determine the nature of reality. This *could be subjective, objective and pragmatic*; and
- epistemological question: This question is also asked by individuals to decide what general basic belief is. It draws a disparity from what is viewed as consistent and trustworthy study and what is consider erratic. This is related to *positivism*, *realism* and *interpretivism*.

4.4.1 ONTOLOGICAL CONSIDERATIONS

Ontology is broad; it can be described as conceptions of reality. Fitzgerald and Howcroft (1998) classified ontological position into two different categories. These are: *realist* and *relativist*. *Realist* perspective; these are external tangible structures or frameworks that are independent to the aptitude to attain knowledge. *Realist* features are non-subjective. While *relativist* perspectives are related to subjective realities constructed in the mind, and they have multiple realities depending on social issues in context such as culture or language. Knight and Ruddock (2008, p. 3) quoted Bryman and Bell (2003, p. 19-20), they stated that in philosophy, ontology can be viewed as *objectivist* or *constructivist*, and that "*objectivist ontology sees social phenomena and their meanings as existing independently of social actions, whereas constructivist ontology infers that social phenomena are produced through social interaction and are therefore in a constant state of revision*".

4.4.2 EPISTEMOLOGICAL CONSIDERATIONS

Epistemology is described as a suitable, adequate and acceptable study within any discipline of knowledge. Knight and Ruddock (2008, p. 3) described epistemological perspectives as an approach that is "*bounded by the positivist view that the methods of natural science should be applied to the study of social phenomena, and the alternative orthodoxy of interpretivism view that the method of natural science and people in that phenomena have different subjective meaning for the actors studied*". Epistemology is a division of thinking or ideology that focuses on the nature of knowledge and its relationship with the truth, reality, certainty, belief, justifications and rationalisations. This is how certain individuals perceive the creation of knowledge.

4.4.3 EMPIRICAL CONSIDERATIONS

Kumar (2011, p. 9) described empirical research to be rooted in research tasks conducted through experience or observation without the application of a system or theory. This approach is data based, in so much that assumptions can be easily verified through the application of direct or in-direct experience or observations. These are also based on quantification or qualitative approaches. He further reported that empirical research can begin with a hypothesis that a study can exam or experiment; data generated from the analysis can be used to produce a cause and effect relationship between variables involved. Manor College (2006) stated that there are two categories of empirical considerations, which are *interventionism* and *integrative*; the *interventionism* approach outcome is supported by theories, while the *integrative* approach establishes significance to the context in question.

4.4.4 PHILOSOPHICAL POSITION OF RESEARCH ADOPTED

This research is established through mixed methods which is the combination of qualitative and quantitative research methods. Qualitative research method is understood to be strongly related to the process of collecting in-depth data to achieving desired research outcomes. Therefore, Interpretivist paradigm was considered as it is also strongly associated with qualitative method. Mixed methods were used to achieve the aim and objective of this research as both statistical analysis and in-depth interpretation of qualitative data is required to understand relationships, cause and effect that arise within events. Interpretivist paradigm was used for the purpose of this study; it allows the opportunities to explore realism of context. Achieving a change-ready healthcare facility can be different from other buildings in the AEC industry. The rapid changing nature of a healthcare facility is different from other buildings due to their 24 hours round the clock operation. It is noteworthy to understand that adapting a building requires interpretation of the specific change in context. The future of healthcare buildings is filled with uncertainties, and dealing with uncertainties requires the understanding and interpretation of the context in focus. However, statistical backing or historical evidence is required to support possible future changes occurring in future healthcare facilities.

4.5 RESEARCH METHODOLOGY

When one begins to think of a research methodology, this is basically the entire research process from inception to completion. Research methodology includes the need to identify possible stakeholders that can provide this study with robust data that it can analyse. The entire research sequence has to be drawn at the early research stages to guide the study systematically identifying aims, objectives, research methods, research tasks and so on.

Research objectives are presented in section 1.7.2. *Research objective 1* required understanding of the broad areas of RFSB to explore their impact on healthcare buildings. Also to explore existing flexibility frameworks and theoretical principles that can be used in designing flexible buildings in order to develop a change-ready healthcare facility. *Research objective 2* addressed the challenges of BIM when designing flexible and standardised healthcare facilities; questionnaire surveys were used to collected data from industry professionals to explore the impact of BIM tools on design creativity when designing a flexible facility. However, due to availability of existing literature on BIM implementation plans it was used to explore methods of selecting an appropriate plan when dealing with different stakeholders. BIM has to be implemented before its benefits can be achieved. *Research objective 3* explored methods of organising RFSB within a healthcare project; questionnaire survey was used to explore when flexibility, standardisation and BIM are effective within a refurbishment process. This study is new. Literature review data on RFSB applied together is limited. As a result, statistical backing was required to support their effectiveness within a given project. Furthermore, statistics were also required to support the notion that BIM can help in designing and evaluating different flexible healthcare spaces. *Research objective 4* investigated how to embed flexibility and standardisation in healthcare refurbishment projects with BIM support. This study explored special features of BIM that can be used in healthcare facility design. Eastman *et al.* (2011) stated that BIM is still yet to be fully explored. Interviews were required for in-depth discussions for possible improvisations to support the framework design through information exchange methods, exploring relationships between BIM, flexibility and standardisation as they need to co-exist in the proposed framework. *Research objective 5* explores how, when, who, why and what is required when designing a healthcare facility that can respond to future changes; interviews allowed in-depth discussions with industry practitioners to explore flexibility approaches that are currently applied in practice. *Research objective 6* required a validation exercise for validity and reliability of the revised framework. Interview was conducted as it allowed the participants to see the revised framework, ask questions and make comments. However, a focus group would have been more appropriate, but it was not possible to get all the participants together.

One process was applied to all stages of the refined framework. Deductive reasoning was used to organise findings from different data sources (literature review, questionnaire survey and interviews) into the appropriate RIBA Design Stages. The RIBA Design Stages are linked in a standard format that is sequential and holistic. The RIBA Plan of Work is nationally accepted in the UK. As a result, each finding is placed in one of the following stages: Strategic definition; Design Brief; Conceptual Design; or Design Development.

A framework can be drawn using common sense. However, to achieve reliability and validity literature review was used to develop the first framework through the analysis of existing frameworks and addressing gaps such as lack of BIM input in all the existing flexibility frameworks presented in this research (see Table 3.14) . Literature review also suggested improvisations that can help to achieve a flexible facility. These can be found in the subsets of section 3.4.

The framework developed from literature review had some limitations. These include:

- Absences of features that a change-ready healthcare facility can revolve around, such as a possible changing space;
- Little information was available on BIM supporting flexible space design. Hardin, 2009 stated that BIM is yet to be fully explored;
- Lack of statistical backing that BIM can be used to support the design, analysis and evaluation of flexible healthcare facilities; and
- There was no input from industry professionals.

As a result, questionnaire surveys were used for quick data collection and to explore the most important considerations when designing a flexible healthcare facility in order to improve the framework before presenting it to industry professionals. The framework revised with questionnaire survey findings was improved. However, it also had some limitations:

- A clear holistic process of the framework flow was still indistinctive due to lack of standardisation features;
- The framework does not clearly identify the type of building it focuses on, such as refurbishment or new build;
- Additional information was required for each design task to improve clarification;
- The application of BIM in the framework was superficial.
- There was a need to specify how and when to apply BIM best in the framework. Thus more detail is required from industry practitioners.

An interview was conducted for in-depth data collection that can provide additional information for each design task; it also provided an opportunity for face to face dialogue with industry practitioners and allowed more detailed questions to be asked to deepen the understanding of a flexible healthcare facility design and explain statistical data collected from questionnaire surveys.

This research embraces mixed methods. To establish the research procedure, there has to be a thorough understanding between qualitative and quantitative research. Simply, qualitative research tends to look at studies in a rigorous and detailed manner that is subjective through personal insights, while quantitative research investigates statistical analogy schemes from a possible large number of participants to add new knowledge that is useful. Dawson (2002, p. 14) described qualitative research as a research that explores experiences, attitudes and behavior through interviews or focus groups, while quantitative research generates statistics through questionnaire surveys. Knight and Ruddock (2008, p. 4) stated that there are four broad classifications of construction research which are as follows:

1. quantitative (positivist) research;
2. qualitative (interpretative) research;
3. mixed methods (combination of deductive and inductive research; and
4. review, discarding empirical research method.

But Creswell (2003, p. 5) was of the view that there are three different research approaches that include qualitative, quantitative and mixed methods. Blaxter *et al.* (2006, p. 68) classified research into families, approaches and techniques; the research families were described as qualitative or quantitative. Research methods applied for this research are described in the research method adopted sections.

4.5.1 QUANTITATIVE RESEARCH

Baker and Foy (2008, p. 23) observed that quantitative research is more consistent and trustworthy with no subjective features attached; this enables suitable and acceptable outcomes. Dawson (2002) stated that quantitative research is used to collected numerical data through the use of questionnaire surveys and interviews that can be used to generated statistical facts. Quantitative research strongly deals with figures and deals with studies that ask how much or how many? The research outcomes are presented from statistical methodological or procedural applications.

4.5.2 QUALITATIVE RESEARCH

Bryman (2004) described that qualitative research answers research questions such as what, why and how. Pope and Mays (2006) defined qualitative research as the meaning or interpretation of people`s subjective expressions. It has gain relevance in healthcare research for collecting primary data from healthcare facility users and healthcare designers and planners before designing healthcare facilities. Due to the various cultures and understandings within the social world, meaning is defined in the natural setting of the object in context. Dainty (1998) described qualitative research in Figure 4.2 to have three key processes. These include: *describing* the primary data; identifying *categories*: and also identifying the *relationship and connections* between the categories during the data analysis. The application of qualitative research helps in confirming quantitative research. It can be used after conducting quantitative research. Quantitative research can also be used to confirm qualitative research. Therefore, quantitative and qualitative research can be used vice versa and is also called triangulation.

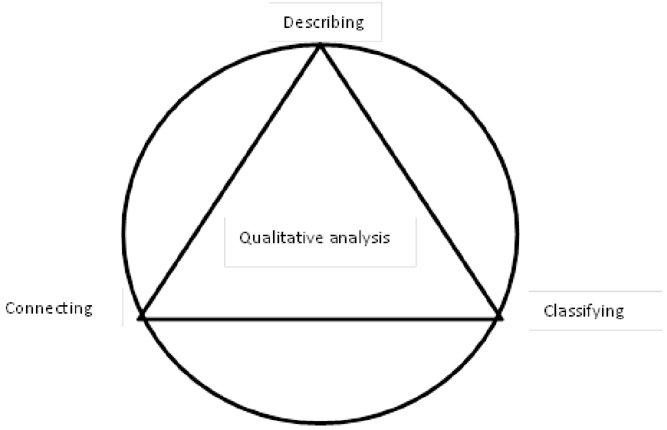


Figure 4.2: *Describing qualitative data. Source: Dainty (1998)*

Flick (2009) reported that both qualitative and quantitative have their specific limitations. It is important to understand the constraints that each research methods come along with in order to make informed decisions while combining them within a single study. Therefore, some contrast between them were illustrated by (Bryman and Bell, 2011, p. 410); Ruddock (2008); Rucker (2004); and Brewer (2007) Marshall and Rossman (2011); and Pope and Mays (2006) in Table 4.1.

Table 4.1: *Quantitative and qualitative research features described Bryman and Bell (2011, p. 410); Ruddock (2008); Ruikar (2004); and Brewer (2007) Marshall and Rossman (2011); Pope and Mays (2006)*

Quantitative research	Qualitative research
Ask how much or how many? Etc.	Ask what or why? Etc.
Focus on numbers	Focus on words
Questionnaire surveys	In-depth interviews
Point of view of researcher	Point of view of participant
Theory testing	Theory developing
Aims at truth	Aims at new perceptions
Static	Process
Structured	Unstructured
Generalisation	Contextual understanding
Hard, reliable data	Rich, deep data
Macro	Micro
Behaviour	Meaning
Artificial setting	Natural setting
Objective	Subjective
Deductive	Inductive
Conclusive	Impressionistic
Considers statistical analysis	Considers studies, content and pattern analysis
Large sample size	Fewer sample size
Descriptive	Interpretative
Pre-specified	Open ended
Outcome oriented	Process oriented

4.5.3 MIXED METHODS

There are challenges of applying a multi-paradigm approach, which is sometimes called pluralism or triangulation. Mixed methods research is the process involving the combined application of qualitative and quantitative research methods. The combination of research methods brings two major challenges identified by Knight and Ruddock (2008). They are problems relating to multi paradigm applications; each one of these paradigms is supported by a different research technique and norms. There are some common features that allow comparison between qualitative and quantitative research. The second challenge is the gap between the *Interpretivist* and the *positivist* groups. They also stated that it is difficult to verify the challenges related to understanding matters from the view point of practitioner which is unfailingly attributed to *interpretivism*, while unfavourable to *positivism*.

Knight and Ruddock (2008, p. 9) Quotes Mingers (1997, p. 9) who stated that

> "*Adopting a particular paradigm is like viewing the world through a particular instrument such as a telescope, an X- tray machine, or an electron microscope. Each reveals certain aspects but is completely blind to others…each instrument produces a totally different and seemingly incompatible representation. Thus adopting only one*

> *paradigm, one is inevitably gaining only a limited view of a particular intervention or research situation…it is always wise to utilize a variety of approaches*".

The difference between the different paradigm were reported by Blaxter *et al*. (2006), they quoted Oakley (1999, p. 156) that qualitative research assumes a dynamic reality; its rich, deep, holistic, natural, uncontrolled, un-generalised, subjective, descriptive, inductive and exploratory, while quantitative research assumes a stable reality; associated with facts, measurement, objectiveness, generalised, ungrounded and removes outside opinions. Both qualitative and quantitative research can be used to conduct deskwork or fieldwork. Deskwork is the type of research tasks that does not necessitate going out to the field for data collection or observations. It involves reviewing other peoples collected data, postal survey, use of libraries, internet, and laboratories etc. While field research is the kind of study that involves data collection through observations, meetings, conducting outside interviews such as interviewing people on the street.

4.5.4 RESEARCH STRATEGY ADOPTED

Mixed methods were applied in this research to allow the use of both statistical analogy and subjective interpretive analysis. This approach was conducted for the purpose of this research to develop a richer and in-depth understanding of the practical applications of refurbishment, flexibility, standardisation and BIM to develop a framework for designing a change-ready healthcare facility that can adapt to future changes and reduce costs during design, construction and facility management while focusing on project quality. The application of mixed methods comes along with a systematic application that guides the research procedure from inception to completion. Statistical data was used to explore the possibility of designing a change-ready healthcare facility with flexibility, standardisation and BIM. Interviews were further used to explore how and when this can be done.

4.6 RESEARCH APPROACH

Research approaches are classified into the deductive and inductive research. The relationship between theory and research is perceived differently in both two research approaches. Blaikie (2010) was of the view that inductive and deductive research can be differentiated based on theory development and theory testing. The basic concept differentiating the two types of approaches is basis of the research. For example, if a research *sets out with a theory* in hand or whether the research *ends with a theory* as the final product achieved from the research conducted.

4.6.1 DEDUCTIVE RESEARCH

Blaikie (2010, p. 154) described a deductive argument to have the capability of producing hypothesis through the use of theoretical models. The process used to achieve the hypothesis can also be achieved by testing which involves the corresponding and matching of hypothesis against data; this could be also conducted through diagrammatic or mathematical representations. Deductive research is viewed as the opposite process of inductive research. Deductive research starts with a more generalised approach and ends with a more focused outcome. It always starts with a theory which is tested through data collection and analysis in order to verify a hypothesis.

4.6.2 INDUCTIVE RESEARCH

Blaikie (2010, p. 154) described inductive research as generalisations or prepositions through a mathematical representation. The generalisation is also generated by induction from data through conceptual frameworks. Glaser and Strauss (1967) stated that inductive approach is highly linked to data and theory associated with qualitative research. There could probably be a degree of uncertainty and a conclusive outcome that is possibly centred on premises at the expense of exploring richer and more detailed data that could produce desired research outcomes. Thomas (2006) described that inductive approach works with data derived from concepts, themes and interpretations.

Newell and Bunard (2011) described deductive reasoning to be associated with quantitative research and have the tendency to move from generalised to more specific while inductive reasoning is associated with qualitative research and has propensity to move from specificity to generalised context. Theory and research are viewed contrarily in the context of deductive and inductive research, theory involves generalisation for inductive research which is continuously supported throughout the research. While research on the hand involves data collection, analysis, creating patterns which is developed into generalisations and finally leads to a theory. In the case of deductive research, which is the reverse of inductive research, a theory is not achieved as the end product of the research; theory has to be created, developed or borrowed (Blaikie, 2009). Koh and Owen (2000, p. 15) stated that "*The deductive researcher is interested in testing effectiveness of interventions*". Grinnell Jr and Unarau (2011) described deductive research as a process of using a theory to deduct a hypothesis, and also to analyse and test against world realities. While inductive research starts with observations and events that would lead to a more general finding that fits into a theory. Inductive research is closely associated to data collection and research. Another difference between inductive and deduction research is that inductive research is *observation based detecting* while deductive research is more knowledge driven that is *based on theory*. Figures 4.3 and 4.4 show features of both inductive and deductive research.

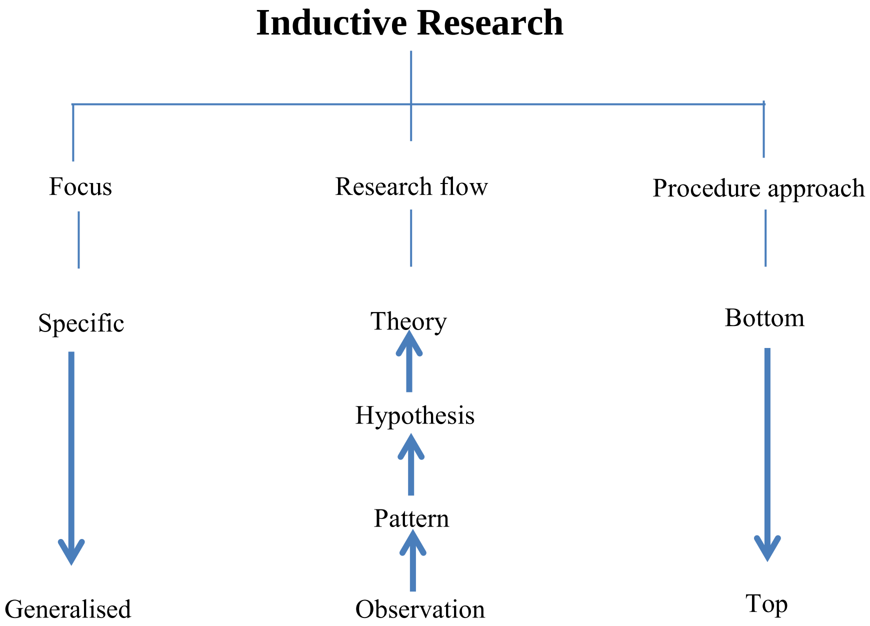


Figure 4.3: *Inductive research features. Source: Newell and Bunard, (2011) and Burney, (2008); (Blaikie, 2009); and Koh and Owen, (2000)*

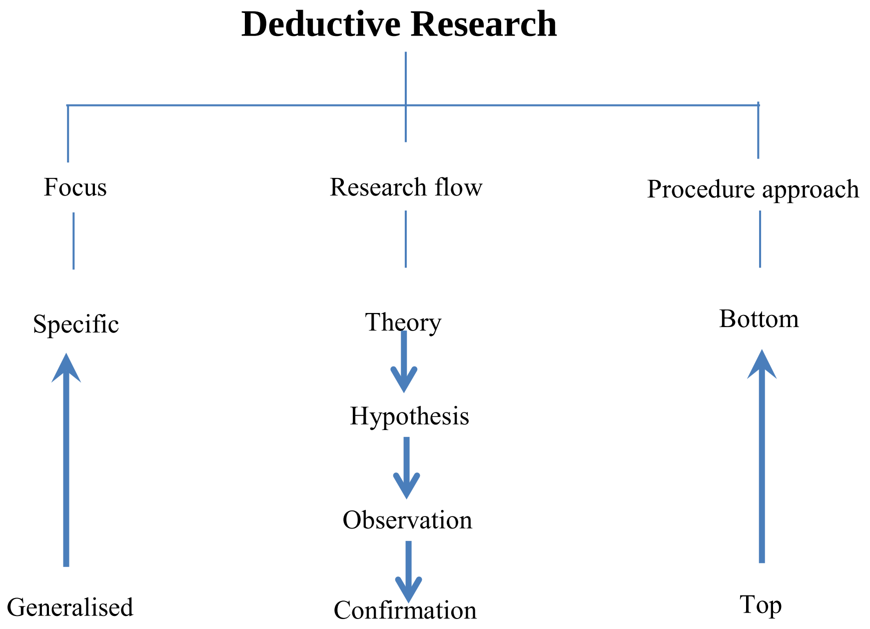


Figure 4.4: *Deductive research features. Source: Newell and Bunard, (2011) and Burney, (2008); (Blaikie, 2009); and Koh and Owen, (2000)*

4.6.3 RESEARCH APPROACH ADOPTED

The use of different research approaches such as deductive and inductive research determines the study approach; they are developed from epistemological or theory applications, and also the type of question a researches ask. Therefore, this research takes a deductive approach, which starts from more generalisations to more specific. Different broad topics such as refurbishment, flexibility, standardisation and BIM were explored at the beginning of the research, at a later stage these components are further narrowed down to the context of space, cost reduction, productivity and improved project quality when designing a change-ready healthcare facility. This study also started with a theory through the use of key features from the different existing frameworks analysed and presented in Table 3.14 of chapter 3. The use of a theory at the early stages of this study and ends with confirmation of hypothesis developed after the use of a theory through data collection. Starting with a theory is one of the basic principles of a deductive research; this shows evidence that this study took a deductive approach. The hypothesis for this study is that a change-ready healthcare facility can be developed through the use of refurbishment, flexibility, standardisation and BIM to enable a facility that can respond to future changes. The features of the framework developed were further refined through data collection.

4.7 RESEARCH METHODS

Different research methods are conducted for data collection purposes. These research methods include: *documents* such as journals, books, and magazines; *interviews* that can be conducted in person, or over the telephone; *observations* that could take place while meetings or experiments are conducted; questionnaire surveys are mostly used for statistical analogies; they can be open, closed or the combination of the two. There is always a need to arrange and organise questionnaire surveys properly before sending them out to specific personnel at specific places. Yin (1994, p. 6) identified five research methods that include: experiment; survey; archival analysis; history; and case studies. Blaxter *et al*. (2006) also described case studies as a type of data collection method; they are basic reviews of practical scenarios by researchers. Blaxter *et al*. (2006, p. 71) quotes Yin (2003, p. 4) that "*case study is the method of choice when the phenomenon under study is not readily distinguishable from its context*". Naoum (2007) noted the following case study types:

- explanatory;
- descriptive; and
- analytical

Bowling (2002, p. 16) described experiments as an invention that involves variables been examined under guided conditions that are experimented systematically, keeping all conditions identical to avoid disparity. However, questionnaire surveys and interviews were used for the purpose of this study. Aldridge and Levine (2001, p. 5) are of the view that all researchers should be asked the same questions. Table 4.2 illustrates features of the different research methods, while Table 4.3 describes advantages and disadvantages of the research methods.

Table 4.2: ***Features of different research methods Source: Yin (1994, p. 6)***

Research strategy	Research questions	Control over behavioural events?	Focuses on contemporary events?
Experiment	How, why	Yes	Yes
Survey	Who, what, where, how many, how much	No	Yes
Archival analysis	Who, what, where, how many, how much	No	Yes / No
History	How, why	No	No
Case study	How, why	No	Yes

Table 4.3: *Advantages and disadvantages of research surveys.*

Research surveys	Advantages	Disadvantages
Online surveys	Fast to distribute	Requires reminders
Postal questionnaire survey	Attract respondents empathy	Expensive
Phone surveys	Fast results at hand	Requires suitable times
Email	Builds contact	Requires reminders

4.7.1 RESEARCH METHODS ADOPTED

There are different research methods applied in research studies, but for the purpose of this research, methods adopted include: literature review that includes a desktop study and exploratory analysis of existing literature; exploratory questionnaire surveys and interviews; and main questionnaire surveys and interviews. Literature review was used to develop understandings of the applications of refurbishment, flexibility, standardisation and BIM in healthcare facilities. Questionnaire surveys were used to develop statistical data that can be used to support the fact that BIM can be used to design, analyse and evaluate different flexible designs in order to choose the most appropriate design option. Interviews were used to analyse how designers embed flexibility in healthcare facilities; in-depth analysis of interview data was required. Exploratory questionnaire survey and interviews were conducted to prepare for the main data collection.

4.7.1.1 Literature review

Literature review processes are described by Davis (2005, p. VIII) as a systematic and symmetric scheme of work flow which starts with planning the literature search, finding the literature, selecting and evaluating the literature and finally the literature review. This review is been extensively summarised. Denholm and Evans (2007, p. 212) stated that literature reviews should not develop to the point of distorting the thesis formation.

The literature review conducted for the purpose of this research is described into the following categories: review of current literature on healthcare in the UK and the challenges of healthcare facility in the NHS. Literature also explored the combined applications of refurbishment, flexibility, standardisation and BIM in healthcare facility design. It also explored healthcare design, construction and operational process as innovative suggestions are expected to have a pioneered impact within the entire healthcare building process. Literature on theoretical and effective practices for applying BIM was also explored to enable projects to learn from successful studies of BIM when implemented by different stakeholders in the AEC industry. One of the main objectives of this research is to merge flexibility and standardisation with BIM. Research also reviews the systematic approaches of implementing BIM to explore and establish a clear and concise approach towards the use of flexibility and standardisation within a change-ready healthcare facility. Inquiries into the activities of flexibility in healthcare facilities is becoming rampant; preparing for change and growth is important in healthcare facility design. Responding to new technology is one of the main features of healthcare facility design. It was noted by Miller (2006, p. 6) that healthcare facilities are becoming out-dated due to lack of flexibility. Literature was used to develop a framework that this study can progress with. The analysis of literature for the purpose of this study showed that BIM is not currently explored in current flexibility frameworks. Therefore, there was a need to explore BIM through questionnaire surveys and interviews.

4.7.1.2 Exploratory questionnaire survey and interviews

Page *et al.* (2012, p. 73) stated that exploratory questionnaire surveys are usually open ended, but can appreciate the use of focused questions. Open ended questions are used to explore studies that could help generate new findings, while close-ended questions limit the opportunity to explore in-depth knowledge. Open-ended questions are closely related to qualitative research, while close-ended questions are related to quantitative research for statistical analogies. With a large number of responses, close-ended questions could be the right approach to improve control. Exploratory interviews were also conducted at the early stages of this research through the use of both open-ended and close-ended questions.

4.7.1.3 Questionnaire survey

The main questionnaire surveys (see appendix 6 and 7) were distributed after conducting the exploratory questionnaire surveys and interviews with colleagues in the Research Hub, Loughborough University. This was conducted to improve research focus and prepare for the main data collection. Table 4.4 shows the advantages and challenges associated with questionnaire surveys. Despite the challenges, a questionnaire survey was distributed to different categories of BIM users to explore the opportunities of BIM in healthcare facility design. Different categorises were required for the research sample size. Page *et al.* (2012, p. 70) described the reasons for choosing an appropriate and suitable sample as "*A sample size calculation justifies the proposed study and in doing so demonstrates that the study has the ability to support the statistical analysis required to answer the research question*". It is also necessary for a quantitative research to generate a sample size that this study can progress with in order to justify the boundaries of the research target.

Table 4.4: *Advantages and challenges of questionnaires surveys*

Questionnaire design and use	
Advantages	**Challenges**
Distribution of questionnaires are categorised into approaches.	Responses could depend on the method of distribution.
Allows primary data collection	There is a need for reminders.
The questionnaire designer doesn't have to be present when questionnaires are completed	There is a need for a return deadline.
Cheap to distribute.	Clarifications cannot be made once deployed.
It provides quantitative data.	Questions must be clear and easy to understand.
Respondents can be unspecified.	Assumptions are made that questions are clear and straight forward.
A time responses can be anticipated.	Difficult to deal with partial or half-finished questionnaires.

4.7.1.3.1 Questionnaire survey sampling

Sampling is conducted to choose research participants and narrow down the numbers, groups, subjects or organisations to interview or to fill out a questionnaire survey. Dawson (2002, p. 48) classified sampling into two main types. These are *probability* and *purposive* sampling.

probability sampling is the process were each sample has an equal opportunity of being chosen, while *purposive* sampling is the type of sampling done when generalisation is the not the issue, in this case, samples do not have an equal opportunity of being chosen at random. Bryman and Bell (2007) also grouped sampling into the *probability* and *non-probability*. Non probability is a method used were some of the elements within a study has zero percentage of been selected or chosen at random. They divided probability sampling into four. These include: simple random sampling; systematic sampling; stratified random sampling; and multi-stage cluster sampling, while non-probability sampling is divided into three. These are: convenience; snowball; and quota sampling. But for the purpose of this research non-probability sampling was taken into consideration to target respondents with the required skill set, while the sample size was situated on an absolute and relative sample size to enable quick and focal data collection. The application of BIM to support the design of a change-ready healthcare facility would require inputs from BIM users and designers with healthcare experience to collect data that can facilitate the design of a healthcare facility and respond to future changes when the need arises. As a result,

- BIM users such as BuildingSmart UK chapter was considered as a sample size. BuildingSmart formerly known as IAI is an organisation that promotes the interoperability of information exchange in the AEC industry. They are one of the strongest proponents of BIM. Questions were focused on information exchange.
- BIM advocates in LinkedIn were also targeted as more than a thousand members were registered within some of the groups (BIM Architecture). Therefore, this group was considered for information regarding design and BIM.
- The application of BIM is conducted in various sector of the world`s industries. BIM users in the AEC industry were purposely targeted for this research (architectural practices). Therefore, the UK top 100 architectural practices were contacted to collected data from architects with healthcare design and BIM experience.

Table 4.5 shows the comparison of the different questionnaire survey methods. However, the internet was used to contact respondents; a phone call was also used to follow up on respondent who fell to respond.

Table 4.5: *Comparison of different questionnaire survey methods. Source: Knight and Ruddock, (2008); Silverman (2004)*

Questionnaire	**Internet**	**Postal**	**Phone**
Data storage	Data is easily managed.	Data in high numbers could be difficult to manage.	Data has to be recorded.
Data quality	The quality of the data would be as expected.	The quality of data would be as expected.	The quality of data can be affected by the network.
Data access	Data can only be accessed through the internet.	Received surveys are easily accessible.	A document might need to be forwarded before the phone survey.
Data analysis	Online surveys can be easily or automatically analysed by some capable software.	Manually organised.	Manually organised.
Data analysis time	Faster	Time consuming	Less time intense
Communication speed	Fast, as quickly as the press of a button.	Delays should be expected depending on the postage type.	Respondents have to be available to participate, otherwise a fast communication method.
Communication flexibility (control)	More information tabs are provided using online surveys for more clarifications.	Does not provide more clarification.	There is an opportunity to make explanations to clarify any complications.
Cost involved	Minimal cost attached to the process of forwarding questionnaire surveys. There are many free online survey websites.	A higher cost is involved in posting out questionnaires which are usually sent out with returned stamps and envelops	Cost is at its maximum when conducting phone interviews, depending on the line called and the phone line used to make the calls.

4.7.1.3.2 Method of questionnaire survey analysis

McNabb (2008) described that questionnaire surveys are used due to their flexibility, ability to meet the objectives of most project and their capability to effectively and efficiently measure some phenomenon. Farrell, (2011) categorised the analysis of questionnaire surveys into two different groups. These are presented in Table 4.6. These are the descriptive statistics and the inferential statistics. The descriptive statistics produces an expressive analysis of the questionnaire survey data collected; this could be conducted by different approaches such as mean, average and mode, while the inferential statistics are conducted through probability and correlational statistics.

Table 4.6: *Methods of questionnaire survey analysis. Source: Farrell, (2011)*

Descriptive statistics features	Inferential statistics features
Ranking	Probability values
Normal distribution: measures of central tendency (mean, median and mode)	The chi-square test
Measure of spread: range, standard deviation, variance	Difference in mean test: the “t” test
Standard score: the Z score	Difference in means
Confident intervals	Correlations
	Difference in means, correlations or both
	Using correlation coefficients to measure internal reliability and validity

A Likert scale has been applied in the questionnaire survey analysis to describe the primary data collected for the purpose of this research. Different Likert scales labelled type A, B and C were used to analyse the data collected and express the findings. The three scales were chosen based on the nature of the questionnaire survey questions. These are illustrated in Tables 4.7, 4.8 and 4.9 below.

Table 4.7: *Weighting factors used in the analysis of the Likert questions; type A*

Scoring scale (Likert)	**1 = Not at all**	**2 = Don`t know**	**3 = Not sure**	**4 = Some of the time**	**5 = Most of the time**
Weighting factor	1	2	3	4	5

Table 4.8: *Weighting factors used in the analysis of the Likert questions; type B*

Scoring scale (Likert)	**0 = Highly ineffective**	**1 = Ineffective**	**2 = Don’t know**	**3 = Neutral**	**4 = Effective**	**5=Highly effective**
Weighting factor	0	1	2	3	4	5

Table 4.9: *Weighting factors used in the analysis of the Likert questions; type C*

Scoring scale (Likert)	**0 = Strongly disagree**	**1 = Disagree**	**2 = Don’t know**	**3 = Neutral**	**4 = Agree**	**5= Strongly agree**
Weighting factor	0	1	2	3	4	5

The questionnaire survey findings presented this study with statistical backing enabling the use of BIM to support the design of a flexible space design in the healthcare sector. Descriptive quantitative analysis methods were used to describe the opinion of the questionnaire survey respondents. The next task was to explore how and when healthcare designers can use BIM to support the design of a change-ready healthcare facility. Also in-depth data was required to explore current methods of incorporating flexibility into a healthcare space in order to respond to future known changes.

4.7.1.4 Interviews

Easterby-Smith *et al.* (2008) were of the view that interviews are one of the suitable systematic approaches towards collecting in-depth primary data that a study can analyse. During an interview process a relationship is created between the interviewee and interviewer; this relationship could affect or improve the outcome of the interviews. Denzin and Lincoln (1998, p. 174) stated that there has to be "*a constructive, organised, well structured, sensible and stable relationship between the interviewee and the interviewer during the interview process to collect impartial, equitable and unbiased data*".

4.7.1.4.1 The type of interviews

Denscombe (2007) stated that interviews are basically classified into three different categorises. These are: structured; unstructured; and semi-structured interviews. The method of collecting the primary data could be conducted by individuals through different methods, such as phone, face to face and so on. An analysis of the methods used for collecting interview data has been explored and discussed in the research method section above. The advantages and disadvantages of the different interview types might not affect the selection process as the most suitable method would depend on the content and context of the research in focus and available time and resources.

The different types of interviews include structured, unstructured and semi-structured interviews. Structured interview are strongly related to quantitative research method and usually closed ended questions. These involve standardisation of question formats. However, structured interviews can also be used in qualitative research. Semi-structured are usually applied in social research, questions are normally open ended.

4.7.1.4.2 Approach to interview design

Semi-structured interview design approach was adopted for the purpose of this research. However, there was a need for both open-ended and close-ended questions due to the need for clarity (statistical data) and in-depth qualitative data collection. There are places were a specific context is in question. For instance, the use of BIM is applicable in the entire AEC industry, but for the purpose of this research, the use of BIM in healthcare facility design is in question; in this case close-ended questions can be used. Literature review findings show no clear answer on how to combine the applications of refurbishment, flexibility, standardisation and BIM to develop a change-ready healthcare facility. Open-ended questions allowed participants to give information on how, when, what, who, and why things should be done in a certain way. Therefore, open-ended and close ended questions were appropriate in order to collect in-depth primary data that this research can analyse. Swetnam and Swetnam, (2007, p. 68) stated that there are interview guidelines that control and lead the process of interviews. These are:

- avoid volunteering to support interviewees with answers;
- treating all interviewees equally;
- do not direct but prompt interviewees for clarifications;
- avoid sarcasm;
- do not be superior when dealing with interviewees;
- be patient;
- be formal and open; and
- follow a systematic approach and develop further.

4.7.1.4.3 Type of interview questions

There are different interview questions used for data collection purposes, each interview question type is characterised with specific features that could help collect data for the different types of studies in focus. Shekedi (2005) described six different interview questions used for conducting interviews. These are:

descriptive questions: These questions could be used for introductory purposes, where the interviewees give his/her background information; this could be a basic description of the contextual area of focus. The interviewer can ask questions like *what?* To collect more information from the interviewees and ease the data analysis process;

meaning questions: These are in a form of follow up questions generated to create reasoning behind some descriptions provided by the interviewees for clarification and in-depth understanding of the subject area in context. The interviewer can ask questions like *why?* To encourage the interviewees to add meaning to his descriptions;

comparison questions**:** These are add-ons responding to the descriptions and reasoning provided from the interviewees to further place questions in context of their area of focus. A comparison a time can help clarify the description provided by the interviewees. The interviewer can ask the respondent if he/she can compare certain information with a similar one for clarification purposes;

complement questions: They are used to verify previous statements or comments made by the interviewee. He/she could be moving from one topic to the other, or discussing from whole to part and part to whole. It is important to understand that the complement questions can help guide the interviewees to clearly present the interests of the interviewer. For example, do you mean it is difficult to manage a poorly designed facility once it is constructed?;

contrast questions: These are similar to the complement questions; they both respond to the information previously provided by the interviewees. Contrast questions are used when the interviewer feels that there is a sort of contradiction within the respondent's information which could arise due to varied contexts of the area in focus; and

triggered questions**:** These questions are also similar to the comparison, complement, and contrast questions, but in this case, the interviewer suggests or confronts the interviewees with certain opinions which could trigger a new conversation or debate. Contrast and triggered questions are very sensitive, at some point they could corrupt the remaining part of the interview by losing the flow, trust, understanding and relationship with the interviewees. Despite this, there could be really productive and successful a times. Perhaps there is always a high risk involved in dealing with both contrast and triggered questions.

4.7.1.4.4 Transcribing interviews

Transcribing interviews is the process of interpreting collected data into text; this could be from phone, online video or face to face recorded interviews to text. This is generally making recorded interviews available in written format, ready for analysis. Huberman and Miles (2002) stated that interview content is usually dynamic with different diversity for analytic analysis. They also noted that data has to be analysed without bias from the researcher, but before the data is analysed it has to be transcribed. It is important to acknowledge that it is difficult to avoid bias from the researcher. Brinkman and Kvale (2009) defined the process of transcribing primary data as an explanatory or interpretative process that involves the conversion of audio, verbal or oral conversations into written text to allow the ease of analysing data for specific research purposes. It is important for the researcher to get close to the data by going over the data a number of times before processing the data.

4.7.1.4.5 Method of interview analysis

What are the methods of analysing qualitative data? The analysis of interviews is complex and crucial to the research focus due to the large amount of primary data available for transcription and analysis. Dainty (1998) in Figure 3.2, chapter 3 illustrated the analysis of qualitative analysis as a process that involves describing, connecting and classifying of primary data. Renner (2003, p. 1) stated that the analysis of qualitative data is mainly dependent on the focus of the analysis; the process of the analysis will depend on three key features. These are:

- the questions you want to answer;
- the need of those who will use the information; and
- available resources.

The interview analysis method was based on the content analysis which is also called coding method: Renner (2003) stated that the content analysis process is made up of three steps. These are: understanding the interview data; focus the analysis; and categorising information; and identifying patterns between categories.

understanding the interview data**:** thoughtful review of the data can help in understanding the quality of the primary data before the analysis begins; this is done by going through the data over and over again to be able to identify the limitation of the interviews and pick up on key factors that can focus the direction of the research more closely;

focus the analysis**:** The primary data collected through interviews, case studies, focus groups can be analysed when they are centred on questions, topics, time periods, events or alternatively the data can be analysed in whole by grouping the data into cases, individuals or groups to have an overall picture of the collected data;

categorising information: categorising is a time referred to as coding or indexing the primary data for analysis purposes. After categorising the primary data, *patterns* can be identified from ideas, phrases, concepts or incidents within the collected data. Abbreviations are assigned to the key issues under a named category. Sub-categories are later drawn from the specified categories; and

***identifying patterns between the categories*:** This helps in re-categorising the sub-categorised information allowing the primary data to be grouped within a certain context or themes. The key ideas, similarities and differences should be identified and summarised to clarify each sub-category theme. The sub-categories are used to create larger categories which will allow patterns to be easily and clearly identified. The relative importance of each theme can be identified by counting the number of times it appears; this is done to identify general patterns but not for statistical purposes. The relationships that could possibly arise from the patterns should also be identified. Cause and effect relationships from the interview analysis should be identified. It is also important to look at themes that do not fit into the sub-categories.

4.7.1.4.6 Adopted interviews

Semi- structured interviews were adopted for further primary data collection. The interview design, approach, questions and analysis method adopted for this research are presented below. The same approach was conducted for the three different interviews conducted in this research. These include exploratory interviews, the main research interviews and the validation interviews.

Approach to interview design: The interview design approach for this research was semi-structured. There are places were a specific context is in question. For instance the use of BIM is applicable in the entire AEC industry, but for the purpose of this research the use of BIM in architectural design is in question. There is no clear answer on how the combined application of flexibility and standardisation can be best achieved; there is a need for open-ended questions to collect in-depth data. Therefore, close-ended and open-ended questions were appropriate to collect rich primary data.

Interview question sequence adopted: The interview questions were arranged in a sequences that starts with questions situated around the need for BIM in healthcare facility design extending to the role of the designers (requirements and activities) when designing flexible healthcare spaces with BIM. This was done to categorise the interview questions into sections for ease of data flow.

Types of questions used for the research: The descriptive questions, meaning questions, comparison and contrast questions were used in the interview process for the purpose of this research. The triggered questions were avoided as they are sensitive and could spoil the flow of the interview, and eventually spoil the quality of the primary data collected.

The main topics in the interview schedule include the broad applications of refurbishment, flexibility, standardisation and BIM in healthcare facility design. Semi-structured interviews were used to explore the gaps discovered after the questionnaire surveys were collected and analysed. Conducting an interview was another research objective for this study; the findings described when and where BIM can be used to support the design of a change-ready healthcare facility. Findings were used to review the framework previously revised using questionnaire surveys. There was a need to validate the framework refined through a final framework revised through (interviews) which is the last research objective.

4.8 RESEARCH TASKS

In a broader sense, this research is associated with *management research*, it is described in the context of organisation and how managerial schemes are used to solve problems (Bryman and Bell, 2007). Saunders *et al*. (2007) stated that management research provides the opportunity to add new knowledge to existing literature through the resolution of practical problems. The use of BIM in the AEC industry requires both managerial implementation and organisation use. The research plan sequence described by Howard and Sharp, (1983), and recently reviewed by Gill and Johnson, (2010) was systematically followed to execute this research.

Triangulation method is also called pluralism or mixed methods. Triangulation was adopted for the purpose of this research through the combination of both qualitative and quantitative research methods. The research plan sequence developed by Howard and Sharp (1983) was followed by conducting a literature review followed by primary data collection. A plan was put in place to conduct exploratory questionnaire survey and interviews, main questionnaire survey and interviews with architectural practices. After the collection of both primary and secondary data, an analysis and reporting tasks established to complete this research. The collection of empirical evidence (primary data) was required to establish a more detailed and comprehensive understanding of current theories and practices. This involved both qualitative and quantitative data collection through open-ended and close-ended questionnaire survey and interviews. Furthermore, analysis and testing of primary data was conducted; a final report writing of general research outcome and lessons learnt were presented.

4.8.1 RESEARCH OBJECTIVES AND METHODS ADOPTED

Different applications have been considered for this research with variable research methods to achieve desired research outcomes. To summarise the research methods adopted, Table 4.10 illustrate the six research objectives and research techniques adopted for the purpose of the research.

Table 4.10: *Research techniques applied*

Research summary						
Research Techniques	Objective: 1	Objective: 2	Objective: 3	Objective: 4	Objective: 5	Objective: 6
Research application	AP; PR					
Research objective	ER					
Research paradigm	IP&PA					
Research methodology	MM					
Research approach	DRA					
Research method	LR; EQ; EI	LR; DS	QS	DS SD	I	I
PR: Pure Research; **AP**: Applied Research; **ER**: Exploratory Research; **IP**: Interpretivist; **PA**: Positivist Approach; **MM**: Mixed Methods; **DRP**: Deductive Research Approach; **LR**: Literature Review; **EQ**: Exploratory Questionnaires; **EI**: Exploratory Interviews; **Q**: Questionnaire Survey; **DS**: Desktop Study; **SD**: Secondary Data; **I**:Interviews						

4.8.2 RESEARCH WORK AND METHODS ADOPTED

The corresponding chapters of this research are clearly described with the research objectives used to enhance guidance that would enable the designer to use BIM with the combined applications of flexibility and standardisation during healthcare refurbishment. Table 4.11 illustrates a summary of this research more closely.

Table 4.11: *Research road map*

Objective	Task	Method	Chapter
One	Establish the context of research.	**LR** **EQI** **SD**	1 2
	Identify different refurbishment, flexibility, standardisation and BIM processes.		
	Explore the impact of refurbishment, flexibility, standardisation and BIM on healthcare.		
Two	Exploring the challenges of BIM	**LR** **DS** **SD**	3
	Comparative analysis of different BIM implementation plans.		
	Identify the opinion of BIM users on tools that could hinder design creativity and standards that can affect flexibility		
	Generate a framework from literature using desktop study.		
Three	To explore an effective and connective strategy for integrating refurbishment, flexibility, standardisation and BIM in healthcare.	**Q** **QA**	5
	Develop the framework generated from literature review using questionnaire survey.		
Four	Identify the opinion of BIM experts on the design of flexible healthcare facilities.	**I** **IA**	6 7
	Develop the framework generated from literature review and questionnaire survey using interviews.		
Five	Analyse methods of evaluating flexible design options with BIM.	**IA**	7
Six	Implementing and validation of the final framework	**IA**	7
Key: **LR**: Literature Review, **DS**: Desktop Study, **SD**: Secondary Data, **Q**: Questionnaire Survey, **QSA**: Questionnaire Survey Analysis, **I**: Interview, **IA**: Interview Analysis			

4.8.3 REJECTED METHODS, THEORIES AND APPROACHES

Some research methodologies, theories and approaches were rejected due to the philosophical position of this research. An exploratory position was considered for achieving the preferred research outcomes. Therefore, a mixed methods research was adopted. Some of the method, theories or approaches rejected are stated. These are:

- open-ended or close-ended questions were not used exclusively, there was a need for both type of questions in the primary data collection process;
- structured interviews were not used at all;

- postal questionnaires were not used due to the ease of online surveys;
- mathematical modelling approach was considered for the utilisation of healthcare spaces, but due to time constraints was not applied;
- quantitative research was not applied solely; there was a need to explore a richer and in-depth primary data regarding the different applications of refurbishment, flexibility, standardisation and BIM in healthcare. Therefore, both qualitative and quantitative were used.

4.8.4 ORGANISATIONAL STRUCTURE OF RESEARCH DATA

Figure 4.5 was used to illustrate the organisational flow of data collection methods to achieve the research outcome of this study. It summarises both method used and output achieved. The data collection was organised into three groups. These are:

- preliminary studies were conducted before the main study data was collected to clearly explore and identify the research gap for this study, and also improve the research aim and objectives;
- the main study was conducted through literature review, questionnaire surveys and interviews to revise a single framework that can facilitate the design of a change-ready healthcare facility; and
- a validation exercise was conducted for reliability and validity of the revised framework through interviews.

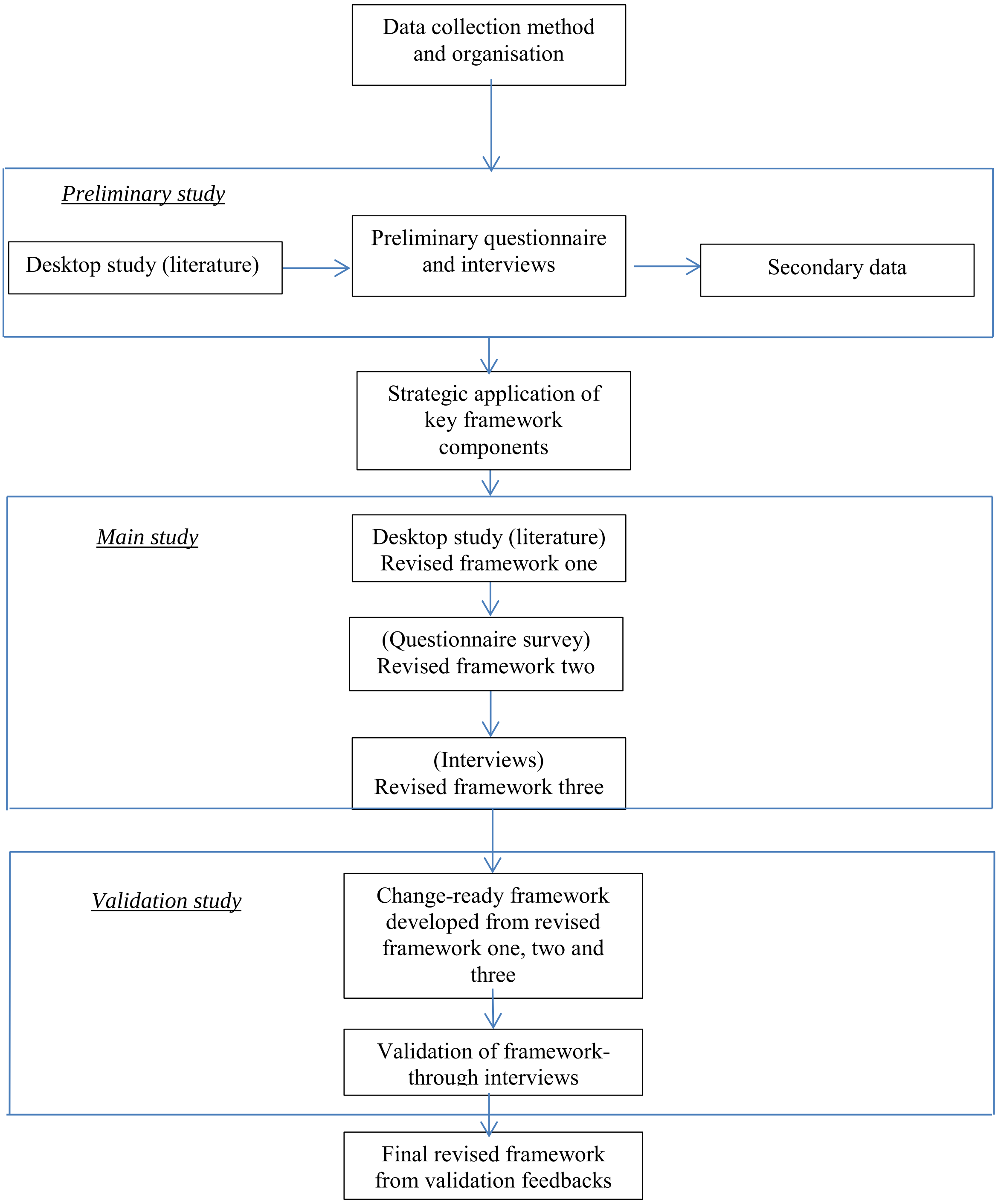


Figure 4.5: *Organisational structure of data collection methods*

4.8.5 PRIMARY DATA POPULATIONS AND SAMPLES

To collect primary data that this research can analyse, selected population and samples were considered for data collection. The research methods applied, proposed population and samples are presented in Table 4.12. The number of invitation and responses recorded are also outlined. The populations and samples were focused on designers, planners, project managers and facility managers with healthcare and BIM experience in the AEC industry. The top 100 UK architectural firms were contacted during the questionnaire survey, and interviews; whiles companies that opted to be contacted for the validation exercise during the interviews were contacted again. The secondary data was the primary data collected from the HaCIRIC team, but was analysed by this study.

Table 4.12: *Research population and samples used for this research*

Research method	Population	Sample	Contacted	Phoned	E-mailed	Outcome
Preliminary questionnaire	Loughborough University, Research Hub.	HaCIRIC, Research team and researchers with similar research areas.	6	-	x	6 Respondents
Preliminary interviews			4	-	x	4 Participants
Secondary data Questionnaire survey	Various lists of HaCIRIC collaborators healthcare project managers, designers and planners (200).	200 professionals were contacted.	200	x	x	70 Respondents
Questionnaire survey	Designers and BIM users found on the internet.	CNBR Yahoo group.	Website	-	x	48 Respondents
		LinkedIn BIM group.	website	-	x	0
	BuildingSmart international.	BuildingSmart UK chapter.	40	x	x	1
	There are about 3000 firms that met the RIBA robust criteria. RIBA, (2013).	Top 100 UK Architectural practices (Building Magazine, 2010).	100	x	x	10 Respondents
		Architects for Health (500 members).	Website	x	x	0
Interview	Top 100 UK architectural firms.	Architects for Health.	Website	x	x	0
		10 respondents from the top 100 UK Architectural firms.	10	x	X	10 Participants
Validation (interview)	Top 100 UK architectural firms.	10 respondents from the top 100 UK Architectural firms.	10	x	X	3 Participants
		11 Britain's Best Architects (Healthcare).	11	x	X	0
	Facility management Conference members.	5 NHS Estates/Foundation Trust groups. Guy`s and St Thomas` NHS.	-	x	X	1 Participant
	Suggested consultancies by interviewees.	1. EC Harris; and 2. Avanti architects.	2	x	X	1 Participant
	RIBA.	RIBA BIM working group.	1	x	X	1 Participant

4.9 DATA VALIDITY AND RELIABILITY

Validity and reliability are sometime interchanged; they are used to assess the quality of research. Oxford online dictionary defined reliability as "*consistently good in quality or performance; able to be trusted*" while validity was defined as *"the quality of being logically or officially binding or acceptable*".

4.9.1 RELIABILITY

Reliability is related to issues of measures. Bryman and Bell (2007, p. 163) stated that there are three different factors used in measuring the reliability of a concept. These are:

- Stability reliability: the ability of a concept to stand the test of time when put into question. Stability requires a concept to be measured over a period of time with a similar result expected; if the outcome fluctuates due to time factor, then a variation can be registered.
- internal reliability: key indicators that make up the scale of measure should be consistent during a study. If the relevant indicators of a concept measure are not consistent or scored opposite; then an internal unreliability can be recorded.
- inter-observer consistency: when analysing concepts, there should be consistency in the decision making. For example, when dealing with qualitative data, content analysis or subjective issues, a decision has to be made on what/how to categorise primary data. This usually happens when there is more than one researcher involved.

4.9.2 VALIDITY

Validity is generally used to validate research through the process of measuring concepts in focus. It can be described as legitimacy, authority or rationality to accept an idea or concept. Bryman and Bell (2007, p.165) categorises validity into five different groups. These are:

Face validity: this is the process of relating the subject face to the context; this could be through the comments or feedbacks from experienced professional in the field of the subject in context. It is conducted to make sure the measurement reflect the content of the concept in question.

Concurrent validity**:** when a researcher is dealing with criterions that are related to subjective perspectives, there is a need to take the research analysis further. For example, to find out students who enjoy studying a particular subject, the grade of students can be used to further verify if all students that opted for enjoying the subject have good grades.

Predictive validity**:** future criterion is used for measuring a new concept rather than a modern approach.

Construct validity**:** the researcher presumes hypothesis from theories applicable to the concept. For example, a cause and effect situation; getting fat and eating junk food. This example cannot be taken for all cases, as there could be some exceptions where the approach is misguiding or invalid.

Convergent validity**:** the researcher might want to measure some concepts through comparisons of outcomes using different research methods. For example, hours spent in training in a football club can be analysed through questionnaires or observations to verify.

4.9.3 VALIDATION AND RELIABILITY ADOPTED FOR THIS RESEARCH

The validity classifications relevant to this study include: face validity; construct validity; concurrent validity; and convergent validity. With the use of scientific theories, the questions used for the data collection were simple and clear. The primary data results relate to the analysis, and the conclusion was compiled from the findings of the data collected. Existing literature was used to support the research findings; making recommendations for future research was conducted to show reliability of the primary data collected. Validation interviews were also conducted with architects, facility managers, NHS trust and the RIBA. Fellow and Liu (2008) stated that possible errors in data collection should also be avoided. This can be triggered mainly by response errors. These are categorised into the researcher errors, interviewer errors and the participant error. To avoid some of these errors, effort was made by redesigning the questionnaire over and over again with the respective project supervisors to make the questions clearer, shorter, precise and easier for the respondents to understand and fill. A more clearer and simple questionnaire survey is most likely to be completed fully and accurately.

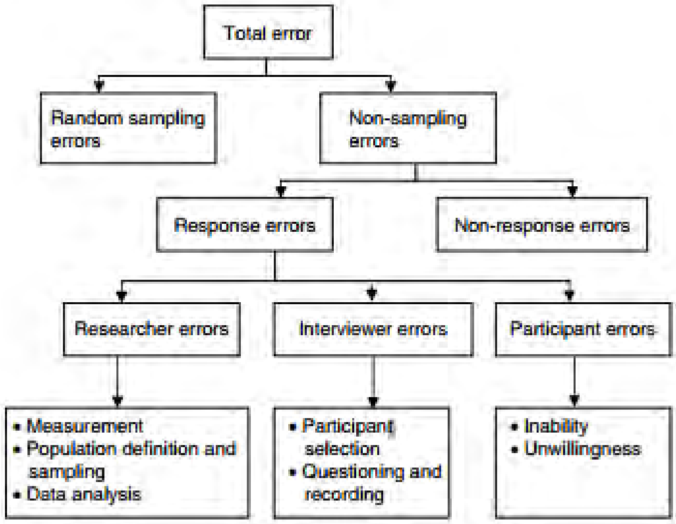


Figure 4.6: *Possible errors in data collection method procedures. Source: Fellow and Liu, (2008) quotes Malhotra and Birks (1999)*

Figure 4.6 presents three errors related to this research. These are: the researcher error; the interviewer errors; and participant errors. Researchers' error was avoided by collecting data from experienced participants and analysing data by sequentially following standardised analysis chronologies identified in section 4.7.1.3.2 and 4.7.1.4. To avoid interviewer errors questions were forwarded to participants before conducting the interviews. Table 4.13 describes reliability and validity of this research through certain classifications of validity identified by Bryman and Bell (2007, p. 165).

Table 4.13: *Reliability and validity of research*

Issues	Measured Used
Reliability	Robust literature review, questionnaires and interviews were used sequentially through the research process. The literature review findings support some of the primary data findings.
Face validity	Professionals were contacted through interviews to verify the content of the framework and its expected task during the validation process.
Construct validity	Data from different sources (samples) were used to explore and confirm research outcome. Theories explored were used to develop a constructive approach towards the findings. For example, when a building adapts to future changes, it is expected to increase its value and reduce the cost of facility management. This is also verified by literature.
Convergent validity	Different research methods were used to explore the same results, and there was a very strong correlation between the results. For example, the same questionnaires were distributed through e-mails (MS word document) and online survey service website.
Concurrent validity	For example, questionnaire findings showed that BIM can be used in the design, analysis and evaluation of the healthcare facility (see chapter 6); interviews were used to find out how and when this can be done (see chapter 7), it confirms the questionnaire survey findings.

4.10 CHAPTER SUMMARY

There are different research methods and methodology adopted for the purpose of this research. A mixed method research was used; statistical analogy and subjective schemes were used to collect primary data. They were adopted to improve the data collection procedure and to gather substantial and rich information that include theoretical data and best practices to produce a credible report at the end of this study. This research was conducted based on six different research techniques due to the breadth of the research objectives. These are: research applications; research objective; research paradigm; research methodology; research approach; and research methods. All the six different research techniques had different categories; the selected categories were outlined and discussed in details in the different sections of this chapter.

5 CHAPTER 5: PRELIMINARY RESEARCH- EFFECTIVE APPLICATION OF FSB WITHIN REFURBISHMENT PROJECTS

5.1 INTRODUCTION

The application of flexibility standardisation and BIM (FSB) can be applied within a refurbishment process. With an ageing and growing population around the globe, healthcare facilities have to provide the necessary standardised healthcare spaces that can accommodate changes. This Research is centred on improving healthcare facilities design by incorporating flexibility and standardisation through the use of BIM. These four applications are proposed to be integrated into a framework for designing a change-ready healthcare facility. This chapter discusses the basis of this research through the use of *preliminary questionnaires survey* and *interviews*, and *third party data* collected from HaCIRIC team but analysed by this research. It shows the systematic development of this research as it narrows down and focuses closely on key issues such as (space/equipment) flexibility, (space/equipment) standardisation, (space/equipment) refurbishment and the designer's role when applying BIM in healthcare. One of the key questions that emerged from literature review is how to integrate the four broad applications of refurbishment, flexibility, standardisation and BIM without compromising cost control and project quality. To focus this research and create a strong case for primary data collection, both qualitative and quantitative data were required to explore a strategy of linking the four applications together and to identify the effectiveness of using flexibility, standardisation and BIM within a refurbishment process.

5.1.1 AIM AND OBJECTIVES OF THE PRELIMINARY RESEARCH

The *aim* of the preliminary primary data collection was to explore the combine applications of refurbishment, flexibility, standardisation and BIM in healthcare and narrow down the four applications, while the *objectives* were:

- to identify the effectiveness of the four applications in healthcare;
- to verify the individuality and originality of the research with research colleagues;
- to explore the potential research gaps between this research and existing studies; and
- to identify areas that further research can improve.

5.1.2 PRELIMINARY RESEARCH

The research methods used for the purpose of the preliminary research includes the use of preliminary questionnaire surveys and interviews. Blaxter *et al*. (2006, p. 214) proposed that questionnaire survey is used as a tool for collecting both qualitative and quantitative data. Questionnaire surveys were used to provide the research with statistical evidence, while semi-structured interviews were used to give an in depth enquiry of the research area in context to develop a clear understanding of the research hypothesis. McNabb (2008) stated that questionnaire surveys are used due to their flexibility, ability to meet the objectives of most projects and their capability to effectively and efficiently measure some phenomenon. A preliminary questionnaire survey was used to identify the potential research gaps in the applications of refurbishment, flexibility, standardisation and BIM within healthcare projects. Preliminary interviews were used to verify the research hypothesis and also explore strategies of improving healthcare facility. A total of 10 research colleagues participated in the preliminary questionnaire survey and interview exercise; the questionnaire surveys were given out to six respondents, while interviews were conducted with four participants. all 10 individuals had both healthcare and BIM experience.

5.1.3 BACKGROUND OF QUESTIONNAIRE SURVEY AND INTERVIEW RESPONDENTS

The 10 respondents were selected based on their general knowledge of healthcare research, refurbishment, flexibility, standardisation and BIM. Six out of the 10 participants were part of the HaCIRIC Loughborough branch, while the other four respondents are fellow research colleagues undertaking doctoral research (PhD students) in the field of healthcare. Findings from the questionnaire survey outlined possible areas of focus, stating issues such as *when best*; *where best*; and *how best* the applications of refurbishment, flexibility, standardisation and BIM can be applied in healthcare refurbishment.

Findings of the conducted interviews showed that the research objectives previously used for the purpose of this study were too broad and needed to be more focused and deal with more specific issues rather than general issues. In relation to the scheduled interviews, all the interviewees suggested different possible ways of focusing on specific issues relating to refurbishment, flexibility, standardisation and BIM. These include describing a central factor relating the four broad applications to focus on healthcare, or by adding prefix such as space flexibility or space standardisation.

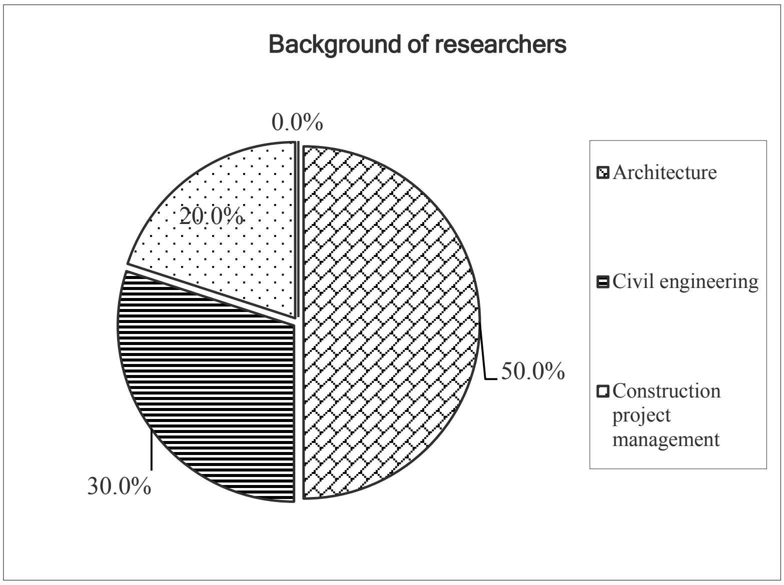


Figure 5.1: *Background (profession) of participants for both questionnaire survey and interviews*

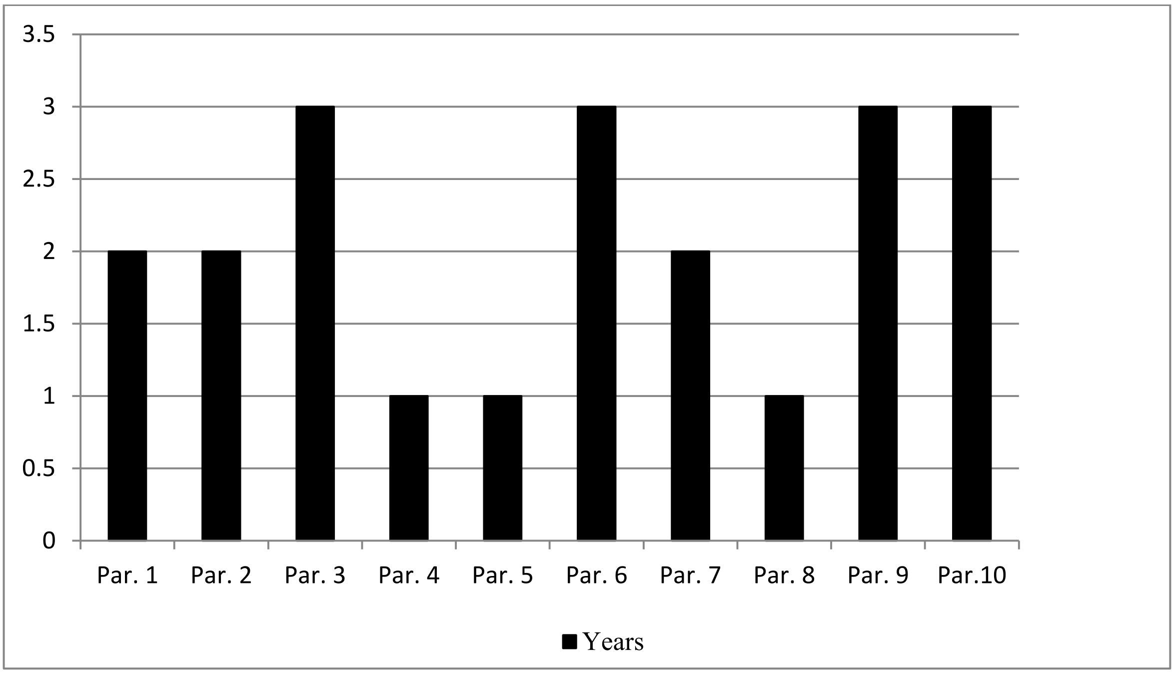


Figure 5.2: *Participant`s years of BIM experience*

5.1.4 LIMITATION OF THE RESEARCH METHODS

Questionnaire survey and semi-structured interview were conducted for the purpose of the preliminary research, while the aim was to explore research gaps. All the four applications are broad topics applicable in various sector of the economy. The process of using open-ended questions invited different issues that do not fall within the context of the research area. Regarding the data collected from the HaCIRIC team; the researcher did not participate in the process of collecting the data, but participated exclusively in the process of analysing the data. Therefore, the primary data collected from the HaCIRIC team can be classified as third party data.

5.2 PRELIMINARY QUESTIONNAIRE SURVEY

The preliminary data collection was conducted at the early stages of this research to explore the use of refurbishment, flexibility, standardisation and BIM in healthcare. The preliminary questionnaire survey findings were used to describe the basis for this research, showing the integration of the four key applications in a healthcare facility. The primary aim of the questionnaire survey and interview were to narrow down the broad areas of this research by providing more realistic and achievable objectives that can help to achieve state of the art healthcare facility design. An innovative strategy would have to be put in place, such as integrating the four key applications of this research; these key applications can contribute in improving cost effectiveness, saving time and improving the quality of healthcare delivery.

5.2.1 AIM AND OBJECTIVE OF PRELIMINARY QUESTIONNAIRE SURVEY

The aim of the preliminary questionnaire survey focuses on one of the aims of the preliminary research. The survey aimed at improving the research scope by narrowing down the applications in question to focus on healthcare; this can be done by systematically achieving the objectives stated below. The objectives of the preliminary questionnaire survey are:

- to explore the application of refurbishment in healthcare;
- to reconnoitre the application of flexibility in healthcare;
- to explore the application of standardisation in healthcare; and
- to investigate the application of BIM in healthcare.

5.2.2 BIM USE IN HEALTHCARE

BIM is characterised with many features, Isikdag and Zlatanova (2009) described these features as; object oriented, three dimensional and noted to have a spatial relationship between building elements. BIM objects are data rich with functional information about a building element; the information enables professionals to make informed decisions within the life cycle of a building. Olofsson *et al.* (2008) described that when using BIM, the client is understood to achieve more benefits, perhaps the UK National Health Service (NHS) can attain the highest benefit. The cost of designing healthcare facilities can be reduced using BIM tools, by generating, analysing and evaluating designs before the construction process takes place. During the construction process, the analysis of the scheduling process can help detect accurate estimates of completion time of any given projects. BIM helps in assessing the cost of managing a facility before its construction. The facility management process is still yet to be fully explored (Eastman *et al.*, 2011).

5.2.3 FLEXIBILITY IN HEALTHCARE

Flexibility can be used to generate different design options; it improves the quality of healthcare facilities by converting, expanding and adapting to changing needs. These include medical staff, patients and visitors. Flexibility is broad, in healthcare; different spaces require different functional requirements to respond to the future needs of facility users. When dealing with cost, flexibility can help in managing the facility management cost, by adapting to future changes. This research studies ways of improving healthcare facilities through the design of flexible equipment, services and functions with a close emphasis on space design.

5.2.4 REFURBISHMENT IN HEALTHCARE

Refurbishment creates an opportunity to improve the existing situation of a facility; it can reduce the operational cost of a facility when conducted effectively and efficiently. This research looks at healthcare refurbishment as a chance or opportunity to increase the life span of a facility due to the rapid changing nature of healthcare facilities. They need to be upgraded a time to adapt to these changes. With the application of flexible approaches, a single refurbishment can improve the operational performance of a facility; it is sometimes a long-term investment within the life cycle of a building.

5.2.5 FINDINGS OF PRELIMINARY QUESTIONNAIRE SURVEY

The sections above provide the relevance of the applications of refurbishment, flexibility, standardisation and BIM in healthcare. The findings from the preliminary questionnaire survey are summarised. They are categorised into four sub-sections. These include questionnaire survey findings on refurbishment, flexibility, standardisation and BIM.

5.2.5.1 Preliminary questionnaire survey findings on refurbishment

The preliminary questions and answers are presented below. Table 5.1 shows that refurbishment is best applied to improve a facility and reduce the operational cost; while a noteworthy factor to consider in healthcare refurbishment is the safety of staff and patient when the facility is operational in the opinion of all the questionnaire survey respondents. Improving the operational cost and management of a facility is one of the most important reasons refurbishment takes places, sometimes within a couple of years, the running cost of a facility could sum up to a substantial percentage of the capital cost of a building. There are many other reasons why buildings are refurbished; these could be due to change in need, increase in population, facility improvement etc. For example, existing facilities can be improved through façade enhancement, space conversion or adapting buildings to respond to the changing needs of facility users. A facility can expand by building near the main building site (Palgrave, 2011).

The questions used in this section of the preliminary questionnaire survey were focused on refurbishment; they were developed from literature review. Literature did not state where best refurbishment can take place in healthcare, or where best it can be applied, or how best it can be applied or what are current tools used to achieving productive refurbishment in healthcare facility design. Despite these findings, most projects are different. As a result, *one size does not fit all*. Questionnaire survey findings might not be applicable to all healthcare projects.

Table 5.1: *Refurbishment in healthcare*

Refurbishment in Healthcare					
Respondent	**Where can it be applied best?**	**When can it be applied best?**	**How can it be applied best?**	**What are the best tools?**	**What are important/ milestones to be considered?**
Respondent 1	Minor and major works.	To improve a facility on long-term basis.	Using guides.	BIM.	Improving the quality of facility /Developing a business case and redesigning a facility.
Respondent 2	-	-	-	-	-
Respondent 3	-	-	-	-	-
Respondent 4	Minor works.	Long-term, mid-term and short -term basis.	Using standards.	BIM.	Patient, staff and visitor`s safety.
Respondent 5	Major works.	To reduce facility management cost on long-term basis.	Collaboration.	HBN.	Moving current occupiers such as patients to safety.
Respondent 6	Major works.	To improve the quality of facility on long-term basis.	Collaborating with all stakeholders involved.	Design Brief.	Current conditions have to be improved. Patient safety.

5.2.5.2 Preliminary questionnaire findings on flexibility

Table 5.2 shows that flexibility is best embedded into a facility at the early design stages in the opinion of the questionnaire survey respondents. Embedding flexibility into any facility design should be effectively set at the Concept Design Stage before the Design Development Stage. The usability and the functionality of the desired functions can be proposed, analysed and evaluated to achieve a change-ready healthcare facility through the use of flexible design approaches. Design options with BIM tools and Evidence Based Design (EBD) standards are used for achieving flexibility in the opinion of the questionnaire survey respondents. Design options are key to designing facilities that can adapt to future changes. The use of standards is evident to make a difference when applied in healthcare facilities. There are other different tools for embedding flexibility such as using *what if scenarios* with BIM; it can also be used as a tool for designing and visualising different design possibilities. Different functional spaces in healthcare facilities need to be flexible. Flexible bedrooms are required for the purpose of adapting to the changing needs of patients. For example, single bedroom designs are crucial to providing patients care and effective staff delivery. Both staff and patients are expected to use single bed or multiple bed units efficiently and effectively through proper designing and planning.

There are many challenges relating to the application of flexibility; possible milestones to be considered when applying flexibility in healthcare facilities include the cost of embedding flexibility, the challenge of dealing with obsolete spaces, predicting future changes and the hurdle of convincing clients the importance of introducing a flexible design strategy into a facility design at a reasonable cost for improving its value. Cost is one of the most critical challenges of embedding flexibility; when valuing the cost of flexibility, the first cost (capital cost) and the amount estimated for managing a facility has to be taken into consideration. Flexibility can be perceived as a process used to improve the life span of a facility; it can also help to reduce the running cost of a building on a longer-term in the opinion of all the questionnaire survey participants.

Table 5.2: *Flexibility in healthcare*

Flexibility in Healthcare					
Respondent	**Where can it be applied best?**	**When can it be applied best?**	**How can it be applied best?**	**What are the best tools?**	**What are importance/ milestones to be considered?**
Respondent 1	Ward/single bedrooms.	Planning/ refurbishment phase. Long term-basis.	Informing Stakeholders, Government and Policy makers the importance of flexibility.	Advance planning, design options and BIM use.	Designing future of medical technologies/ Difficulty in making predictions.
Respondent 2	-	-	-	-	-
Respondent 3	-	-	-	-	-
Respondent 4	Patient bedrooms.	Long term-basis.	Early design stages.	Design options.	To pro-long facility life/
Respondent 5	Wards/ single bedrooms.	Long term-basis.	Pre-design stages.	Design options.	Saving cost/ Making flexibility affordable.
Respondent 6	Acute hospitals.	Refurbishment. Long term-basis.	Collaborating with stakeholders.	Using previous case studies.	Improve space use/ informing and convincing stakeholders.

5.2.5.3 Preliminary questionnaire survey findings on standardisation

The process of applying standards involves identifying the source of information, selecting appropriate specifications from bunch of available standards, categorising relevant information, reviewing existing information for possible updates and adopting specifications that can easily adapt to the healthcare space in context. McCullough (2009) stated that according to Eileen Malone (2007) the process of creating healing environments includes the use of five EBD principles which comprises designing for maximum standardisation, future flexibility and growth. Apart from providing quality spaces that can multi-function and provide comfort to patients; staff performance has an impact on patient care. Standardising staff routine processes develops a working pattern that can simplify staff workload. Standardisation can help improve healthcare space by adapting to patient needs and providing standardised procedures and guidelines through user participation, but a question emerges; where can standardisation be applied best within a healthcare facility?

Four out of the six respondents suggest that standardisation is best applied in wards, while two respondents suggested theatres. Four out of the six respondents suggest that standardisation should be applied *all the time*, while two respondents suggested that standardisation should be applied *some of the time*. Standardisation can be best applied when it is mandatory; it is human nature to always take the shortest and easiest route *all the time*. For the purpose of this study, standardisation should be applied *all of the time* to enable use of standardised features or specifications that have been tested and proven to be effective and efficient. Activity Database (ADB) is one of the most common sources for gaining access to healthcare specifications. The important consideration for applying standardisation in healthcare is mainly for staff and patient activities. Table 5.3 present findings of the application of standardisation in healthcare.

Table 5.3: *Standardisation in healthcare*

Standardisation in Healthcare					
Respondent	**Where can it be applied best?**	**When can it be applied best?**	**How can it be applied best?**	**What are the best tools / sources?**	**What are important/ milestones to be considered?**
Respondent 1	Rooms and Units spaces.	All the time.	Management drive.	HTN.	User participation.
Respondent 2	Theatres.	All of the time.	Adhere to specifications provided.	ADB.	Safety.
Respondent 3	Treatment areas.	All of the time.	When enforced.	ADB.	The compatibility of facility users.
Respondent 4	Single rooms.	All the time.	Stakeholder approval.	ADB.	Patient, staff and visitor`s safety.
Respondent 5	Wards.	Most of the time.	Legislation.	HTN.	Simplification.
Respondent 6	Single rooms.	Most of the time.	Government push.	Design Brief.	Patient safety and staff comfort.

5.2.5.4 Preliminary questionnaire survey findings on BIM

Table 5.4 show that BIM is best applied during the construction phase followed by the facility management phase. However, it can be applied throughout the life cycle of a building, but applied best when collaborating with all appropriate stakeholders involved within a given project. Interoperability is the major concern in the application of BIM in the opinion of the questionnaire survey respondents. It is interesting that culture change was not identified in the challenges or most important milestones to consider when applying BIM in healthcare. With the ability to analyse the operational cost of a building within a BIM environment; the cost involved can be optimised. BIM also supports the generation of different design options which can help reduce the running cost of a building through innovative designing and planning (flexible approaches) within a virtual environment. Analysing the operational cost of a building will require real live information management within a BIM model, but can be affected by lack or interoperatability.

Table 5.4: *BIM use in healthcare*

BIM use in Healthcare					
Respondent	**Where can it be applied best?**	**When can it be applied best?**	**How can it be applied best?**	**What are the architectural tools?**	**What are important /milestones to be considered?**
Respondent 1	Almost the entire building process.	Designing and redesigning.	Depends on stakeholders' needs and designers` requirement.	Revit, Rhino and Ecotect.	Life cycle use/ planning commissioning and refurbishment.
Respondent 2	Design and Construction.	Design and construction phase.	Collaboration, modelling.	ArchiCAD.	Inspecting models/ interoperability.
Respondent 3	Design and Construction.	Pre-design and pre-construction.	Collaboration, modelling.	Revit.	Interoperability.
Respondent 4	Design and Construction.	Design.	Undergoing training.	Revit.	Interoperability/funds for training and software.
Respondent 5	Whole building life cycle.	Early design and construction stages.	BIM +creative thinking.	ArchiCAD.	Legal issues.
Respondent 6	Throughout the building life-cycle.	Construction.	Collaboration.	Revit, ArchiCAD, Nemetschek.	Cost of BIM implementation.

5.3 PRELIMINARY INTERVIEWS

The preliminary interviews were conducted after the preliminary questionnaire survey was distributed, collected and analysed. The interviews were conducted to further develop the research by exploring the areas of refurbishment, flexibility, standardisation and BIM more closely.

5.3.1 AIM AND OBJECTIVE OF PRELIMINARY INTERVIEWS

5.3.1.1 Aims of preliminary interviews

The aim of the preliminary interviews was to briefly discuss the research focus with selected colleagues within the Research Hub of the School of Civil and Building Engineering at Loughborough University to elicit their opinion on the hypothetical concepts used in this research. The hypothetical concept is to strategically combine the applications of flexibility and standardisation within a refurbishment process using BIM to achieve cost effectiveness and project quality. The research aim and objectives were discussed in details with the four researchers from the Research Hub. There are four preliminary interviewees.

5.3.1.2 Objectives of the preliminary interviews

The objectives of the preliminary interviews are:

- to identify gaps in the research;
- to refine the research focus;
- to refine the research objectives; and
- to explore method of integrating refurbishment, flexibility, standardisation and BIM.

5.3.2 THE APPLICATION OF FLEXIBILITY AND STANDARDISATION

The application of flexibility and standardisation is suggested to be combined. A flexible approach facilitates the ability of a facility to be adaptable, but the application of flexibility at any level should be governed by some standards. The interview participants are tagged (I1)-(I4). One of the interviewee (I2) stated that

> "*Applying flexibility without acknowledging standards is nearly impossible, especially in a healthcare environment where standardisation is very important; healthcare planners tend to use evidence based design which comes with standardised applications that have already been put to use and have achieved success in their application. I would say there is a thin line between the application of flexibility and standardisation in healthcare facility design".*

It would be interesting to focus the research on the application of flexibility and standardisation in healthcare facilities as they both take part in improving the quality of healthcare facilities. The focal concern of this research is to explore a strategic method of merging flexibility and standardisation or to define a specific scheme that is relevant to both processes. It is important to understand that current research has shown no ratio of combining flexibility and standardisation in healthcare (Price and Lu, 2012). This creates a gap in literature to find a possible combination ratio.

5.3.3 BROADNESS OF TOPICS

The broad use of refurbishment, flexibility, standardisation and BIM are very extensive; the broadness of RFSB has to be understood; and possible strategies of merging them should be acknowledged. In summary, two out of the four preliminary interviewees had concerns with the choice of research areas: refurbishment; flexibility; standardisation; and BIM due to their broadness. One interviewee (I3) stated that" *it is difficult to have achievable and realistic objectives with such broad research areas in focus, it will therefore be necessary to re-focus and re-strategize the aim and objectives showing some consistency in the build-up of the research objectives to achieve the aim of the research".* Another interviewee (I4) suggested that

> *"The research objectives are too broad and loose, the research aim and objectives should be more specific at this stage of the research, the subject areas involved are broad and need to be focused on specific issues, and this can be done by simply specifying the context of flexibility or BIM you are looking at. For example, is it the implementation of BIM within a building organisation? Is it the use of BIM in healthcare? Is it the use of flexible furniture, flexible construction, or flexible power supply services? You need to be specific".*

The research aim and objectives have been revised to a clearer, simpler and achievable research target by adding a prefix to the research areas of focus. For example, *space* refurbishment, *space* flexibility, *space* standardisation, and the *role of the designer* when applying BIM.

5.3.4 FINDINGS OF PRELIMINARY INTERVIEWS

This research focuses on designing a change-ready healthcare facility through the application of refurbishment, flexibility, standardisation and BIM. This research has recognised that there is no current study that shows a detail process of combining flexibility and standardisation. Therefore, there is no specific method of combining them. Furthermore, this research has focused on cost reduction and possible methods of increasing value and quality through the combined applications of the four areas of study when designing a change-ready healthcare facility. The interviewees identified that there is a need to narrow down the research focus by specifying the principal context that relates to refurbishment, flexibility, standardisation and BIM. Healthcare space is the key element that is common between the four applications. The business case for this research is the capability of reducing cost through designing and maintaining facilities to produce more value for money on short-term, mid-term and long-term basis.

Key issues identified from interviewee I1.

- define the type of flexibility;
- define the phase of research impact, stating applicability: pre-design / design / construction / facility management;
- revise research focus to be more specific;
- identify the need for the application of standards in healthcare facilities;
- discuss decision making in flexibility; and
- finding an innovative merger between refurbishment flexibility, standardisation and BIM.

Key issues identified from interviewee I2

- what type of flexibility does this research addresses?;
- what standards are relevant to this research?;
- what phase of refurbishment does this research discourses?; and
- what context of BIM is applicable to this research?

Key issues identified from interviewee I3

- is there a business case for this research?;
- who are the potential stakeholders involved?; and
- research needs to narrow down?

Key issues identified from interviewee I4

- refurbishment, flexibility, standardisation and BIM standalone in improving the aim and objectives of this research;
- refurbishment, flexibility, standardisation and BIM (all together) are rarely explored;

- topics are too broad; and
- how can the application of refurbishment, flexibility, standardisation and BIM be combined within a single platform?

5.4 SPACE STANDARDISATION AND FLEXIBILITY (SECONDARY DATA)

The questionnaire survey data collected from the HaCIRIC team, Loughborough University branch was analysed in this research. The questionnaire survey population was based on the lists of HaCIRIC team collaborators with healthcare experience. See appendix 4 for questionnaire survey questions. It was issued out to 200 prospective respondents. 70 responses were returned, giving a response rate of 35 percent. The questionnaire survey respondents were chosen based on their experience in healthcare design. The professionals selected to complete the questionnaires survey included: architects; healthcare planners; and project managers. The questionnaire survey respondents came from different parts of the world, comprising UK, Europe, North America, Africa, Far East and the Middle East. Half of the respondents had over 10 years working experience on new build hospital projects, while 41 percent of the respondents had over 10 years working experience on refurbished hospital projects. The questionnaire survey respondents were asked to indicate their degree of agreement with certain statements on a five point Likert scale. Questionnaires surveys were distributed via e-mail. The collected questionnaire survey data was analysed using descriptive statistics techniques to summarise the view of the majority of the sample and focus on the data rather than using the data to learn about the population selected for this study.

5.4.1 SPACE STANDARDISATION AND SPACE FLEXIBILITY IN HEALTHCARE DELIVERY?

The questionnaire survey was centred on issues relating to space standardisation and space flexibility in healthcare facility design. One of the most common aims of healthcare space standardisation is to improve the design, construction and service delivery. All key stakeholders within the lifecycle of a healthcare facility should participate in producing these standards. Malone *et al.* (2007) noted that standardised workflows contribute to patient care and safety. Space flexibility can reduce travelling distances between patient units (served area) and healthcare delivery units (serving area). This can be achieved by using multi-purpose spaces (universal spaces) or through the use of mobile healthcare equipment. Space flexibility is designed to systematically adapt to the changing needs of a facility. Kobus *et al.*

(2008); Reiling (2007) and Pati *et al.* (2008) described that flexibility reduces travelling distance within a healthcare facility. For the purpose of this research, space flexibility and space standardisation are considered as the most closely related within the four applications presented in this research.

5.4.1.1 Barriers to standardisation in healthcare delivery

Some of the questionnaire survey respondents within the R1-R70 participants had some concerns regarding standardisation: these can be identified as possible barriers towards space standardisation. A space was provided "*additional information*" for questionnaire respondents to give more data. Three questionnaire survey respondents had some concerns that standardisation could affect design creativity. Two questionnaire survey respondents (R2 and R9) pointed out a noteworthy recommendation that "*standardisation will depend on type of building, whether the project is new built or refurbished*". One questionnaire survey respondent (R11) stated that "*it could be difficult to fully standardise buildings due to different requirements for different projects*" when designing a facility. One questionnaire survey respondent (R4) stated that "*the application of standardisation could lead to one size fits all, which is not a good approach when designing healthcare building*". One questionnaire respondent (R1) stated that "*Due to the constraints of existing structures during refurbishment, standardisation should be guides not rules*". Two of the questionnaire respondents (R14 and R4) were of the view that "*standardisation could make buildings old before they are even lunched, due to use of out-dated standards*". But one questionnaire respondent (R4) was of the view that there is a need to update standards frequently to adapt to current changes in healthcare facilities to prevent the use of out-dated standards that could render the facility old when constructed. Three questionnaire respondents (R23; R13; and R24) pointed out that there are "*some companies that produce their own standards due to contradiction in publications*" while other two questionnaire respondents (R24 and R32) also stated that "*ADB at times conflicts with building standards*". Some of the questionnaire respondents suggested certain approaches towards the application of standardisation in healthcare. Two respondents (R41 and R32) suggested that clinical output can lead to standardisation as the clinical procedures are mostly formatted in a regular pattern that can easily be repeated by healthcare staff. One of the questionnaire respondents (R23) stated that standardisation occurs better in clinical areas. Three questionnaire respondents (R2; R13; and R24) suggested that standardisation should be prescribed for space function and layout; it can easily be re-used in other healthcare facilities. This study acknowledges that there are some challenges to the application of standardisation, these are centred on rigidity in their applications and the need for frequent specification updates.

5.4.1.2 Tools for achieving flexibility and standardisation

Figure 5.1 illustrates responses to a questionnaire survey question from the data collected from the HaCIRIC team. The respondents were asked: what are the most important tools used to practically implement space standardisation in healthcare facilities? Another question was asked: what are the most effective tools used in achieving space flexibility in healthcare facilities? Out of 70 respondents: 53 answered; and 17 skipped the question with regards to space standardisation. While out of 70 respondents: 49 answered; and 21 skipped the question with regards to space flexibility. The mean from each question is presented in Figure 5.3. It shows that the questionnaire survey respondents are of the opinion that it is more effective to apply the selected tools/guidance/software to achieving space standardisation compared to space flexibility. There have been serious concerns by some of the questionnaire respondents that sometime guidance such as Health Building Notes (HBN) and Health Technical Notes (HTN) are out dated, when used to design a facility. It was stated by some of the questionnaire survey respondents that a design can be inefficient and out dated, before the facility is even lunched for use due to the use of out-dated standards. From the questionnaire survey findings, four key tools have been agreed to be the most efficient tools that help in achieving both space flexibility and space standardisation. These are:

- Activity DataBase (ADB);
- Health Building Notes (HBN);
- DH schedule of accommodation; and
- Design brief.

Software use for achieving both space flexibility and space standardisation depends on the user's ability to understand and use a given application. Software tools such as Activity DataBase will not help to solve a problem, but will provide professionals with relevant information to perform their relative tasks effectively and efficiently. There are concerns of out-dated guidance and the availability of different standards for similar functional purposes. Sometimes there is duplication in guidance provided to health planners. Literature findings from the Department of Health showed that there are more than 1240 different room specifications. Hignett and Lu, (2007) noted that there is a lack of confidence in the availability of information, there is also conflict between the information focus for patient *care* and staff *efficiency* to be applied in the facility design. Therefore, both patients and staff are required to participate in the design of healthcare standards. BIM can also be used as a tool to support both space flexibility and space standardisation. BIM can aid the process of practically implementing space standardisation by storing some or all the standardised data within a BIM environment using various BIM tools. For example, equipment and furniture can be stored in ArchiCAD or Revit Architecture as a BIM object (BIM library) that can easily be reused in any given project when required. BIM can aid the process of virtually implementing space flexibility within a BIM environment using different available BIM tools. For example, Revit Architecture can be used to generate different *options* from one design source into several possible design options facilitating different plan generation.

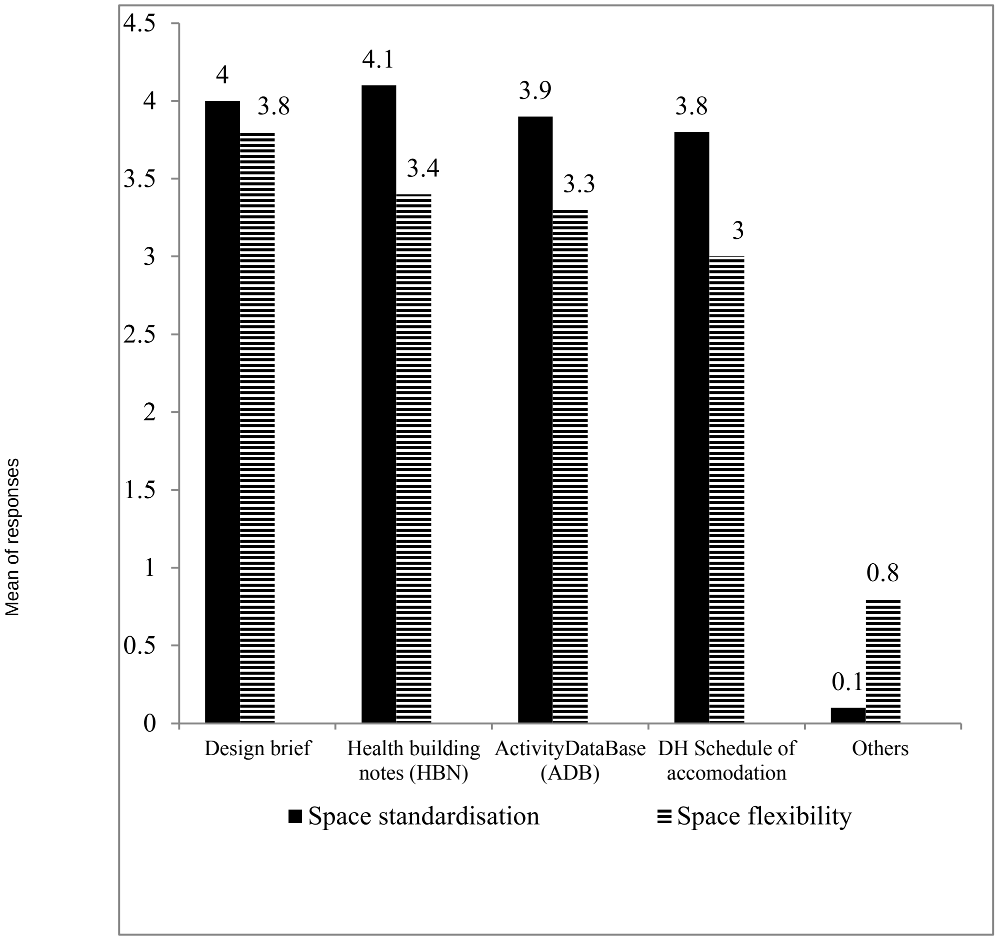


Figure 5.3: ***Q****uestionnaire responses on tools/guidance/software used for space flexibility and space standardisation*

5.4.2 SPACE STANDARDISATION AND SPACE FLEXIBILITY IN HEALTHCARE REFURBISHMENT

Neufville *et al.* (2008) stated that space flexibility can facilitate the design of a flexible healthcare facility by adapting to growth and uncertainties, while space standardisation encourages and guides the process of achieving patient care and staff performance. All these factors listed above make up the key drivers for refurbishment. Swayne *et al.* (2006, p. 413) described that to embed flexibility or standardisation, it is vital to consider the following: financial resources available; skills; policies; human resources; management talent; facility and equipment; and the required information to standardise.

5.4.2.1 Impact of space flexibility and standardisation on refurbishment drivers

Table 5.5 shows the impact and drivers for space standardisation and space flexibility within a healthcare environment. Space flexibility and forecasting for uncertainties are key to a change-ready healthcare facility. Dealing with uncertainty is a major problem relating to the operation of facilities in the future. For example, within the next 10 years or 30 years, the changes that will occur cannot be predicted with a high degree of accuracy; the time and extent of changes can hardly be specified, but the future can be predicted based on evidence based research or precedent studies from previous projects. Healthcare designers and planners can learn from previous and relevant studies. For example, the spaces that frequently change within every five to 10 years in a healthcare facility can be documented, analysed and considered in the design of new or refurbished healthcare facilities. Predicting spaces that do not need to be used instantly, but will be needed in the near future would be another problem. When making flexible design decisions, stakeholders involved should participate in achieving desired project quality. At times healthcare facilities might need to be downsizing by offering these spaces to third parties. For example, the NHS estate can temporary sub-letting some part of its estates for other purposes such as commercial use. Neufville *et al.* (2008) reported that it is not possible to forecast forthcoming patient activities within a healthcare facility with a high level of accuracy. However, Lam (2008) suggested that one can forecast flexibility in healthcare using historical data or precedent studies.

Space standardisation plays a major role in patient care when designing a facility, standardisation is attributed to patient health and safety. To achieve efficiency in healthcare design certain factors have be considered. These include, the quality of working environment, healing environments (quality air flow, natural and artificial distractions, closeness to green environments, closeness of visitors) privacy, infection free healthcare environment (Newell and Burnard, 2011). Apart from providing quality spaces that are intended to provide desirable comfort to patients; staff performance has an impact on patient care. Standardisation can help improve healthcare space by providing standardised procedures and guides. Standardisation can also reduce patient incidents, such as falling down in the bath room by providing handrails. A standardised space is designed in so much that patients can use healthcare facility with ease, while staff can work efficiently and effectively. These spaces take into account patient`s needs and safety requirements in order to improve the quality of care

5.4.2.2 Proposed relationship between flexibility and standardisation within refurbishment scales of work

Due to the importance and impact of space flexibility and space standardisation on healthcare staff and patients, it is crucial that they are applied during refurbishment projects. Sheth (2010) grouped refurbishment into four different levels. These include: 1) “Do nothing”, 2) Interior works, 3) Exterior works, 4) Demolish. Flexibility and standardisation can be applied at different scales of the refurbishment process. These include minor, average and major scope of work. The limitations of refurbishment identified by the questionnaire survey respondents include budgets, constraints of existing structures and functions. Flexibility concepts can be applied at specific times and places to achieve effective project outcomes. Figure 5.4 proposes a possible relationship between refurbishment and (space flexibility and space standardisation). The effective implementation of this strategic innovation can be facilitated by the concept of task partitioning. Von Hippel (1990) stated that “*An innovation project of any magnitude is divided up (partitioned) into a number of tasks and subtasks that may then be distributed among a number of individuals, and perhaps among a number of firms*”. He also stated that most problems can be resolved by decomposing them to tasks and reducing the cost involved with cross boundary problem solving. Tasks for both space functions at different refurbishment phases can be assigned to different individuals or firms. Task partitioning simplifies the whole process of integration by dividing and breaking down goals into targets that are easily achievable.

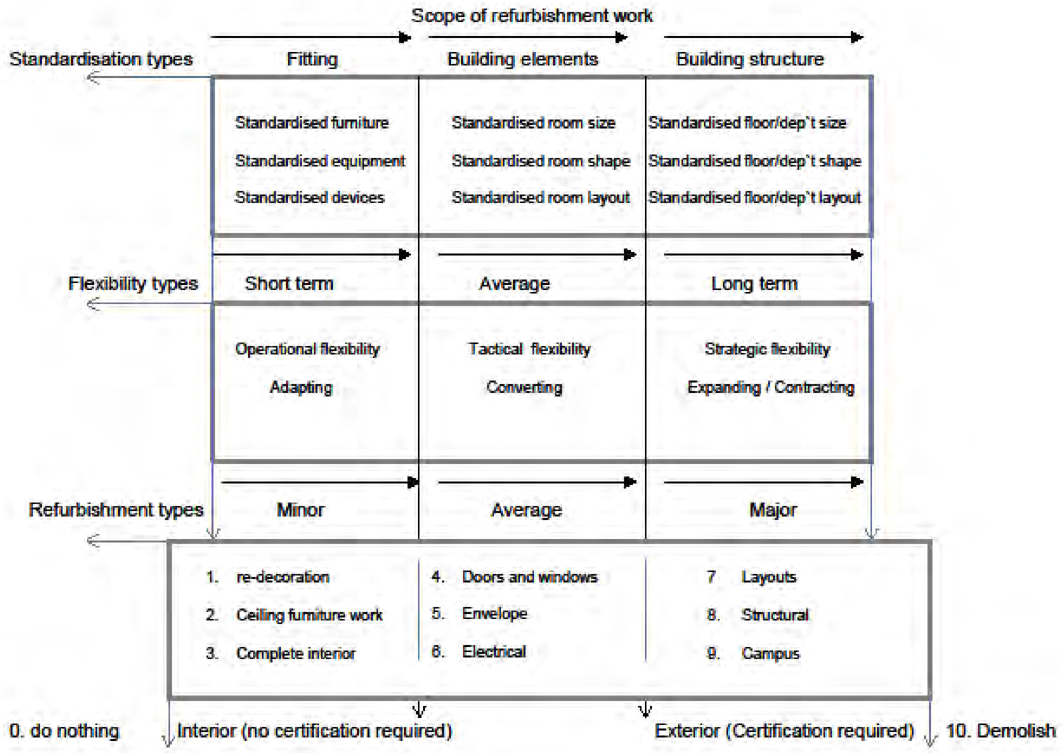


Figure 5.4: *Proposed relationship between refurbishment flexibility and standardisation. Adapted from: Ahmad et al. (2011) see appendix 1*

5.4.3 FLEXIBILITY, STANDARDISATION AND BIM IN HEALTHCARE REFURBISHMENT

Figure 5.4 illustrates a proposed strategic integration between refurbishment, flexibility and standardisation developed by Ahmad *et al*. (2011), see appendix 1. It was further developed using the third party questionnaire survey findings (HaCIRIC team). The application of BIM was also integrated into the proposed integration strategy in order to resolve the research problems identified in chapter 1. As a result, it became the relationship between refurbishment, flexibility, standardisation, and BIM. Section 5.2 suggests the use of BIM in healthcare (see Table 5.4). To propose a more detailed relationship, it was important to identify where standardisation, flexibility and BIM are more effectively applied within the proposed integration strategy.

5.4.3.1 Effective use of standardisation

Figure 5.5 was generated using the third party questionnaire survey responses on a specific question: what is the most important application of space standardisation? Out of 70 respondents, 53 answered the question and 17 skipped. The most important type of space standardisation in healthcare was identified as standardised room/space, while standardised unit/floor/department layout was found to be the least essential. When designing healthcare spaces, standardisation can be applied to rooms as it is efficient and effective in improving the quality of healthcare delivery received by patients from healthcare staff. Egan, (1998) noted that prefabricated parts of private hospitals are pre-assembled using a sequential set of standardised rooms. Sine and Hunt, (2009) stated that patients expect more quality in healthcare bedrooms, perhaps the quality of these rooms should be standardised. Pickard (2005, p. 10) stated that "*total standardisation may sometimes be appropriate for small buildings, but the most common and effective application of standardisation is to room layouts and assemblies of furniture and equipment, such as the NHS Estates Activity DataBase*". Pickard`s view coincidence with the opinion of the questionnaire survey respondents. It was identified by the respondents that standardisation is easier to implement at room level. When a refurbishment project is taking place, rooms can be standardised to achieve optimum healthcare outcomes. Joint Commission Resources (2004) stated that "*standardisation of treatment areas, room layout, and medical equipment supplies provide flexibility to accommodate changing patient care needs*" this shows that rooms are successfully standardised within healthcare facilities to achieve desired quality and operational output.

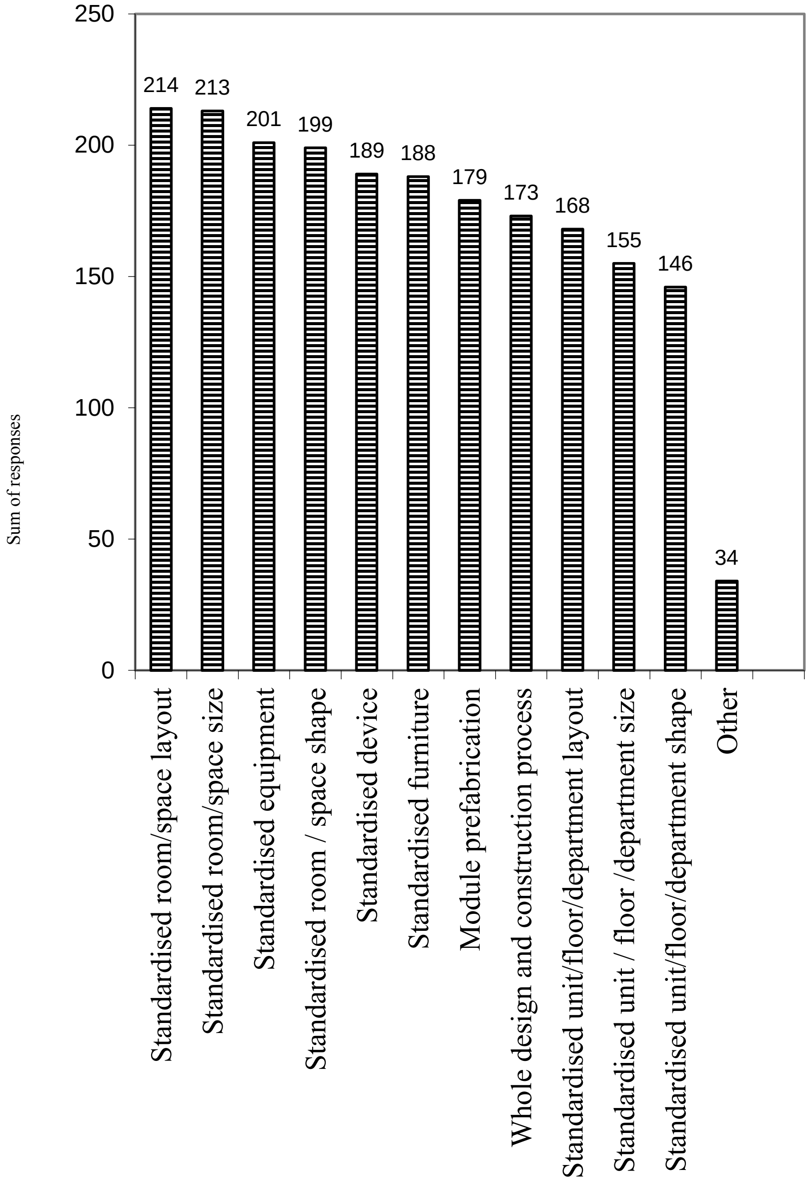


Figure 5.5: *Questionnaire responses on the most effective application of space standardisation*

5.4.3.2 Effective use of flexibility

Figure 5.6 summarises the findings from three different questionnaire survey responses from the HaCIRIC team data; it shows questionnaire survey responses on the effectiveness of flexibility at a building level or site level within four different basis that include: daily basis; weekly basis; monthly basis; and yearly basis. The second shows questionnaire survey responses on the effectiveness of flexibility at a specific area or room area on the four bases stated above. The third shows questionnaire survey responses on the effectiveness of flexibility at ward or departmental level on the four bases stated above. Figure 5.6 shows that space flexibility can be implemented effectively on a long-term basis with regards to the entire site, building level, departmental level, ward levels, patient bedroom level or a specific area within a given healthcare facility in the opinion of the questionnaire survey respondents. This can be taken into consideration when redesigning or refurbishing healthcare buildings for effective and efficient use of flexibility (Ahmad *et al*., 2011). Neufville *et al*. (2008) stated that a long-term (strategic) flexibility is suited for major developments. This coincides with the questionnaire survey respondents’ opinion.

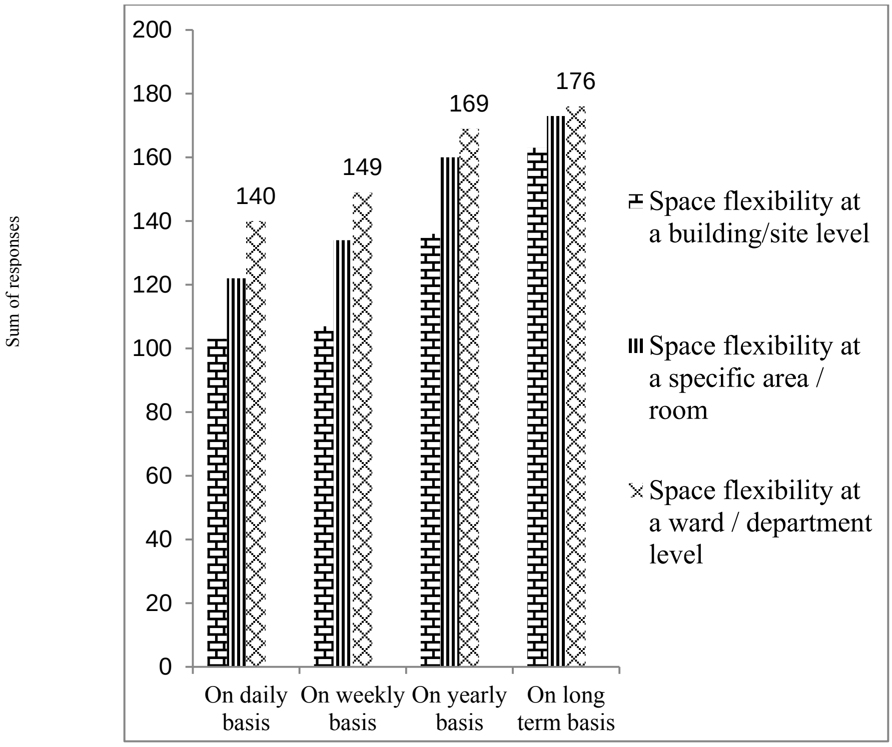


Figure 5.6: *Questionnaire responses on the effectiveness of space flexibility at three different places*

5.4.3.3 Effective use of BIM

This section presents findings from questionnaire survey and literature to support the use of BIM in the AEC industry. The application of BIM was not proposed in the third party questionnaire survey from the HaCIRIC team; therefore the effective application of BIM was verified from literature and preliminary questionnaire survey. Table 5.1 in section 5.2.5.1 show preliminary questionnaire findings from Loughborough University colleagues addressing that BIM is more effective when project participants collaborate. Hardin (2009); Weygant (2011); Eastman *et al*. (2011); and Succar (2009) agreed that the application of BIM is effective when stakeholders collaborate during the entire building process through analysis, evaluation and decision making within the design, construction or facility management stages. For example, when the contractor and other stakeholders are introduced into the building process at the early design stages to collaborate from inception to completion; more informed decision are made that could save cost and improve the quality of a facility. Perhaps BIM is more effective when collaborating with appropriate stakeholders involved. It can be used to improve cost control through automation and cost analysis of existing and proposed designs. BIM can also help with energy analysis to compare the existing performance of a facility with the proposed facility design; this allows performance optimisation when designing a facility. The application of BIM can help with virtual models of the proposed refurbishment project before the actual construction takes places. Team work is one of the main drivers for the application of BIM to improve quality, cost efficiency and cost effectiveness.

5.5 STRATEGIC APPROACH TOWARDS THE COMBINED APPLICATION OF RFSB WITHIN A HEALTHCARE FACILITY DESIGN PROCESS

Table 3.1 in chapter 3 suggested some relationship between refurbishment, flexibility, standardisation and BIM. A holistic approach was taken to explore and combine the four applications. Some literature was available on flexibility and standardisation. As a result, a sequence was considered at the early stages of this study. However, data collection was considered for further study. Relationships between the following were considered:

- flexibility and standardisation;
- (flexibility and standardisation) within a refurbishment project; and
- (flexibility, standardisation and BIM) within a refurbishment project

This study considers the combine application of flexibility, standardisation and BIM within a refurbishment project. However, it is important to explore when flexibility, standardisation and BIM are effective, this was achieved through primary data collection. Findings can be used to improve the refurbishment process. Section 5.4.3 presents these findings.

Section 5.4.1 suggests the combined application of flexibility and standardisation in healthcare delivery. For the purpose of this study, flexibility is considered as a sub-set of standardisation. For example, when a standardised modular space is used for different purposes, it enables the flexible use of space (functions can be interchanged due to similarity of space sizes).

Section 5.4.2 describes the application of flexibility and standardisation in healthcare refurbishment. The analysis of literature review showed flexibility and standardisation has an impact on refurbishment (see Table 5.5); appendix 1 discusses their impact in detail. Flexibility has an impact on growth of healthcare facilities when conducting refurbishment, while standardisation tends to improve healthcare delivery for staff and patients.

Table 5.5: *The impact of space flexibility and space standardisation on refurbishment drivers. Source: Ahmad et al. (2011)*

Space functions	Impact	Category of refurbishment driver
Space flexibility	Growth/uncertainties	Future challenges
Space standardisation	Staff performance	Users
Space standardisation	Patient care	Users

The effectiveness of applying flexibility, standardisation and BIM in healthcare is identified in this research. These findings are strategically applied to improve the process of responding to future changes within a refurbishment project. Figure 5.7 describes a map showing refurbishment scales of work and the effectiveness of flexibility, standardisation and BIM within a refurbishment project. The refurbishment project scales were developed and modified by Sheth *et al*. (2010) and was later re-modified by Ahmad *et al*. (2011), see appendix 1. The refurbishment process was categorised into four stages. These are: to propose and strategies project goals; to develop and integrate project needs; to organise and implement facility design; and to evaluate the facility after implementation through user feedback and to make amends based on the evaluated feedbacks.

Figure 5.7 shows the three scales of refurbishment, illustrating different scopes of work. These include: redecoration of a facility; altering building elements; and modifying the building structure. The features of the three applications include: use of standards; flexibility; and BIM; they were grouped under the three categories of refurbishment identified above. Figure 5.7 also illustrates four horizontal levels showing the applications of refurbishment, flexibility, standardisation and BIM and their corresponding features. Figure 5.7 also shows a detailed description of flexibility to be effective on a long-term basis; standardisation within a room level or specific unit; and the application of BIM when collaborating with relevant stakeholders at early project stages.

The refurbishment process is outlined in Figure 5.7 to have three key features. These are refurbishment: lifecycle; stages; and focus. The refurbishment lifecycle covers pre-refurbishment (design), construction and post-refurbishment which involve accessing and evaluating the performance of a building over time when it is fully occupied. The refurbishment stages were designed to have four stages. The first stage describes the briefing process; the second stage presents the Conceptual Design Stage where flexibility and standardisation can be applied. BIM modelling is conducted to optimise the design and construction process virtually before the construction takes place. The third stage describes the construction, recycling and disposal work. The fourth stage emphasises the occupancy analysis and possible prescription for performance optimisation. The refurbishment *focus* describes the entire process in four different focuses; the first is to propose and strategies projects goals; the second is to develop a concept and integrated into a single plan; the third is to organise the methods to achieve the plan and implement through construction; and the fourth is to evaluate the virtual design outcomes and proposed performance against the real live occupancy performance, and make informed suggestions to improve facility performance; these were adopted from sheth *et al.* (2010)

Figure 5.7 also illustrates the combined strategic application of the four research areas; three scopes of work (minor, average and major works) are common factors within the applications of refurbishment, flexibility, standardisation and BIM. The applications of flexibility, standardisation and BIM can be conducted within the three refurbishment scopes of work. There is a need to strategically apply refurbishment, flexibility, standardisation and BIM together in order to achieve their combined benefits. The four applications can standalone in improving healthcare delivery outcomes. Therefore their combined applications can guide the design of a change-ready healthcare facility. Figure 5.7 also show that designers can use the four applications in a certain order to achieve desired project quality. Findings from three research methods: Literature review; the preliminary questionnaire survey and interview findings; and HaCIRIC questionnaire survey data analysed showed three key findings:

- flexibility can be applied more effectively on a long-term basis;
- standardisation can be applied more effectively within a room/space/specified unit; and
- BIM can be applied more effectively when collaborating and integrating information between project stakeholders at early project stages.

The combined application of refurbishment, flexibility, standardisation and BIM within a refurbished or new project was further strategically explored into a framework for designing a change-ready healthcare facility. Therefore, further research was conducted to conceptualising they four broad applications through the use of questionnaire surveys and interviews. They were strategically applied within a design scheme using the RIBA Plan of Work (2007) and later the 2013 version which is one of the most important components of the framework; it is accepted by most companies in the UK building sector.

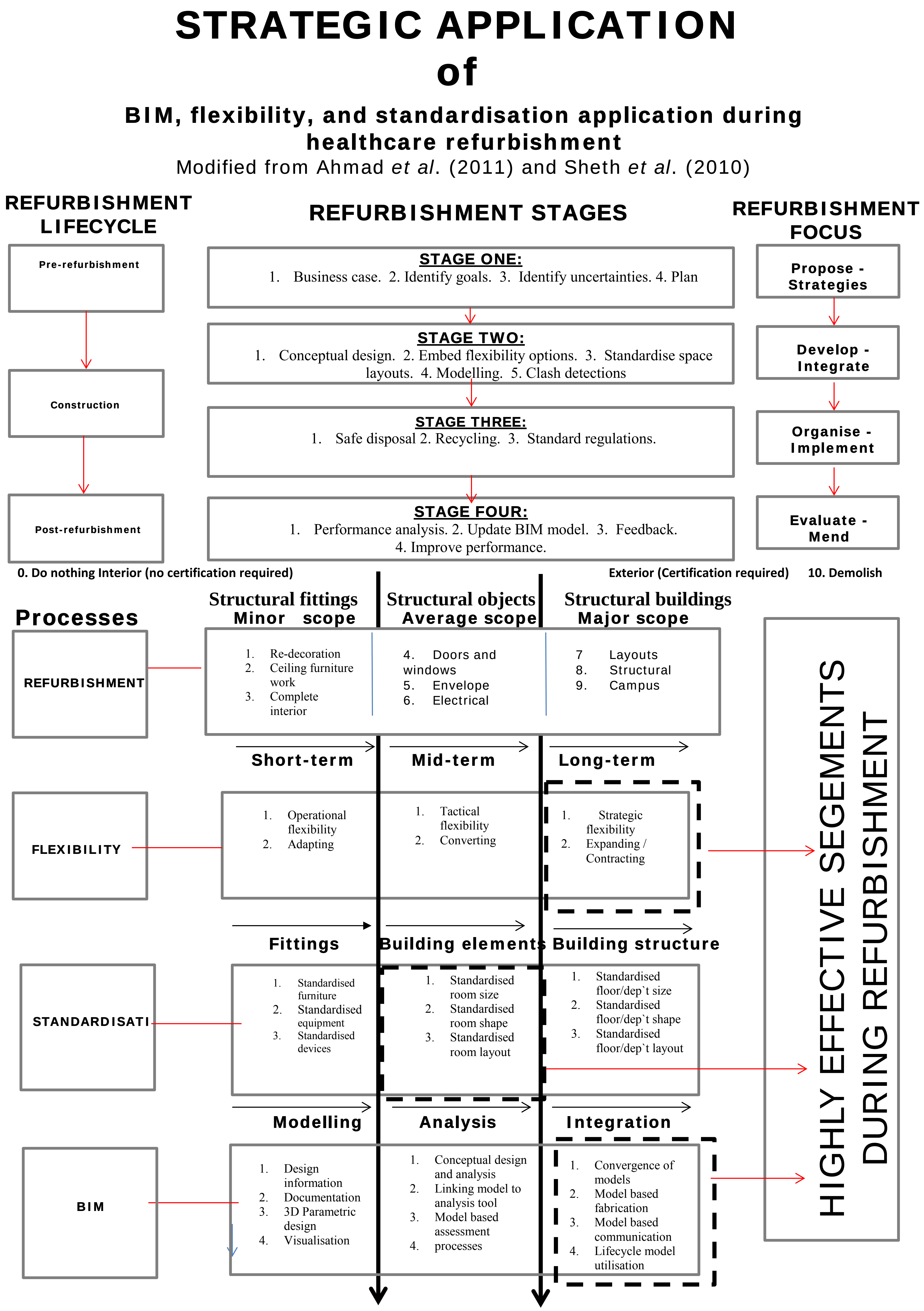


Figure 5.7: *Strategic application of standardisation, flexibility and BIM during healthcare refurbishment*

5.6 CHAPTER SUMMARY

The findings from the conducted preliminary interviews showed that refurbishment, flexibility, standardisation and BIM can standalone in improving and optimising healthcare delivery; but there is a need to have an innovative approach that can facilitate their integration. As a result, flexibility, standardisation and BIM were proposed to be applied within three different scopes of refurbishment works. Data collection findings presented in this chapter showed that flexibility is effective on the long-term basis; standardisation is effective when applied at room level, while BIM is effective when appropriate stakeholders are collaborating. A question arises, can BIM be used to analyse and evaluate virtual change-ready healthcare facilities? And if there are combined, what are the impact of standardisation on flexible design layouts? Chapter 6 presents these findings. However, it is important to note that future challenges associated with innovation in healthcare are sometime associated with the concern of patient safety, while patients is key to the existence of healthcare facilities and should not be compromised while trying to achieve novelty in healthcare environments. Therefore, this research has explored innovative solutions to improve the existing conditions of healthcare facilities, while giving top priority healthcare design productivity.

6 RESEARCH UNDERTAKEN (QUESTIONNAIRE SURVEY): ORGANISING THE APPLICATIONS OF RFSB WITHIN A CHANGE-READY HEALTHCARE FACILITY

6.1 QUESTIONNAIRE INTRODUCTION

The *Aim* of the questionnaire survey was to explore key factors that can enhance the designer`s role when designing space flexibility with standards through the focal use of BIM within a change-ready healthcare facility. The preliminary questionnaires targeted fellow colleagues with similar research in the field of BIM and healthcare, while the main questionnaire survey targeted respondents such as architectural designers, healthcare planners and BIM users with healthcare experience. The preliminary questionnaire survey fixated on combining the application of refurbishment, flexibility, standardisation and BIM, while the main questionnaire survey was centred on the designer`s response when applying flexibility, standardisation and BIM within a healthcare facility design process. The *approach* to the main questionnaire survey design was established on close-ended and open-ended questions to collect rich and in-depth primary data. The questionnaire survey (appendix 6) takes an average of 30 minutes to complete; it was grouped into four sections. These are:

A. background information;
B. designing flexible healthcare spaces;
C. standardisation of healthcare spaces; and
D. flexible space design with BIM.

6.1.1 BACKGROUND OF RESPONDENTS

Hardin (2009) agrees that BIM means different things to different people, groups or organisations within the AEC industry. Therefore, different sample groups were identified and considered for the purpose of this research. The study of the different understandings of BIM within the AEC industry can provide this research with different approaches towards the applications of BIM within the life cycle of a building process. This study requires inputs from BIM users, BIM exchange experts and healthcare designers, As a result, the questionnaire survey *sampling* considered firms and individuals from various groups for the purpose of collecting rich and robust data. The research targeted samples such as architectural firms, BIM groups, BIM users, mixed group of professionals and so on. Three populations were identified. These are: internet based groups such as CNBR Yahoo Groups and LinkedIn BIM Groups as a sample; BuildingSmart international with BuildingSmart UK chapter as a sample; and UK registered RIBA architectural firms with the top 100 UK architectural firms based on the Building Magazine, (2010) and Architects for Health as possible samples. As a result, five samples were outlined for primary data collection. These include:

- the top UK 100 architectural firms (sample one);
- Web based sample; CNBR yahoo groups (sample two);
- BuildingSmart UK chapter members (others);
- LinkedIn BIM Group (others); and
- Architects for Health (others).

6.1.2 SAMPLE ONE: TOP 100 UK ARCHITECTURAL FIRMS BASED ON THE BUILDING MAGAZINE 2010.

*Relevance of sample one to this research***:** There are different categories of the top 100 UK architectural firms; these are classified based on annual profit in the UK, number of employees and so on. The top 100 UK architectural firms were categorised by the Building Magazine in 2010 based on the best architectural firms and the firm with the highest number of UK chartered architects. These firms were also selected based on their practical experience in the design of buildings in and outside the UK as described by the Building Magazine. *Who are the Building Magazine group?* They are an established grouped within the UK also called "Building.co.uk" or "building". They are a group of advocates that provides information regarding the built environment and are responsible for producing the Building Magazine which focuses on the construction industry. The Building group was launched in 1843 and claims to have about 125,000 professional readers every week. Building, (2013) stated that "*Building is the only Magazine covering all levels of the specification chain, reaching an audience of contractors, housebuilders, architects, clients and surveyors reflected in the high numbers of subscribers with an average circulation of 21,271*". *Location of sample*: the architectural firms contacted for the purpose of this research are UK based; most of the architectural firms have international offices around the globe. Thus, with both UK and international working experience in the field of architecture; the participation of such firms would provide ethics and robust practical data that this research can analyse and evaluate. *Questionnaire survey response outcome*: Out of the 100 architectural firms ranked by the Building Magazine, (2010), only 10 architectural firms responded to the questionnaire survey invitations.

6.1.3 SAMPLE TWO: WEB BASED GROUP (CNBR).

Relevance of sample two to this research: CNBR Yahoo Group was selected due to the diversity of the professionals within the group. There are different individual understandings and definitions of BIM from different stakeholders. This group was contacted to provide this study with theoretical grounding regarding the application of BIM in healthcare; most of the members are academicians. Perhaps it was important to explore the different opinions of stakeholders within the AEC industry. *Who are CNBR Yahoo group?* The Co-operative Network for Building Researchers (CNBR) is a basic mailing list for people interested and fascinated with building research. The group include professionals such as project managers, architects, contractors, real estate managers, researchers, and so on. They are provided with news about conferences, journals, vacancies, new books, new findings and so on. *Location of this sample:* the participants from this sample could be from different parts of the world; CNBR Yahoo group is open to all professionals around the globe. *The questionnaire survey response rate from this sample:* there were a total of 48 responses. The questionnaire survey was uploaded on the CNBR Yahoo group website; the entire number of members in the sample who received the invitation cannot be specified. However, there are over 3000 registered members on the CNBR Yahoo group website, but only registered members who had set their accounts to receive updates would have seen the link without logging on to the group webpage.

6.1.4 OTHER SAMPLES CONSIDERED

Primary data was scheduled for collection from BuildingSmart UK Chapter members for the analysis of this research. UK chapter was considered as this study was centred on the UK healthcare sector. *Relevance of sample to this research*: BuildingSmart UK chapter members were selected as respondents due to their relevance in the BIM community. There are expected to provide this study with information exchange opinions when applying BIM with other project stakeholders. *Who are BuildingSmart*? They are a group of BIM advocates with the principal aim of promoting interoperability within the various BIM platforms. There are many BuildingSmart "*chapters*" based in different countries, but the UK BuildingSmart chapter was selected as this research is centred on the application of BIM in the UK healthcare sector. The *questionnaire survey response outcome***:** the outcome of the questionnaire survey turnout was poor, with a total of 40 members in the BuildingSmart UK chapter, one response was registered. *Reason for the poor turnout:* Due to the lack of direct contact with respondents. The administrative department of BuildingSmart UK chapter were contacted, but they took responsibility of engaging, organising and distributing the questionnaires survey to their members. The contact details of the individual members of BuildingSmart were held as highly classified information by the BuildingSmart UK chapter administration personnel. As a result, the administrative department volunteered to forward the questionnaire survey via online and as an attached MS word document. Hence with limited control over the distribution, a very low response was inevitable.

LinkedIn BIM group was selected as a possible population; this research has understood that the number of members from the group might not be entirely experienced BIM users, but it is a haven of BIM proponents; their knowledge could inform this research. *Relevance of sample to this research:* with the opinion of experienced and advocates of BIM in the built environment, diverse information can be collected and analysed for the purpose of this research. *Who are LinkedIn BIM group*: LinkedIn is a social website for professionals from different backgrounds. The group is formed specifically for BIM advocates within the LinkedIn social website. *Questionnaire survey response outcome***:** the outcome of the questionnaire survey turnout was poor; the total number of members in the LinkedIn BIM group is growing. There were a total of zero responses within the specific time frame of putting up the web link. *Reason for the poor turnout:* Due to the lack of direct contact with respondents; the members of the LinkedIn BIM group would not necessary see the questionnaire survey if they do not log onto the website, except if a member subscribes to be updated with new issues from the group. Another problem is the longer the link stays on the website, the harder it gets to see a post; the most recent post always stays up on the webpage.

The population for this research targeted architects and planners with healthcare and BIM experience. Therefore, primary data was scheduled to be collected from Architects for Health. *Relevance of sample to this research*: Architects for Health has more than 500 registered architectural firms in the UK. The importance of sample five to this research is that the members are proponents of healthcare and architectural design with an interesting and passion for innovation in healthcare facility design. *Who are Architects for Health*? This is a non-profit organisation that associates with healthcare architects, planners, and designers; they are a group of healthcare advocates with the principal aim of encouraging quality practices in healthcare facility design. The *questionnaire survey response outcome*: the outcome of the questionnaire survey turnout was poor, with a total of 500 members, there was no response recorded. *Reason for the poor turnout:* this can be associated to the lack of direct contact with architect for health members. The administrative department volunteered to put up the link to the questionnaire survey on the News section of their website. Due to the lack of direct contact with the members, little consideration was given to the questionnaire surveys.

From the five samples stated above, questionnaire survey responses were collected from sample one and two only; sample three questionnaire survey category had only one response rate. For this reason, response from sample three was not in-cooperated into this research. Sample four and five had a zero percent turnout. Table 6.1 shows details of the 10 respondents from the top 100 UK architectural firms based on the Building Magazine 2010.

Table 6.1: *Ranking of top 100 UK architects*

Architectural firm ID	Number of chartered architects	Staff capacity	UK Offices	BIM experience: Application on project
ARCHITECTURAL FIRM F1	384	1032	10	81-100 %
ARCHITECTURAL FIRM F2	116	221	7	61-80 %
ARCHITECTURAL FIRM F3	247	879	2	41-60 %
ARCHITECTURAL FIRM F4	226	4611	64	81-100 %
ARCHITECTURAL FIRM F5	30	59	1	41-60 %
ARCHITECTURAL FIRM F6	140	296	4	61-80 %
ARCHITECTURAL FIRM F7	77	187	3	21 -40 %
ARCHITECTURAL FIRM F8	35	259	9	41-60 %
ARCHITECTURAL FIRM F9	46	377	8	41-60 %
ARCHITECTURAL FIRM F10	113	193	6	21-40 %

6.1.5 METHOD OF ANALYSIS

Farrell (2011) categorised the analysis of questionnaire surveys into two different categories; these are the descriptive and the inferential statistics. The descriptive statistics was used for the purposes of this research in order to produce a statistical backing for the support of flexibility, standardisation and BIM in the design of healthcare facilities; it was used to produce an expressive analysis of the questionnaire survey data. Descriptive analysis can be conducted through different approaches depending on the context in question. The combination of the ranking approach and the normal distribution within the descriptive statistics category were used to analyse the collected questionnaire survey data. The measures of central tendency (mean and mode) were adopted in the questionnaire survey analysis. The questionnaire survey had both open-ended and close-ended questions; the analysis of the qualitative data was sometimes centred on the number of reoccurrence of certain keywords within some questions.

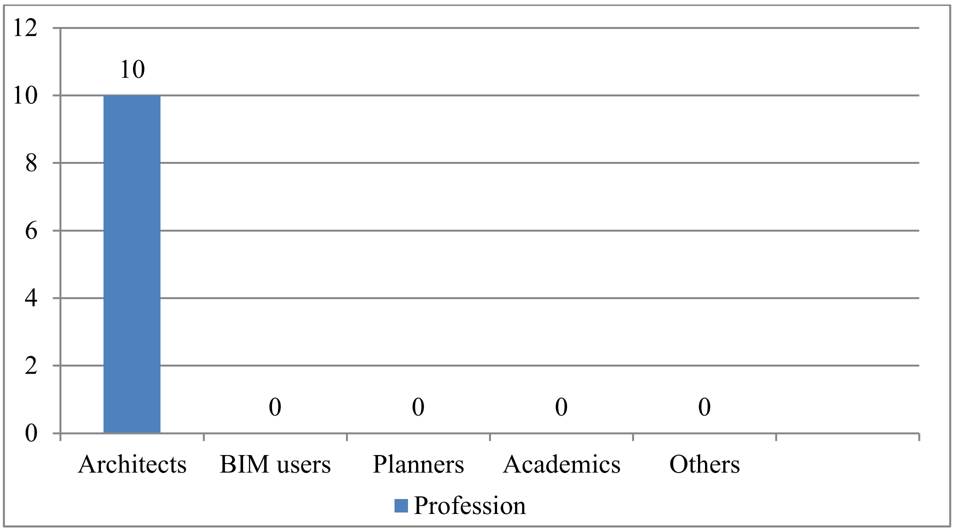


Figure 6.1: *Profession that most relates to Sample One?*

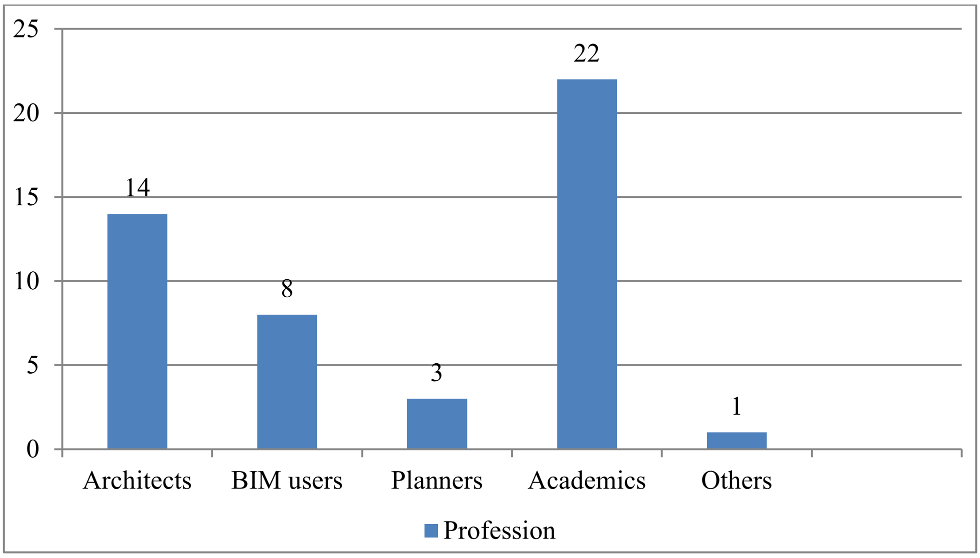


Figure 6.2: ***Profession that most relates to Sample Two?***

Figure 6.1 shows the background of *Sample One* as a group made up of architects only, while Figure 6.2 describes *Sample Two* as the combination of different category of professions. These include architects, BIM users, planners, academicians and others. The category "*others*" was also provided as an option to the questionnaire survey respondents to provide other specific professions not listed; only one other profession (project manager) was recorded from the respondents. The findings of the two questionnaire survey samples were presented to explore the diversity of BIM use within the AEC industry.

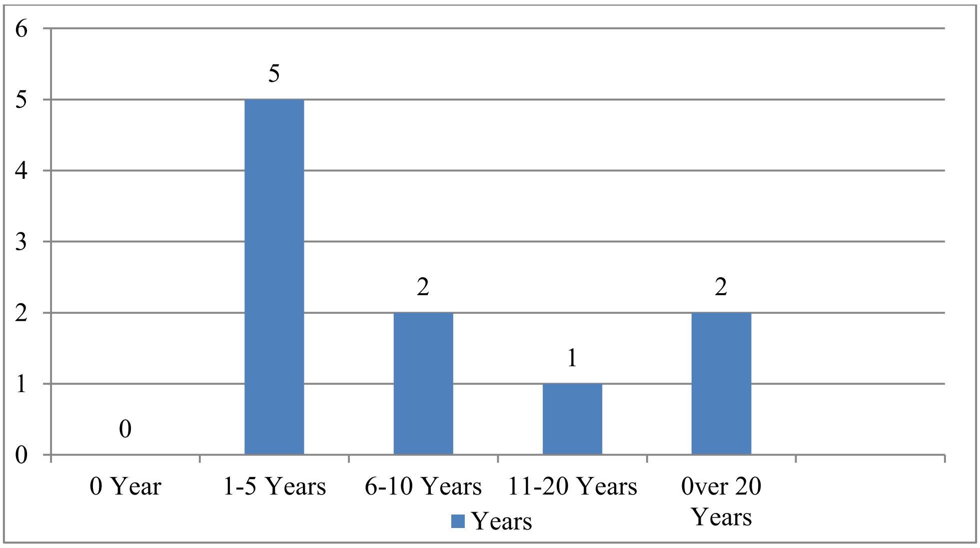


Figure 6.3: *Years of BIM experience within Sample One*

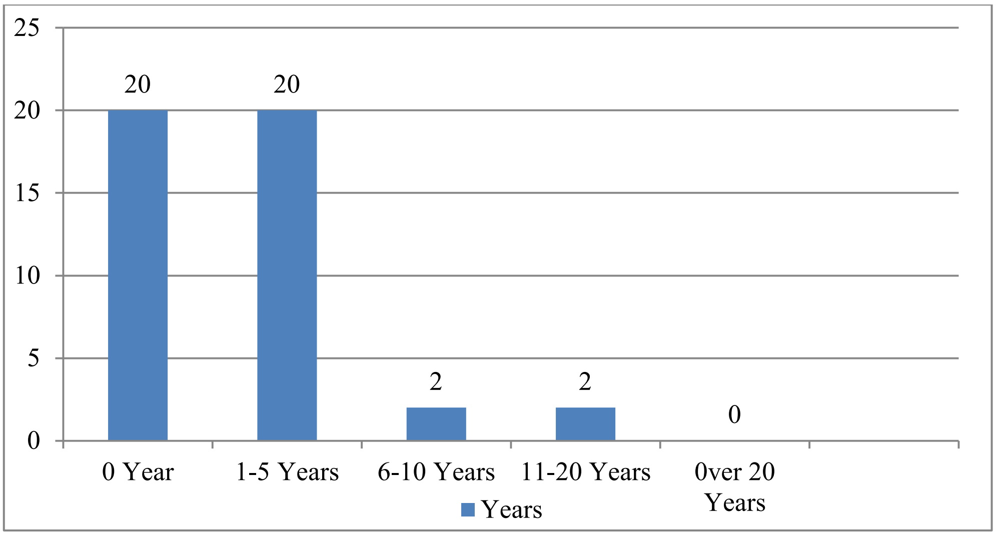


Figure 6.4: *Years of BIM experience within Sample Two*

The comparison of experience from both samples helps to strengthen views of the questionnaire respondents. Figure 6.3 show the years of BIM experience for respondents in Sample One. Over 50 percent of the respondents had over five years of BIM experience, while Figure 6.4 show the years of BIM experience within Sample Two; below 50 percent had five years of BIM experience; this can be clearly seen in Table 6.2. Therefore, this research can report that Sample One questionnaire survey respondents have more BIM experiences compared to Sample Two.

Table 6.2: *Maximum and minimum number of respondents and years of BIM experience from both samples*

Years of BIM experience	Questionnaire respondents (Sample One)	Years of BIM experience	Questionnaire respondents (Sample Two)
Max. = over 20 years	2	Max. = over 20 years	2
Min. = 1-5 years	5	Min. = 0 years	20
Within a total of:	10	Within a total of:	48

Figure 6.5 and Figure 6.6 show the years of healthcare experience from questionnaire survey respondents in Sample One and Two. Sample One has over 50 percent of their respondents with over 11 years of healthcare experience, while Sample Two has less than 50 percent of their respondents with over 11 years of healthcare experience; this is illustrated in Table 6.3. As a result, this research can report that the questionnaire survey respondents from Sample One has more experienced healthcare professionals compared to the questionnaire survey respondents in Sample Two. About 20 respondents from Sample Two have *0 year* of healthcare experience, but they have experience of other building sectors such as institutional, industrial and commercial sectors. Nevertheless, healthcare experience is most relevant to this research.

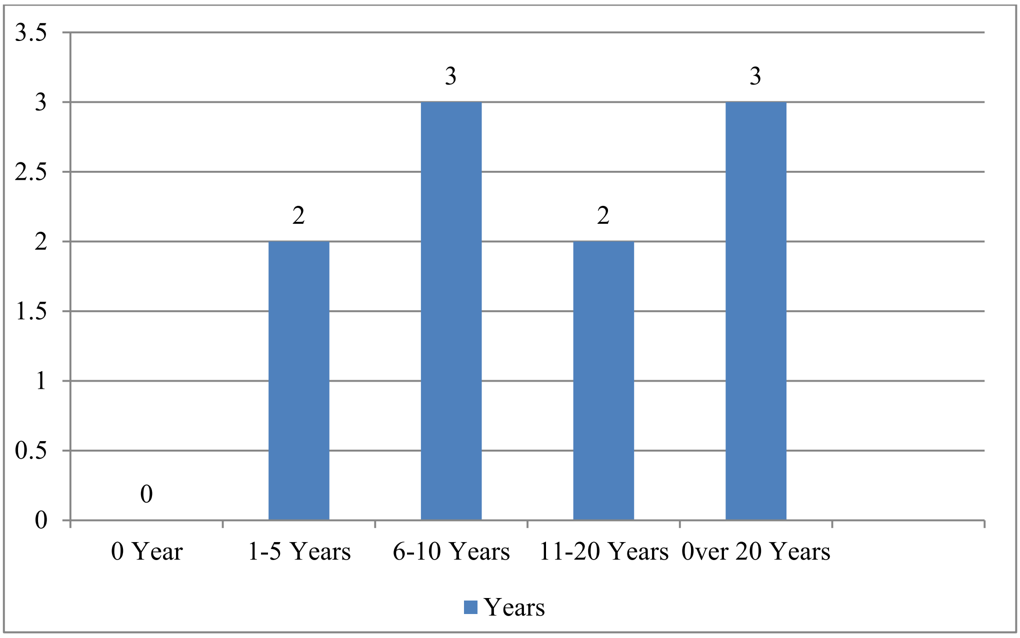


Figure 6.5: *Years of healthcare experience from Sample One*

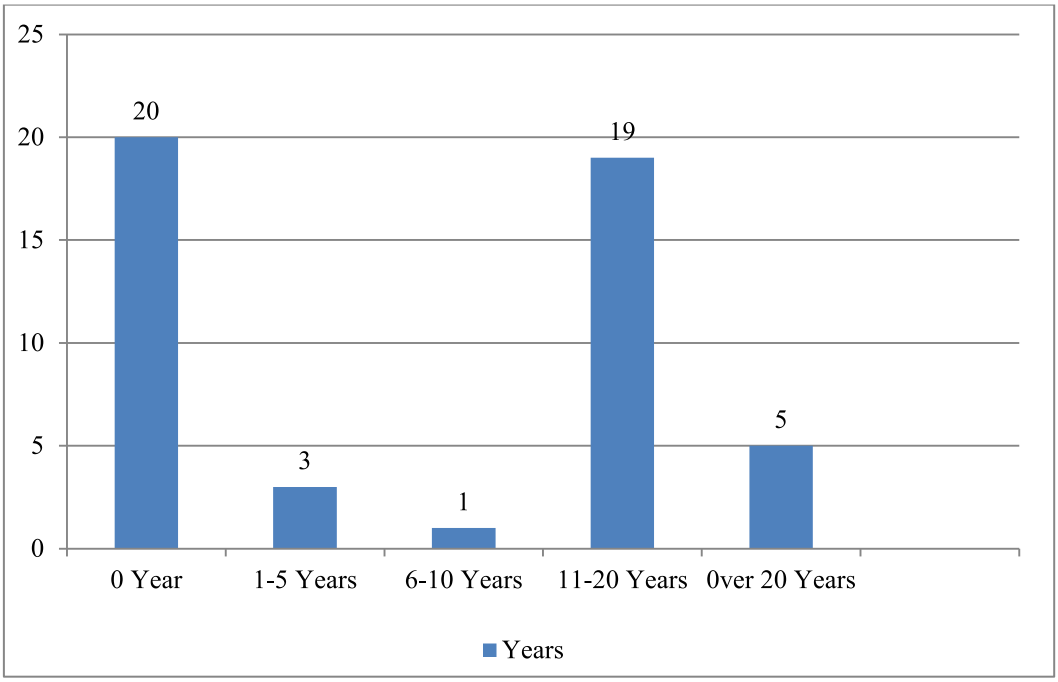


Figure 6.6: *Years of healthcare experience within Sample Two*

Table 6.3: *Maximum and minimum number of respondent and years of healthcare experience from both samples*

Years of healthcare experience	Questionnaire respondents (Sample One)	Years of healthcare experience	Questionnaire respondents (Sample Two)
Max. = over 20 years	3	Max. = over 20 years	5
Min. = 1-5 years	2	Min. = 0 year	20
Within a total of:	10	Within a total of:	48

Figures 6.7 and 6.8 show the percentage of BIM use on live projects in Sample One and Sample Two below. Table 6.4 shows about 40 percent of Sample One having 40-60 percent of BIM experience on live projects; and another 40 percent have 60-100 percent BIM experience on live projects. This indicates that over 50 percent of respondents from Sample One have over 50 percent of BIM experience on live projects. Sample One can be classified as a good sample for exploring the application of BIM in healthcare facility design. Sample Two has over 60 percent of its respondents with 1-20 percent of BIM experience on live projects; this makes Sample Two a less strong category with little industrial experience in BIM applications compared to Sample One. Both samples are relevant as this research explores but theoretical and industrial application of BIM in healthcare facility design, making Sample Two relevant to achieve the aim and objectives of this research.

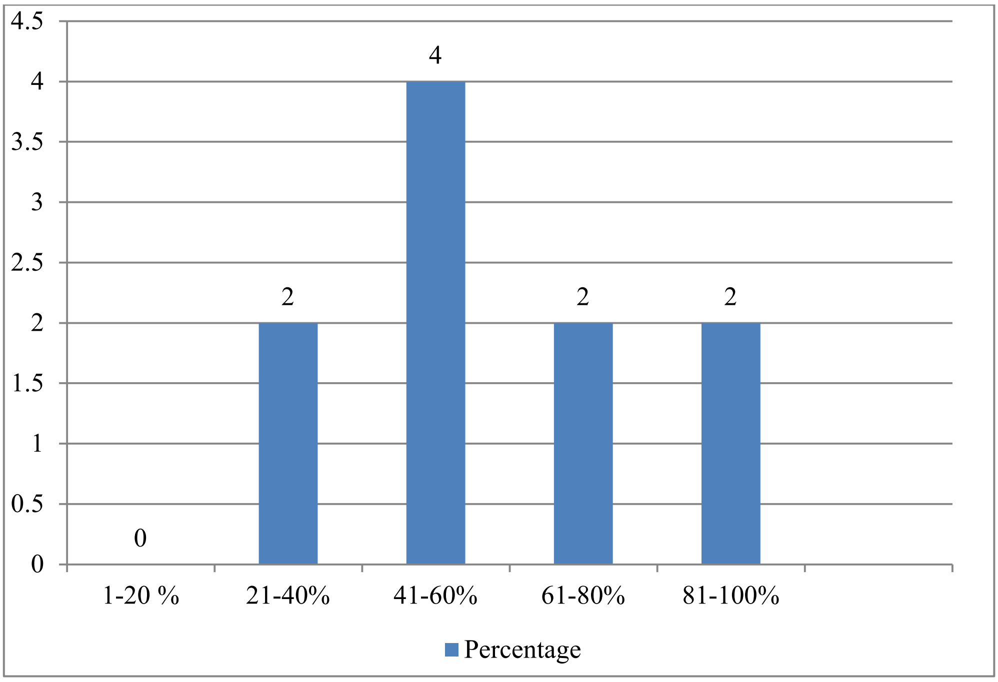


Figure 6.7: *Percentage of BIM applied on live projects within Sample One*

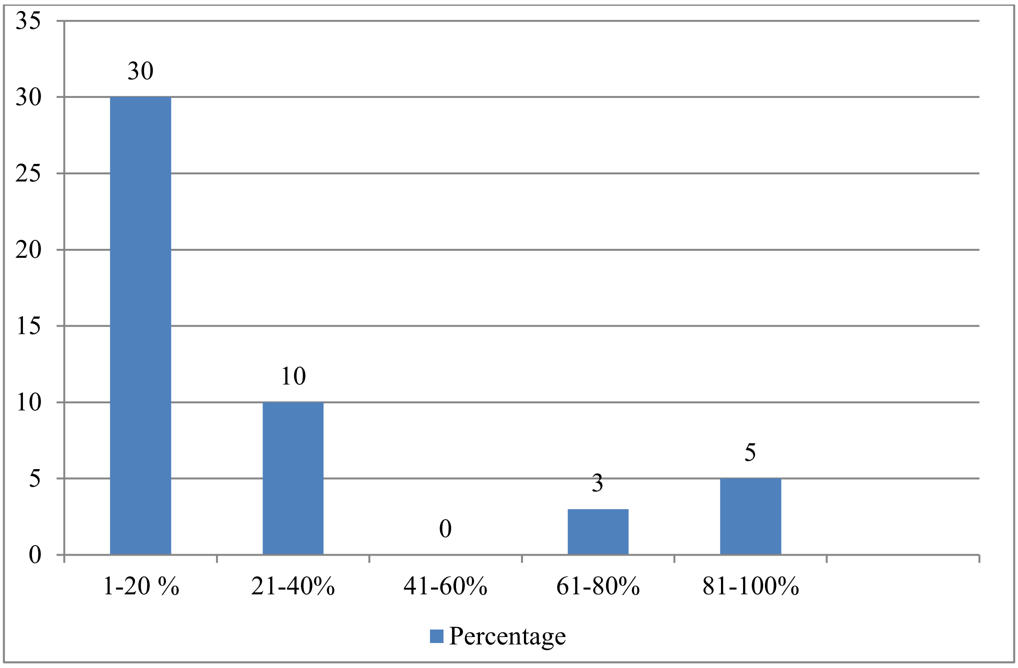


Figure 6.8: *Percentage of BIM applied on live projects within Sample Two*

Table 6.4: *Maximum and minimum number of respondent and percentage of BIM use on projects from both samples*

Percentage of BIM use on projects	Questionnaire respondents (Sample One)	Percentage of BIM use on projects	Questionnaire respondents (Sample Two)
Max. = 81-100 %	2	Max. = 0-20 %	30
Min. = 21-40 %	2	Min. = 81-100 |%	5
Within a total of:	10	Within a total of:	48

Figure 6.9 and Figure 6.10 illustrates the involvement of the questionnaire survey respondents within the different building sectors from Samples One and Two. Sample One has more construction industry practitioners with healthcare experience compared to Sample Two. The questionnaire survey respondents from Sample One and Two have participated in the different building sectors within the AEC industry; the diversity will provide this research with rich in-depth data to analyse. Sample One has 60 percent of respondents with healthcare experience to some extent, while 40 percent of respondents participated in healthcare projects frequently. This indicates that all samples had some healthcare experience. Sample Two has 58 percent of their respondents with healthcare experience; 19 respondents participated in healthcare projects *frequently*, while nine respondents participated in healthcare projects to *some extent*. Sample One has a higher percentage of respondents with healthcare experience.

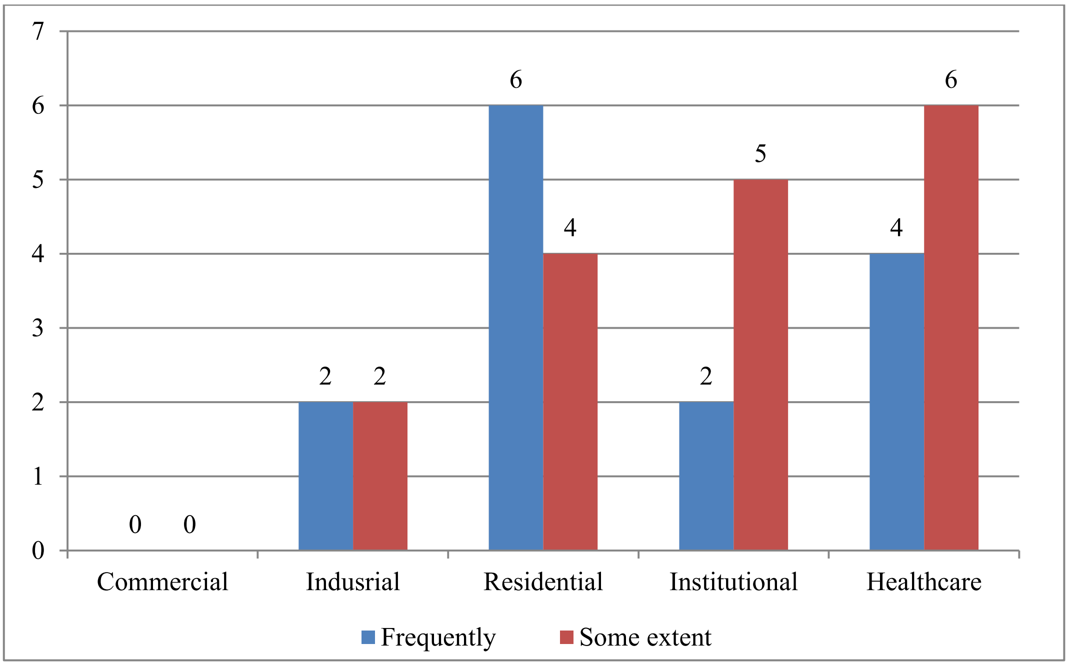


Figure 6.9: *Involvement of Sample One respondents within the different building sectors*

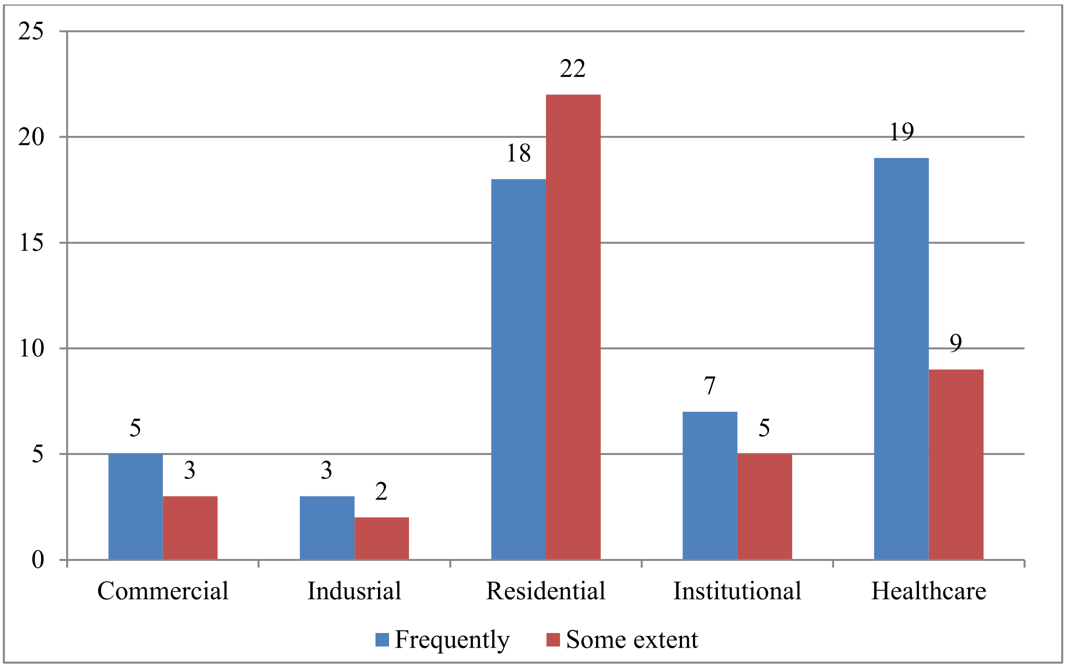


Figure 6.10: *Involvement of Sample Two respondents within the different building sectors*

6.2 DESIGNING FLEXIBLE HEALTHCARE SPACES

Designing a facility today that would meet the future needs of users in the next five, 10 or 20 years from now is possible but difficult. Gressel and Hilands (2008) stated that "*the only certainty in healthcare is change*". If change will always take its place in the management of healthcare facilities, then there is a need to plan for future changes. The development of a framework for designing a change-ready healthcare facility was generated through the applications of refurbishment, flexibility, standardisation and BIM. A research question that arises is how do we provide flexibility in a cost effective manner? Certain design principles should be adopted with a collaborative scheme of working between all stakeholders. The important considerations when planning and designing flexible healthcare spaces were identified by the questionnaire survey respondents; these should be considered in order to achieve an effective and efficient healthcare facility.

6.2.1 HEALTHCARE SPACES THAT RAPIDLY CHANGES

Healthcare spaces such as surgery theatres, clinical laboratories, consultant treatment areas and patient wards seems to be the top most frequent spaces that changes rapidly in healthcare facilities in the opinion of the questionnaire survey respondents. Wards or single bed units are one of the most common spaces affected by an ageing or growing population. Despite the impact of a growing population on healthcare spaces; during the weekends, the Accident and Emergences (A&E) experience high pressure together with its unnecessary use by a large public number. BBC (2012a) stated that in a report conducted by the Care Quality Commission (CQC) their findings showed a high number of people spending more than four hours in the A&E department before they are treated; the waiting time is increasing and the percentage of people waiting is said to have increased from 27 percent in 2008 to 33 percent in 2012. On a very busy day in the A&E unit, there are high numbers of patients putting pressure on waiting areas, theatres, patient bed units, nursing stations and other healthcare facilities spaces. This research also identifies the spaces that could be affected by the pressures bestowed on healthcare facilities.

It is important to identify the healthcare spaces that could rapidly change when adapting to pressure such as an ageing or growing population or advance technology on healthcare infrastructures. Neufville *et al*. (2008) illustrated that beds were the first spaces to change in an event of a possible expansion in a healthcare facility. Cleveland Clinic (2010) agrees with Chefurka *et al*. (2006) that identifying immovable spaces are important when expanding healthcare spaces. Therefore, immovable or fixed spaces should not be placed close to places likely to expand. Cleveland Clinic (2010); Chefurka *et al*. (2006) and Joint Commission Resources (2006, p. 21) also agree that placing spaces likely to expand on exterior walls is key to planning for expanding a facility. Another planning strategy for healthcare flexibility is to group and layout services likely to expand (Cleveland Clinic, 2010; Pati *et al*., 2008). When planning for a possible facility expansion, the potential or proposed expanding spaces within the healthcare facility should be identified to allow for strategic planning of the flexibility process. It is noteworthy to understand that rapid changing spaces in any healthcare facility depend on the context in question. The questionnaire survey respondents from Sample One and Two have identified the top six possible rapid changing healthcare spaces in Tables 6.5 and 6.6.

Table 6.5

Table 6.5: *Spaces that frequently changes in healthcare facilities (Sample One)*

Rapidly changing spaces	Ranked	No. of respondents
Surgery theatres	1	8
Wards	2	6
Clinical laboratories	3	5
Consultant treatment areas	4	3
Imaging unit	5	2
Entrance areas	5	2

Table 6.6: *Spaces that frequently changes in healthcare facilities (Sample Two)*

Rapidly changing spaces	Ranked	No. of respondents
Laboratory	1	40
Wards	2	36
Surgery theatre	3	31
Emergency unit	4	28
Nurse station	5	12
Public support spaces	6	10

The similarities between Tables 6.5 and 6.6 is that *surgery theatres*, *wards* and *clinical laboratories* are listed as the top three rapid changing spaces within the six identified healthcare spaces in Sample One and Two. When designing for flexibility, a lot of planning is required around possible rapid changing spaces; but these spaces could vary depending on the specific needs of specific healthcare facilities at specific places. In general, the healthcare spaces identified above can be acknowledged as common rapid changing spaces in healthcare facilities in the opinion of the questionnaire survey respondents from Sample One and Two. Therefore, for the purpose of designing, re-designing or refurbishing a healthcare facility, there is a need to explore possible rapid changing spaces at early design stages.

6.2.2 DESIGNING PRINCIPLES FOR ACHIEVING FLEXIBILITY

Tables 6.7 and 6.8 identified the top three design principles from Sample One and Two. The similarity between the two samples is grouped into two categories: the use of modular design and the structural grid design; and the open building planning and the building shell space planning. Modular design is similar to structural grid; they are both expected to make the design and construction process easier and simpler. Modular design planning considers the integration process of different construction elements. Proper planning and the selection of appropriate construction elements can save future cost within the life cycle of a building. For example, future restructuring of the modular design elements could be possible if the relationship of these elements are studied at an early stage. The more compatible these elements are the more the flexibility. To achieve future flexibility through modular design approach, the services are distributed in grids or zoning layouts that can allow more flexibility. The building shell planning and open planning are also similar; they both allow the different use of open spaces. It is important that modular and flexible loose fit walls be fitted at different places to create opportunities for generating different spaces (flexible spaces) for different purposes at different times and places. While customised modular walls could limit the opportunity of creating different spaces within the interior of a building shell. The flexible curtain walls could also be affected by uneven ceiling heights; it is important to have a universal ceiling height within the entire shell space to avoid disrupting the movement of flexible partitions, furniture or equipment within a flexible shell space. Some partitions are made up of wood, glass, plastic or aluminium etc. But irrespective of the partition type, material or location, they should be flexible and replaceable. The flexible design approaches identified can be mixed or used separately depending on the context and type of flexibility in focus.

Table 6.7: *Top three flexibility design principles from (Sample One)*

Flexible design approaches	Ranked	No. of respondents
Modular design	1	8
Universal / generic space design	2	6
Open building planning	3	5

Table 6.8:

Table 6.8: *Top three flexibility design principles from (Sample Two)*

Flexible design approaches	Ranked	No. of respondents
Use of structural grid design	1	21
Building shell space planning	2	16
Scenario planning	3	10

6.2.3 IMPORTANT STAKEHOLDERS MAKING FLEXIBILITY DECISIONS

The client/owner seems to be the main decision maker in the opinion of the questionnaire survey respondents. Table 6.9 and Table 6.10 show the top four important stakeholders making decisions in the opinion of the questionnaire survey respondents from Sample One and Two. Flexibility is client driven, as flexibility could easily increase the capital budget of a facility and can be justified over a long-term during the operational use of a facility. But Neufville and Scholtes (2011, p. 57) argued that "*most remarkably, flexible designs often cost less than inflexible designs*". It is difficult to mathematically justify the cost of flexibility; for this reason, flexibility can be seen as an *insurance strategy* when planning and designing healthcare facilities. With additional cost involved, the client should be the main decision maker, but should always include the designers and facility users in the decision making process to possibly cut the costs of designing, constructing or managing facilities. User participation is very important when designing for healthcare flexibility. The designers do not live in the facilities, but they are professionally trained to make design decisions about the facility. The designers can work together with the facility users to make more collaborative and informed decisions that would be effective and efficient on a long-term. The decisions made as an outcome of collaboration between the consultants and facility users can be further discussed with the client to sign off the proposal; this is one of the advantages of collaborative stakeholder decision making.

Table 6.9: *Top four important stakeholders making flexibility decisions from (Sample One)*

Dominant stakeholders	Ranked	No. of respondents
Client/contractor	1	6
Designers /architects	2	5
A team of healthcare professionals	3	3
MEP services contractor	4	2

Table 6.10: *Top four important stakeholders making flexibility decisions from (Sample Two)*

Dominant stakeholders	Ranked	No. of respondents
Owner	1	26
Designers	2	25
A team of healthcare professionals	3	23
Patients and staff	4	20

6.2.4 IMPORTANT FACTORS TO CONSIDER WHEN DESIGNING FLEXIBLE SPACES

The design for future flexibility works around a possible rapid changing or expanding space. Table 6.12 identifies possible changing spaces as the most important factors to consider in the opinion of the questionnaire survey respondents from Sample Two, while cost is identified in Table 6.11 as the most important factor to consider in the opinion of the questionnaire survey respondents from Sample One. As previously stated, the cost of embedding flexibility is difficult to justify accurately or mathematically with real time values. The process of responding to future changes can hardly be justified before the facility is fully constructed and operational. But, consultants can learn from previous studies to make informed decisions. Cleveland Clinic (2010) has presented a formula for mathematically calculating the value of flexibility. Cleveland Clinic (2010) expressed the value of flexibility as:

First cost premium + Operating cost premium

Vs.

Future cost savings + Mitigated disruption

Future cost saving can hardly be identified in the *present*, while the mitigated disruption can only be identified in the future when the flexible scenario is put in place; the value of flexibility can only be easily calculated with accuracy in the future, when a facility is adapting to changes. Future cost can be predicted with a very low degree of accuracy (Neufville *et al.*, 2008). Flexibility can increase the value of a facility. Neufville and Scholtes (2011, p. 39) stated that "*flexibility in design routinely improves performance by 25 percent or more*". Neufville and Scholtes (2011, p. 10) also stated that when dealing with flexibility "*the case studies we report in this book show increases of up to 80 percent in expected value*". The increase in value can justify the cost of embedding the flexibility. The use of standards has been identified in both Tables 6.11 and 6.12 as the second top factor to consider when designing flexible healthcare spaces. This study further looks at standardisation in a flexible design context. Standardisation in flexible space design can facilitate the process of re-using a successful and quality space within a healthcare facility. The universal space can also be adopted using modular standards to allow generic use of space. For example, a consultant`s office can easily be changed to a treatment unit. This involves the use of standardised components such as size, layout, and equipment etc. Another important consideration identified by Sample One and Two is the centralised support service system; it enables furniture, equipment and power supply to be flexible within a universal space or in a shell space by providing services in grid or zone layouts to allow changes such as conversion and relocation of spaces or functions.

Table 6.11: *Top three important considerations for designing flexible spaces from (Sample One)*

Important considerations	Ranked	No. of respondents (mentioned)
Cost	1	5
Standardisation	2	3
Centralised support services and systems	3	2

Table 6.12: *Top three important considerations for designing flexible spaces from (Sample Two)*

Important considerations	Ranked	No of respondents (mentioned)
Identifying possible expanding /changing spaces	1	45
Standardisation	2	36
Services	3	30

6.2.5 EFFECTIVENESS OF SOME FLEXIBILITY CONCEPTS

Figure 6.11 and Figure 6.12 show the responses for Sample One and Two respectively. Table 6.13 shows the ranking for the effectiveness of some flexibility concepts identified in Figures 6.11 and 6.12; these are tabulated based on the sum of the questionnaire survey responses using the Likert scale which rates highly ineffective as zero and highly effective as five. Modular design and shell space design were the most effective flexibility concepts in the opinion of the questionnaire survey respondents from Samples One and Two. Flexible furniture and equipment were ranked as the fourth most effective flexibility concept in the opinion of the questionnaire survey respondents from both samples. The flexible concepts that had the widest difference between the two samples was the multi-purposes foundations which Sample One ranked as the most effective flexibility concepts, while Sample Two ranked it as the least most effective flexible concept. The ranking also identified the use of modular design, shell space and flexible partitions as the most effective concepts agreed by respondents from both samples. Modular design is understood by Neufville and Scholtes (2011, p. 9) to ease the process of increasing the capacity of a facility by simply adding another similar part to the whole. Multi-purpose foundations can be used to increase the capacity of a building in the near future; these foundations are designed into buildings and build upon when the need arises.

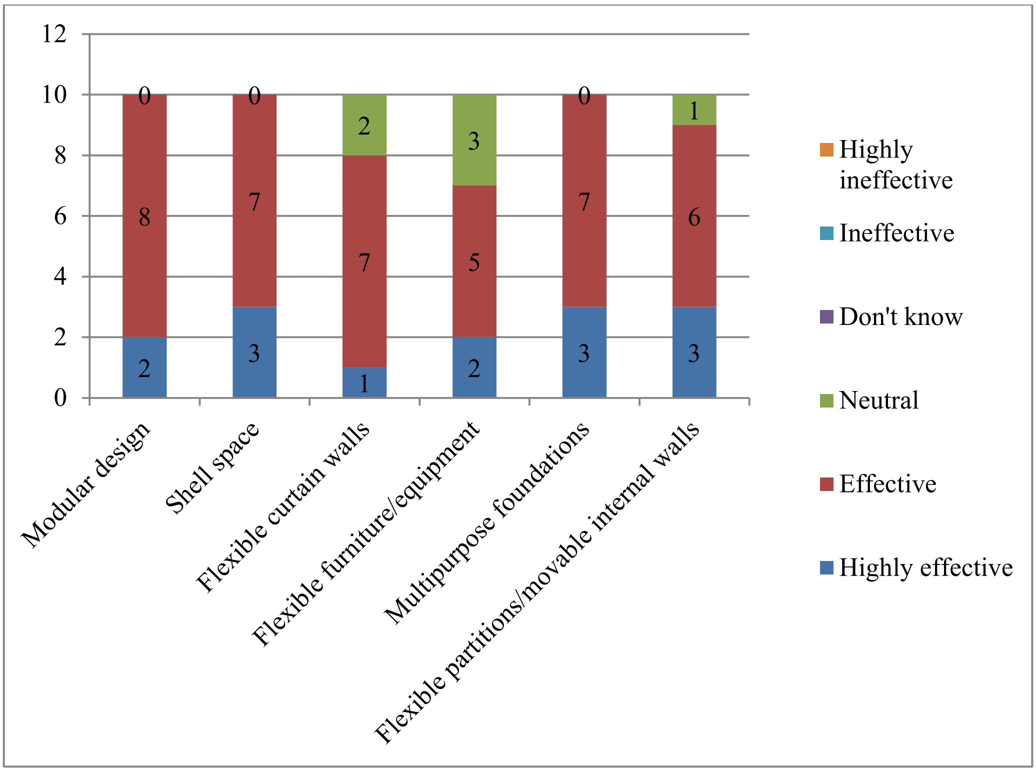


Figure 6.11: *Opinion of questionnaire survey respondents on degree of effectiveness of the following flexibility concepts from (Sample One)*

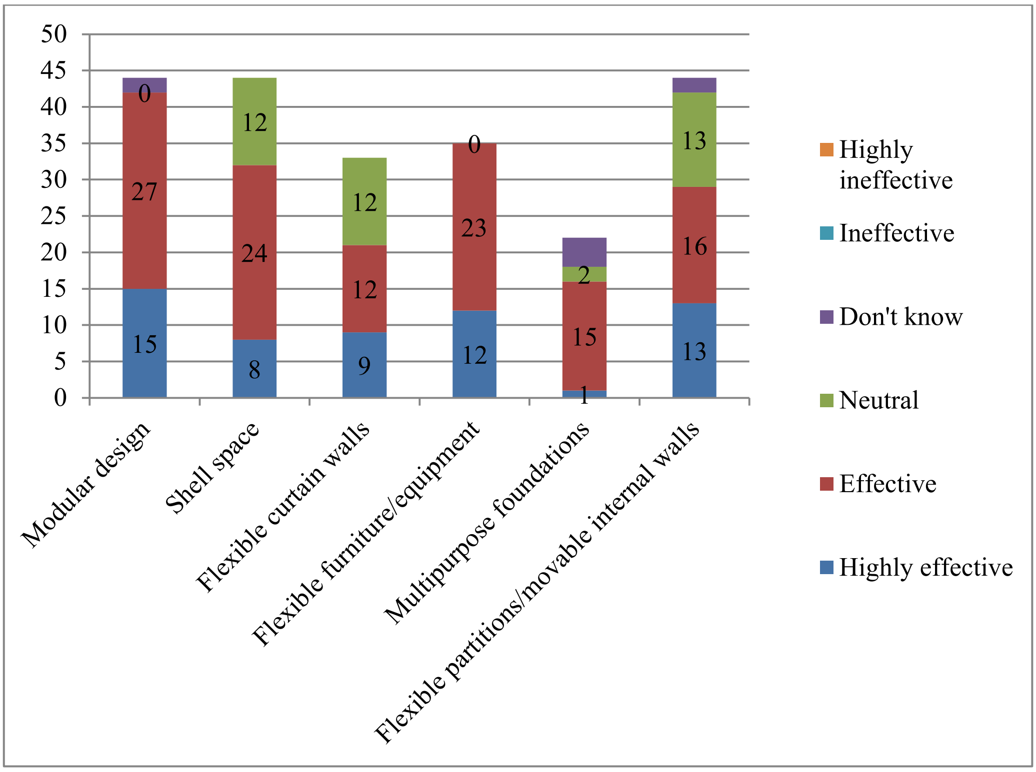


Figure 6.12: *Opinion of questionnaire survey respondents on degree of effectiveness of the following flexibility concepts from (Sample Two)*

Likert Scoring scale: Highly ineffective=0; Ineffective=1; Don't know= 2; Neutral=3

Effective=4; and Highly effective=5

Table 6.13: *Ranking on the flexibility concepts from both (Sample One and Two)*

Flexibility Concepts	Ranked (1)	Ranked (2)	Responses (1)	Responses (2)
Modular design	3	1	2x5+ 8x4 =42	15x5+27x4+2x2=187
Shell space	1	2	3x5+7x4=43	8x5+24x4+12x3=172
Flexible curtain walls	4	5	1x5+7x4+2x3=39	9x5+12x4+12x3=129
Flexible furniture/equipment	4	4	2x5+5x4+3x3=39	12x5+23x4=152
Multipurpose foundation	1	6	3x5+7x4=43	1x5+15x4+2x3+4x2=79
Flexible partitions / movable internal walls	6	3	3x5+6x4+1x3=32	13x5+16x4+13x3=170

6.3 STANDARDISATION IN FLEXIBLE HEALTHCARE SPACE

Standardisation in flexible design allows designs to be generic and universal; it also aids in re-designing healthcare facilities by specifying parts that make up the whole facility. For example, a 25 square meter area can be specified to all single beds and offices; in a situation where the capacity of a healthcare facility is stretched, the offices could be easily converted into single beds. Although zoning of bed areas and office areas will have to be considered. Perhaps a lot goes into the planning process of converting healthcare spaces to achieve optimum flexibility.

6.3.1 IMPORTANT STAKEHOLDERS MAKING STANDARDISATION DECISIONS

Decision making is very important when selecting standards for a specific project. There are various standards for similar function, spaces, furniture, or equipment. Hignett and Lu, (2008), stated that "*it emerged that some of the interviewed architects described their experience of having been involved in 15 different hospitals and seeing the clinical layout for the same functional area in 15 different ways*". This can inform the selection process, as there are many standards available for the same function. This research identifies the need to select standards from the different available standards. Table 5.14 agrees with Table 6.15 that owners, designers and facility users are listed as the most importance stakeholders making decision when selecting the most appropriate and effective standards.

Table 6.14: *Top four most important stakeholders making decisions during the selection process of the most effective standards from (Sample One)*

Dominant stakeholders	Ranking	No. of respondents (mentioned)
Owner	1	9
Designers	2	8
Contractor	3	6
Facility users	4	5

Table 6.15: *Top four most important stakeholders making decisions during the selection process of the most effective standards from (sample two)*

Dominant stakeholders	Ranking	No. of respondents (mentioned)
Healthcare bodies (e.g ASPECT)	1	42
Healthcare designers	2	40
Owner / client	3	36
Facility users	4	32

6.3.2 STANDARDISATION AND FLEXIBLE HEALTHCARE SPACE DESIGN

This research explored the opinion of the questionnaire survey respondents on the possibility of standardisation impeding flexible space opportunities by providing specification within three different scenarios. These include: producing rigid spaces/layout; producing interrelationship of spaces that are highly complex; and hindering modularity concept layout. There is a need to explore the application of standardisation in flexible healthcare space to achieve added value, cost effectiveness and project efficiency. Most of the respondents presented in Figure 6.13 agreed that standardisation could affect flexibility in all three categories *some of the times.* Table 6.16 was tabulate using the sum of the questionnaire survey responses from Figure 6.13 (Samples One) and Figure 6.14 (Sample Two). One of the Likert scales used for the analysis of the quantitative data collected rates *some of the time* at five and *not at all* as one. There is a strong disagreement within Figure 6.14, some questionnaire survey respondents opted for *not at all*, while others opted for standardisation impeding flexibility *most of the time*. The lack of agreement between Sample One and Sample Two is clearly illustrated in Table 5.16. Standardisation is understood to impede flexible healthcare spaces by hindering modularity concept layout. It is ranked as number one by Sample One, while it is ranked as number three by Sample Two. Standardisation creating interrelationships of spaces that are highly complex was ranked as number one in findings from Sample Two, while it is ranked as number three by Sample One. The similarity of findings from both questionnaire survey samples was identified. Questionnaire survey respondents from both samples have ranked *standardisation creating rigid spaces/layout* as number two. These findings in general illustrate a strong disagreement between standardisation complicating flexibility and standardisation not affecting flexibility opportunities; both flexibility and standardisation may affect each other.

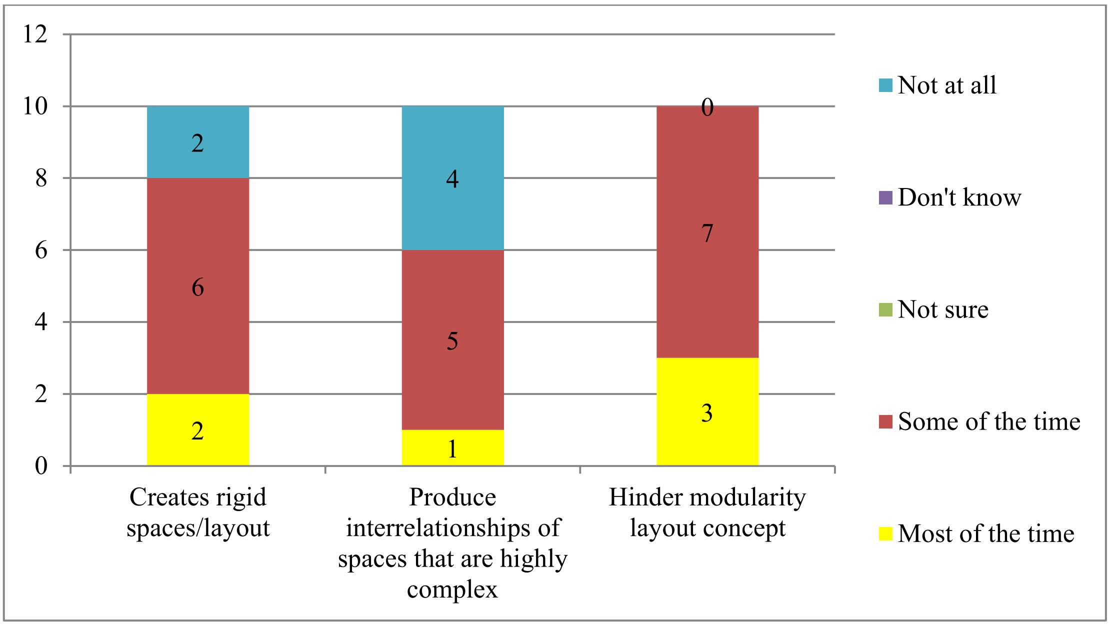


Figure 6.13: *Opinion of questionnaire survey respondents on standardisation impeding flexible space opportunities by providing specification that involves the three different categories in (Sample One)*

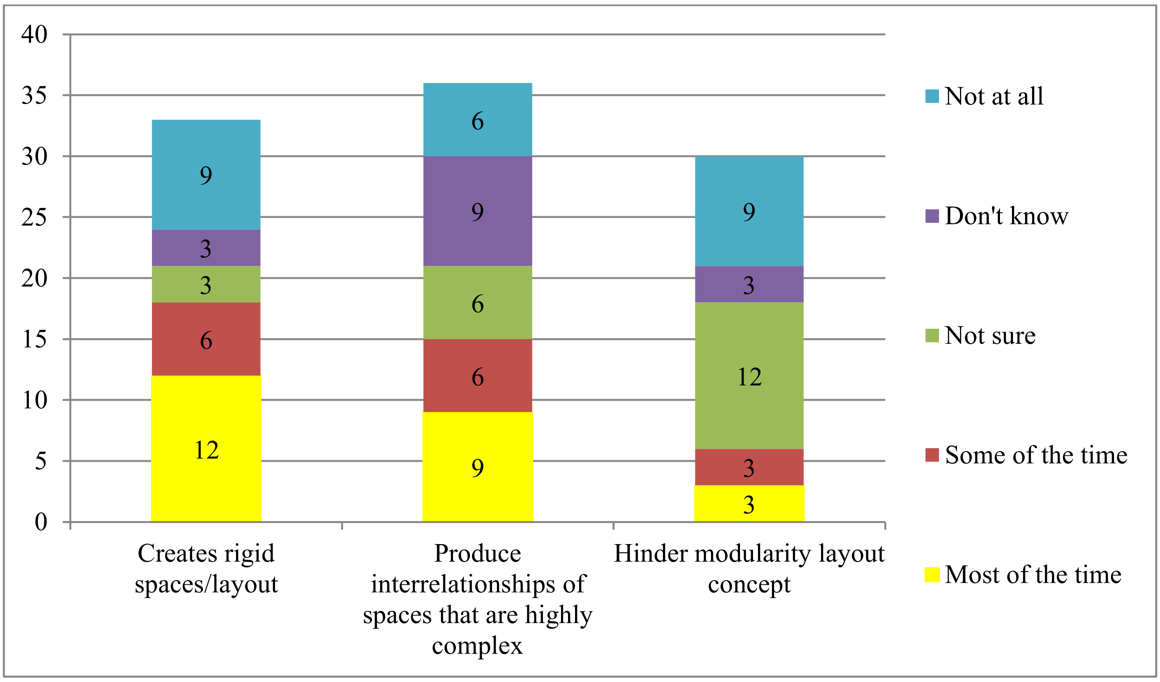


Figure 6.14: *Opinion of the questionnaire survey respondents on standardisation impeding flexible space opportunities by providing specification that involves the three different categories in (Sample Two)*

Likert Scoring scale: not at all =1; don`t know=2; not sure=3; some of the time=4; and most of the time=5

Table 6.16: *Opinion of the questionnaire survey respondents on standardisation impeding flexible space opportunities from Sample One and Two*

Flexibility Concepts	**Ranked (1)**	**Ranked (2)**	**Responses (1)**	**Responses (2)**
Creates rigid spaces / layout	2	2	2x5+6x4+2x1=36	12x5+6x4+3x3+3x2+9x1=108
Produce interrelationships of spaces that are highly complex	3	1	1x5+5x4+4x1=29	9x5+6x4+6x3+9x2+6x1=111
Hinder modularity layout concept	1	3	3x5+7x4=43	3x5+3x4+12x3+3x2+9x1=78

6.4 BIM SUPPORTING FLEXIBLE HEALTHCARE SPACE DESIGN

The application of BIM is currently growing in the AEC industry. The application of flexibility can be enhanced and achieved with *what if scenarios* to design different design options. BIM provides the platform to use different tools with the capability of analysing and evaluating alternative design scenarios within a virtual environment. The different design options are usually generated from an agreed plan that is improved in the Development Design Stage. When designing flexible spaces, there are some concerns within some groups claiming that flexibility could limit design creativity. Therefore, this research further explored the impact of BIM tools on design creativity by eliciting the opinion of questionnaire survey respondents from Samples One and Two.

6.4.1 CREATIVITY WITH BIM

Whilst the application of BIM continues to be acknowledged and prevailing, design practitioners and academics find themselves in a paradox with an on-going discussion on the impact of BIM tools on design creativity and innovation. Literature suggests that BIM tools can hinder design creativity due to: parametric limitations; interoperability; and the demand for detailed information at preliminary design stages. However, other literature shows that BIM tools increase design creativity, and at some point provide limitless opportunities to be creative. BIM tools have an impact on design creativity; this could be negative or positive. Creativity is not necessarily directly affected by design tools, rather the ability of a designer to use the design tools for optimum creativity. Nevertheless, some design tools have more flexibility and freedom compared to others. For example, freehand sketching with a pencil creates design freedom with less information required at preliminary conceptual design stage. While digital sketching requires the designer to learn the software packages before using it, and a time requires early precise data.

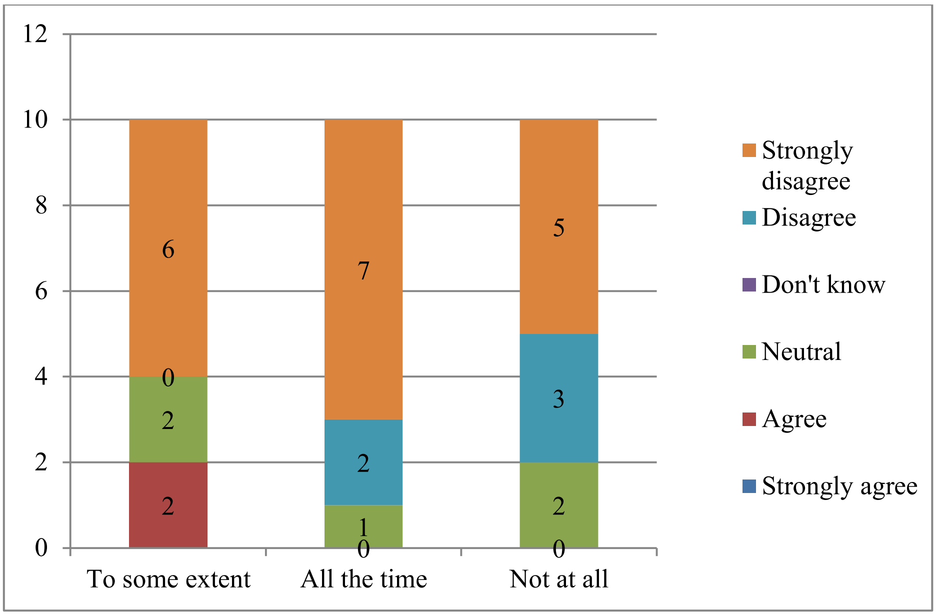


Figure 6.15: *Opinion of the questionnaire survey respondents on the degree of dis (agreement) that BIM tools hinder design innovation and creativity from three different scenarios (Sample One)*

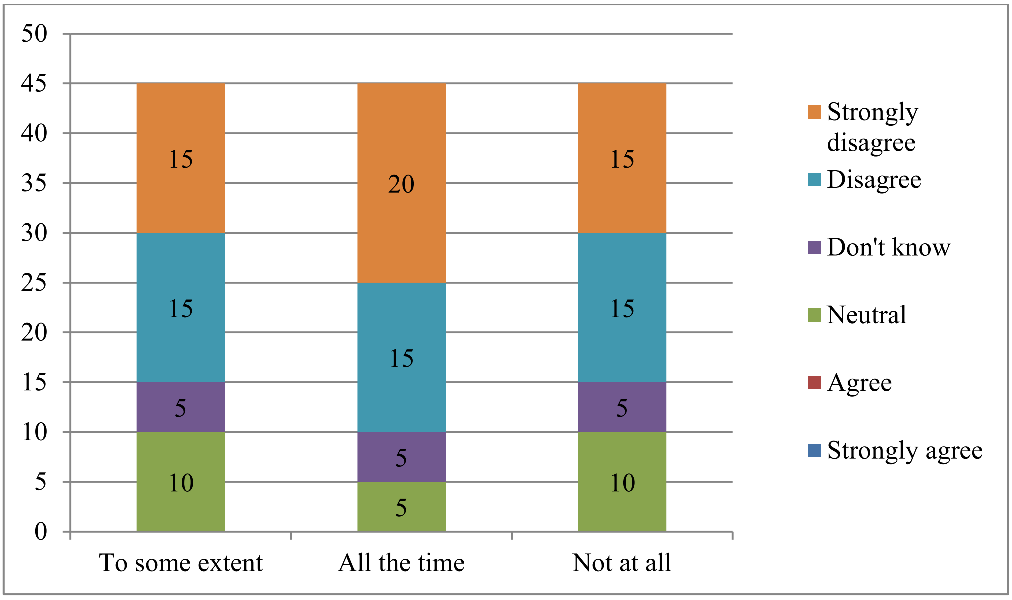


Figure 6.16: *Opinion of the questionnaire survey respondents on the degree of dis (agreement) that BIM tools hinder design innovation and creativity from three different scenarios (Sample Two)*

A higher percentage of the questionnaire survey respondents from Figure 6.15 (Sample One) strongly disagree that BIM tools could hinder design innovation and creativity compared to the percentage of respondents of the opinion that BIM tools do not hinder design creativity. While equal number of the questionnaire survey respondents from Figure 6.16 (Sample Two) were of the opinion that BIM tools hinder designs *to some extent* and *not at all*. There are reasonable numbers of the questionnaire survey respondents from both samples that disagree that BIM tools hinder design creativity. The findings from Sample One and Sample Two raised concerns that there is a need to develop more understandings of BIM and its impact on design creativity.

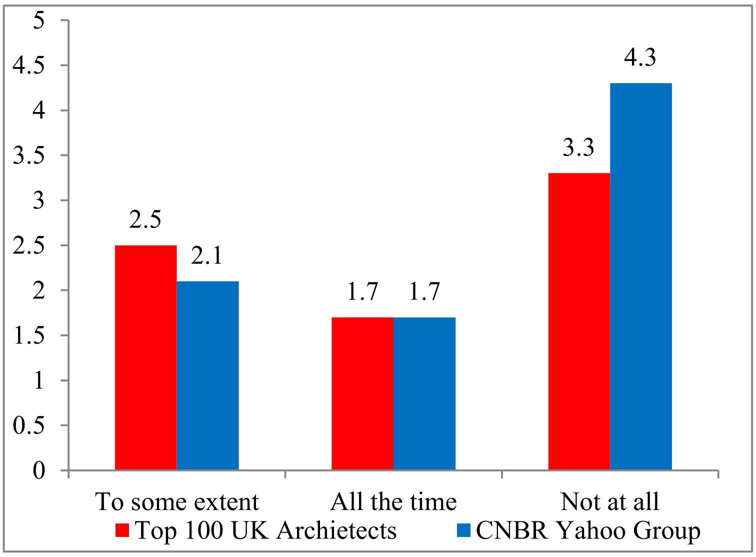


Figure 6.17: *Comparability between the two different groups of questionnaire survey respondents (average mean)*

Likert scoring scale: strongly disagree =0; disagree = 1; don't know = 2; neutral =3; agree = 4; and strongly agree =5

Figure 6.17 shows a higher mean of responses from both groups agreeing with each other's opinion that BIM tools do not hinder design creativity by opting for *not at all*. But in the opinion of some questionnaire respondents, BIM tools hinder design creativity to *some extent*, while the lowest mean of respondents opted for *all the time*. Therefore this research further explored strategies of overcoming the possible limitations of applying BIM tools to achieve design creativity. This is explored and described explicitly in appendix 3.

6.4.2 WHAT IF SCENARIOS WITH BIM

To achieve future flexibility, a future scenario has to be put in place to focus the flexibility strategy. The process of adopting "*What if scenario*" suggests likely scenarios and allows the designer to propose and recommend possible solutions with cost effectiveness and efficiency as a primary concern. BIM application helps in creating different design layouts in 2D and 3D that can be easily analysed and optimised to achieve a sustainable and suitable design option that is appropriate for construction. The questionnaire survey respondents in Figure 6.18 (Sample One) illustrated that "*what if scenarios*" with BIM are more effective on a long-term basis while questionnaires respondents in Figure 6.19 (Sample Two) identified "*what if scenarios*" with BIM to be more effective on a short-term basis.

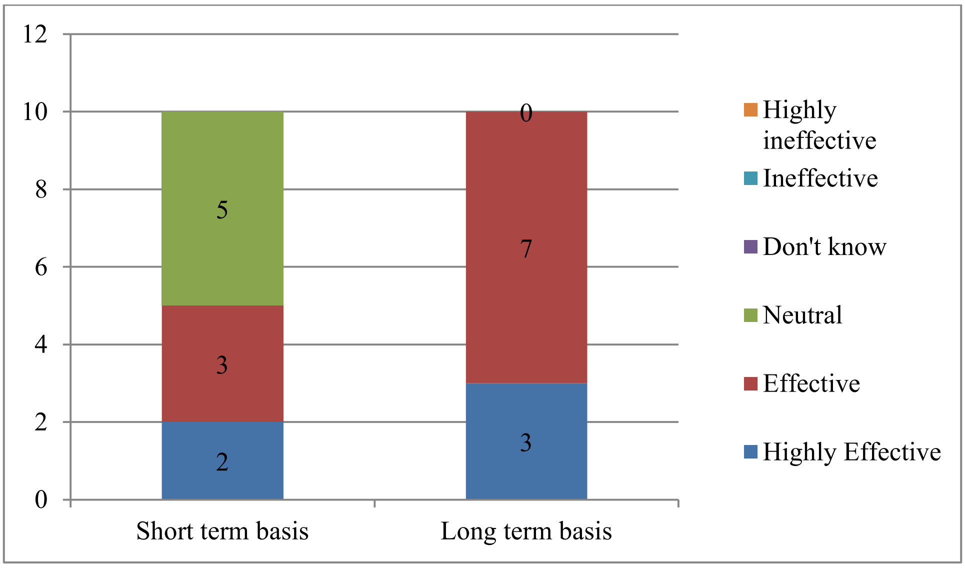


Figure 6.18: *Opinion of the questionnaire survey respondents on the effectiveness of using "what if scenarios" with BIM in the design of flexible healthcare spaces from Sample One*

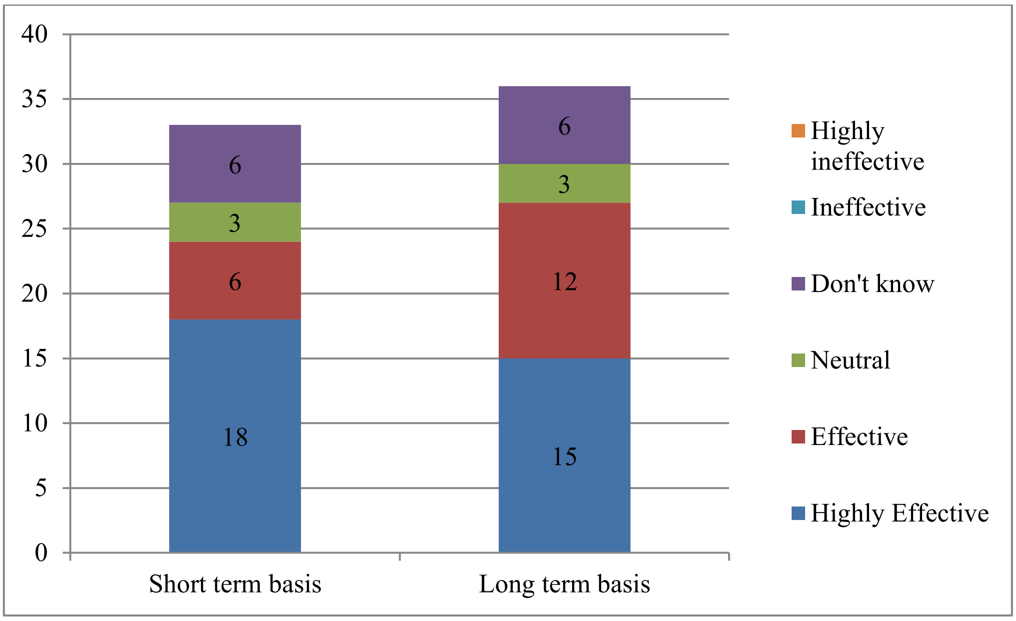


Figure 6.19: *Opinion of the questionnaire survey respondents on the effectiveness of using "what if scenarios" with BIM in the design of flexible healthcare spaces from Sample Two*

6.4.3 BIM USE FOR ANALYSING AND EVALUATING FLEXIBLE HEALTHCARE SPACE

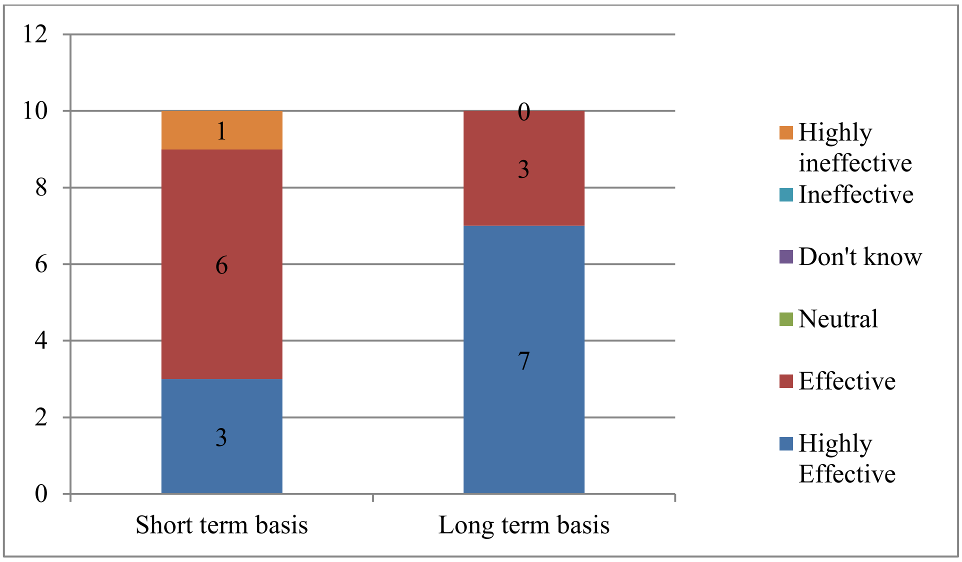


Figure 6.20: *Opinion of the questionnaire survey respondents on the effectiveness of using BIM for analysing and evaluating flexible healthcare space to inform decisions on short-term and long-term basis from (Sample One)*

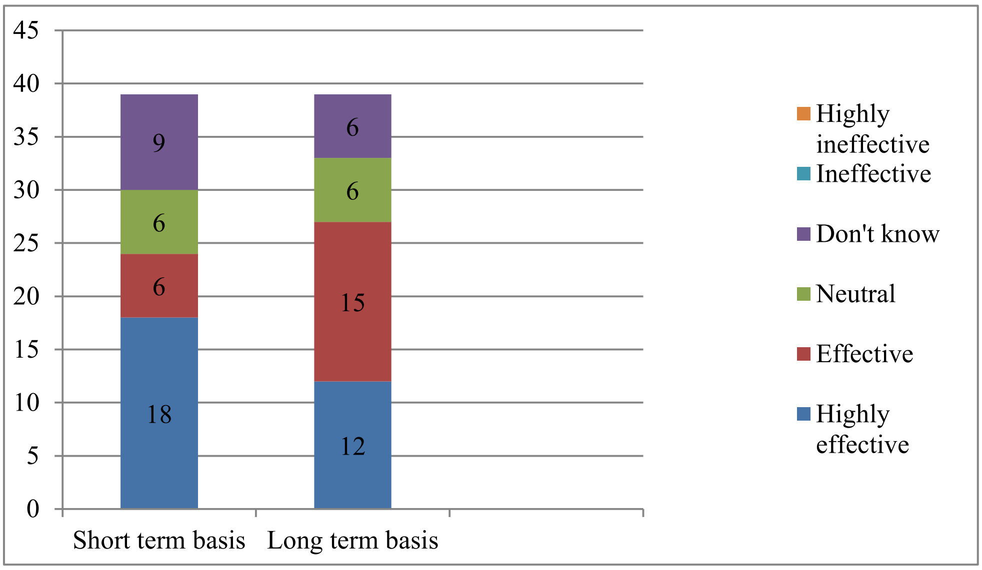


Figure 6.21: *Opinion of the questionnaire survey respondents on the effectiveness of using BIM for analysing and evaluating flexible healthcare space to inform decisions on short-term and long-term basis from (Sample Two)*

There is an agreement between both the questionnaire survey respondents from Figures 6.20 (Sample One) and 6.21 (Sample Two) that BIM is effective when analysing and evaluating flexible healthcare space to inform decisions on both short-term and long-term basis. Findings showed that BIM is effective in analysing flexible healthcare spaces on long-term basis in both Samples One and Two.

6.4.4 BIM USE FOR ADAPTING, EXPANDING, CONVERTING AND RELOCATING SPACE

Both questionnaire survey respondents from Figures 6.22 and 6.23 have agreement that BIM use is effective when analysing, evaluating and modelling flexible healthcare facility spaces expanding, contracting, relocating or adapting to changes. BIM is agreed by the questionnaire survey respondents from both samples to be applicable for designing a flexible healthcare facility that can adapt to futures changes. The questionnaire survey respondents from Sample One are of the view that BIM is more applicable when expanding healthcare spaces followed by contracting, adapting and relocating. A question arises; how can this be achieved with BIM? In chapter 7, the use of BIM to aid the design of a change-ready healthcare facility was explored with healthcare facility designers.

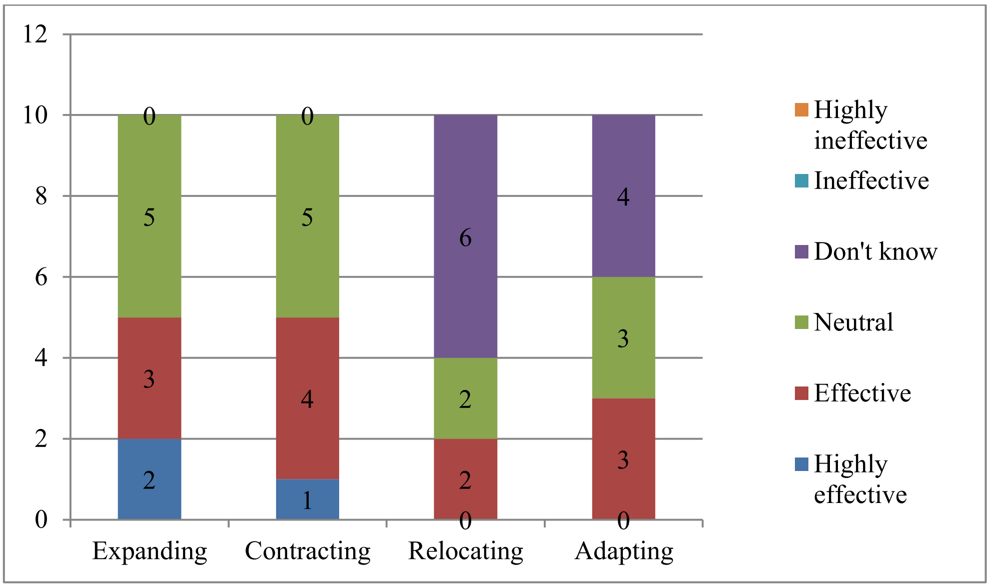


Figure 6.22: *Opinion of the questionnaire survey respondents on the effectiveness of using BIM for analysing, evaluating and modelling flexible healthcare facility space expanding, contracting, relocating and adapting to changes from (Sample One)*

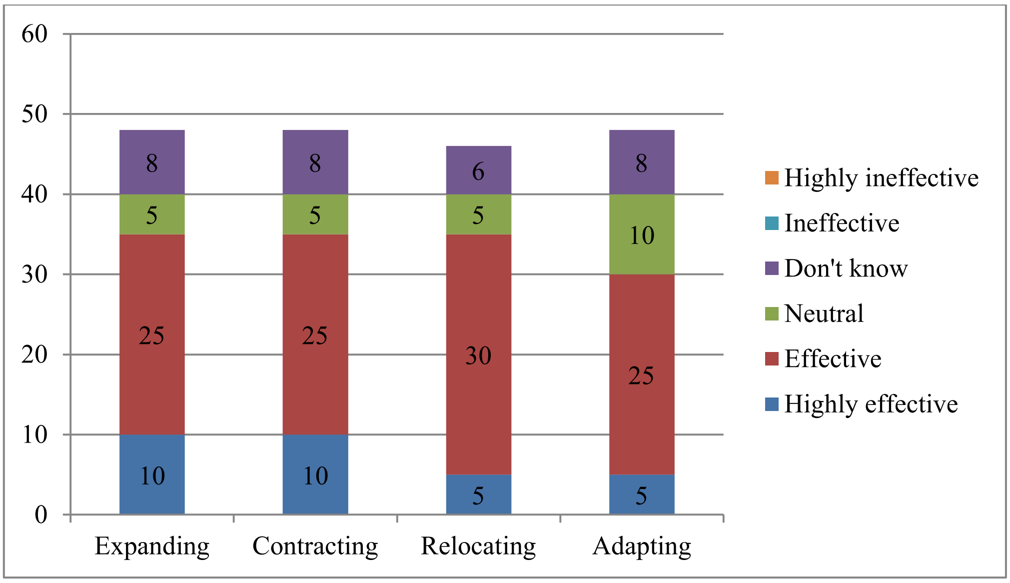


Figure 6.23: *Opinion of the questionnaire survey respondents on the effectiveness of using BIM for analysing, evaluating and modelling flexible healthcare facility space expanding, contracting, relocating and adapting to changes from (Sample Two)*

6.4.5 IMPORTANT CONSIDERATIONS WHEN SHARING INFORMATION WITH BIM

A noteworthy finding regarding the process of sharing information with BIM was that most of the questionnaire survey respondents skipped this question. The important considerations for sharing information within an organisation or with external organisations were not differentiated a lot by both Samples One and Two. In a space provided for “additional information” some of the questionnaire survey respondents added some information. Sample Two respondents are outlined as CNBR1-CNBR48. But one of the questionnaire survey respondents from Sample Two CNBR-15 stated that when sharing information with BIM within an organisation, the stakeholders involved should “*develop in-house BIM standards and constantly review and improve upon the emerges of new knowledge*” while with external organisations, the internal organisation “*should review BIM standards from external parties to establish whether they can be used to influence or improve their own standards*”. Respondents F3 from Sample One stated that “*systems should be in place that will ensure that everyone on the design team can work within a single model*”. Respondent F4 from Sample One also stated that it is important to “*control the information that is put into the single BIM model to ensure only agreed changes are incorporated*”. One of the respondents from Sample Two CNBR-22 also stated that “*A BIM execution plan is vital to achieving BIM benefits; but the BIM execution plan has to define the process, roles, responsibility, object naming and classification and also object project data to be captured for data exchange purposes”*. The questionnaire survey respondents from both Samples One and Two have agreed that interoperability and setting modelling and collaboration protocols are key factors to consider when sharing information within an organisation and with external organisations.

6.5 REFINEMENT OF THE FRAMEWORK DEVELOPED FROM LITERATURE REVIEW ANALYSIS

The questionnaire survey findings were used to further revise the framework for designing a change-ready healthcare facility; the previous framework was generated from literature review. The findings from the questionnaire survey are presented in Table 6.17; they show recommendations that could support the design of a change-ready healthcare facility in the opinion of the questionnaire survey respondents. Key findings of the questionnaire survey include:

- identifying the possible changing spaces;
- identifying the type of change;
- identifying the time-frame the flexibility is most likely to take place;
- applying standards to healthcare spaces;
- exploring various scenarios or design options with BIM; and
- analysing and evaluating with BIM

Figure 6.24 presents a revision on the framework developed from literature review analysis in chapter 3. The key finding of the questionnaire survey was that a change-ready healthcare facility revolves around possible changing spaces. However, the following inputs in Figure 6.24 are presented below.

A- Same as in Figure 3.17 in chapter 3;

B- Same as in Figure 3.17;

C- Same as in Figure 3.17;

D- Same as in Figure 3.17;

E- Same as in Figure 3.17. Nevertheless, questionnaire survey respondents identified cost as one of the most important factors to consider when building flexibility into a healthcare facility. As a result, the need to identify proposed cost of a flexible facility design is identified at the early design stages (see Table 6.17);

F- Same as in Figure 3.17;

G- The need to identify possible changing spaces is important in an effort to design a facility that can respond to future healthcare changes. As need changes, spaces have to adapt to these variations. Table 6.5 and Table 6.11 show results of the questionnaire survey respondents. Therefore, arguably flexible healthcare spaces revolves around possible changing spaces;

H- Same as in Figure 3.17;

I- Same as in Figure 3.17;

J- Questionnaire survey respondents identified that there is disagreement on standardisation affecting flexible design layout, while others are of the few that flexibility affects the ability to standardise specifications for spaces. However, questionnaire survey findings showed that it is important to standardise flexible spaces. See Figure 6.13 and Figure 6.15 for details;

K- Same as in Figure 3.17;

L- Questionnaire survey findings presented in Figure 6.20, Figure 6.21, Figure 6.22 and Figure 6.23 show that BIM can be used to analyse and evaluate flexible spaces;

M- Same as in Figure 3.17

N- Same as in Figure 3.17

Findings from literature review in chapter 3 showed that improvisations can be made if the final design is in-appropriate with the project target. The designing process might be fully or partial revised in order to design a flexible plan that is appropriate, that is within a proposed budget target and project quality.

O- Same as in Figure 3.17

The findings associated with the following RIBA Stages were strategically categorised. D and E (Appraisal); F (Design Brief); G, H, I, J and K (Concept); and L, M, N and O (Design Development). However, the framework stages are linked in the same order as the RIBA Plan of Work Stages.

There was a need to further develop the framework generated from the questionnaire survey findings; a framework for designing a change-ready healthcare facility with the use of refurbishment, flexibility, standardisation and BIM has not been fully explored yet. There is a need to define what? When? And how to plan and schedule the design of a facility that can respond to future changes? Therefore, there is a need to support the framework design with qualitative data. The findings from this research have established the structural organisation of the four applications in the design of a change-ready healthcare facility. BIM can support the combined application of flexibility and standardisation within a refurbished project or new built. There is a need to provide more detailed information on the four applications used in this study. It was conducted through the process of interviews with architectural firms in the UK. Chapter 7 presents the interview findings; it is an improvement on the framework revised from literature review and the questionnaire survey findings.

Table 6.17: *Questionnaire survey findings used to further develop the framework for designing a change-ready healthcare facility*

Recommendations	**Questionnaire Survey Findings**	**Description of Figures and Tables**
Identify spaces that rapidly change	**Table 6.5**	Spaces that frequently changes in healthcare facilities.
	Table 6.11	Top three important considerations for designing flexible spaces.
Applying standards to flexible spaces	**Fig. 6.13**	Opinion of questionnaire survey respondents on standardisation impeding flexible space opportunities by providing specification that involves the three different categories.
	Fig. **6.15**	Opinion of the questionnaire survey respondents on the degree of dis (agreement) that BIM tools hinder design innovation and creativity.
Creating different scenarios/ design options with BIM support	**Fig. 6.18**	Opinion of the questionnaire survey respondents on the effectiveness of using "what if scenarios" with BIM in the design of flexible healthcare spaces from sample one.
	Fig. 6.19	Opinion of the questionnaire survey respondents on the effectiveness of using "what if scenarios" with BIM in the design of flexible healthcare spaces from sample two.
Analysing and evaluating flexible spaces with BIM	**Fig. 6.20**	Opinion of the questionnaire survey respondents on the effectiveness of using BIM for analysing and evaluating flexible healthcare space to inform decisions on short-term and long-term basis from sample one.
	Fig. 6.21	Opinion of the questionnaire survey respondents on the effectiveness of using BIM for analysing and evaluating flexible healthcare space to inform decisions on short-term and long-term basis from sample two.
	Fig. 6.22	Opinion of the questionnaire survey respondents on the effectiveness of using BIM for analysing, evaluating and modelling flexible healthcare facility space expanding, contracting, relocating and adapting to changes from (sample one).
	Fig. 6.23	Opinion of the questionnaire survey respondents on the effectiveness of using BIM for analysing, evaluating and modelling flexible healthcare facility space expanding, contracting, relocating and adapting to changes from (sample two).

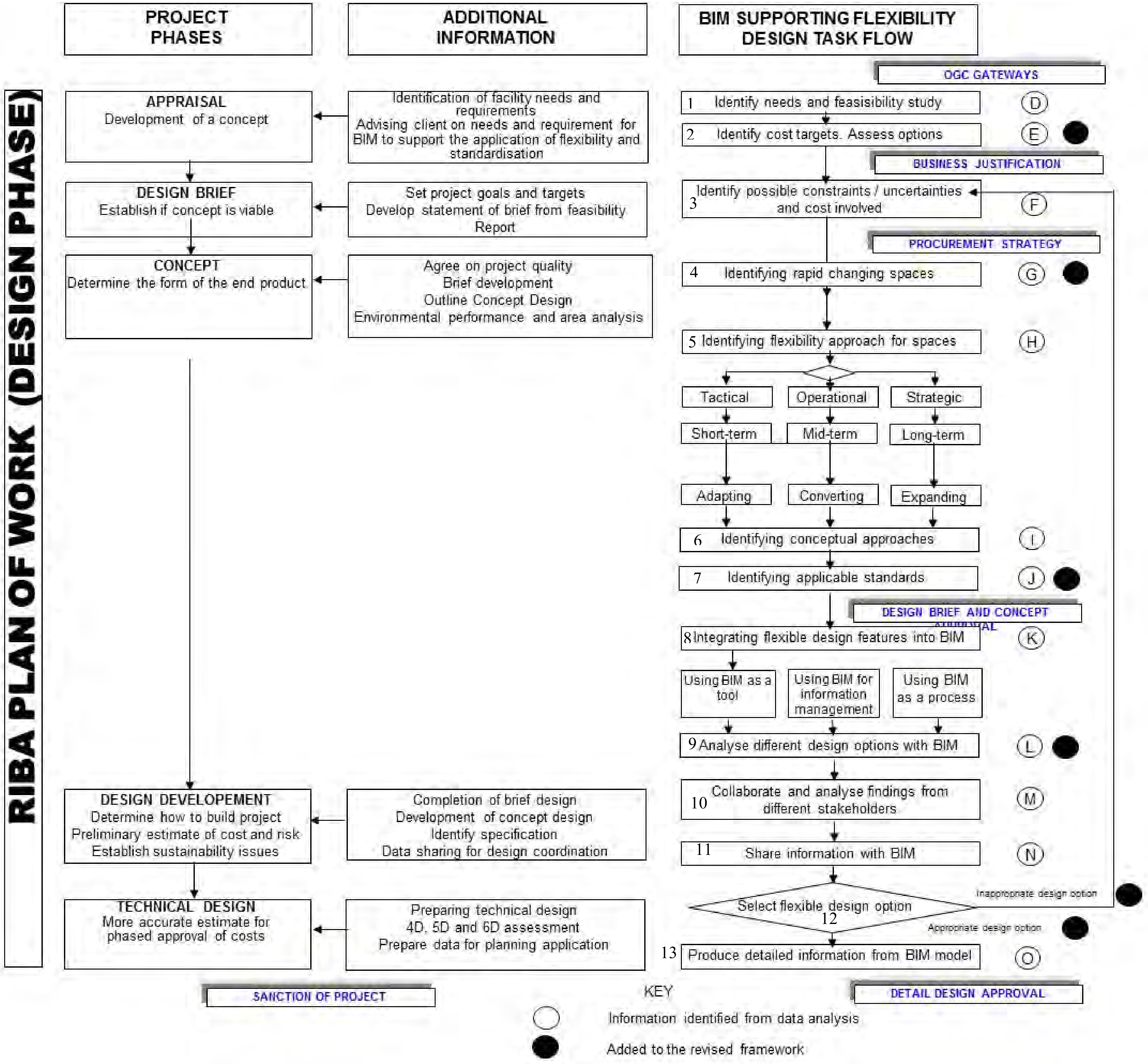


Figure 6.24: *framework for designing a change-ready healthcare facility developed from literature review and questionnaire survey findings.*

6.6 LIMITATION OF QUESTIONNAIRE SURVEY

The location of the questionnaire survey respondents from the CNBR Yahoo Group sample could be from different parts of the world; the questionnaire was open to all CNBR Yahoo Group professionals around the globe. The basis of comparison is that both Samples One and Two have answered the same questions, but the problem was the number of responses registered from each sample was different. Therefore, equal comparison is not possible; hence, the comparison of the two samples was conducted to observe the pattern of responses. During the early analysis stages, it was clear that questionnaire survey (Sample One) category was an industry based group, while the questionnaire survey (Sample Two) category was a mixture of professionals from various backgrounds and a few industry professionals; most of the respondents from Sample Two were academicians. It was stated in the beginning of this research that two samples were considered to observe the different opinion of different professionals from the built environment, but only the pattern and ranking of elements within the two samples were explored and presented for reliability and rigour of the study.

6.7 CHAPTER SUMMARY

The limitless opportunity to achieve design creativity during the conceptual stage supports the ability to creatively embed flexibility into a facility. Some of the findings from the robust analysis of the questionnaire survey showed that the application of flexibility is limited by standardisation in the opinion of some questionnaire survey respondents, while in the opinion of some other questionnaire survey respondents; standardisation does not affect the ability to achieve flexible design layouts. The questionnaire survey findings were used to revise the framework. Four key additions have been made to the framework revised in chapter 3. These are: the need to identify and design within project budgets; to identify possible rapid changing spaces that might be affected when a facility adapts to changes; the use of standards when dealing with flexible spaces allows similar spaces to be used for different functional purposes; and BIM can be used to virtually analyse and evaluate different design options through editing and collaboration with different project stakeholders. There is a need to define what? When? And how to plan and schedule the design of a facility that can respond to future changes? As a result, interviews were conducted.

7 CHAPTER 7: RESEARCH UNDERTAKEN (INTERVIEWS): ORGANISING RFSB WITHIN A CHANGE-READY HEALTHCARE FACILITY

7.1 INTERVIEW INTRODUCTION

The questionnaire survey findings presented in chapter 6 has verified that BIM can be used in the design, analyse and optimisation of a change-ready healthcare facility; the findings were also used to revise the framework developed from literature review analysis. A question emerges: how and when is BIM effective in the framework for designing a change-ready healthcare facility. Semi-structured interviews were used as the *approach to the interview design*. The use of BIM is applicable to all sectors of the AEC industry, but for the purpose of this research the use of BIM in architectural design was in question. There is no clear answer on how to combine flexibility and standardisation. As a result, close and open-ended questions were applied as one of the best approaches to get in-depth primary data. Interview facilitates the process of extracting in-depth and robust data for research purposes (Holstein and Gubrium, 2006). To collect detail information on applying flexibility, standardisation and BIM in healthcare refurbishment projects, a quantitative and qualitative approach was used. Dawson (2002, p. 14) described qualitative research as a research that explores experiences, attitudes and behavior through interviews or focus groups.

7.1.1 AIM OF THE INTERVIEWS

The *aim* of the interviews was to explore how designers incorporate flexibility, standardisation and BIM within healthcare refurbishment projects. Findings from the interviews were used to develop a framework that could be used to guide (best practices) the design of flexible healthcare spaces using BIM during healthcare refurbishment.

7.1.2 OBJECTIVES OF THE INTERVIEWS

The *objectives* of the interviews are set on designing healthcare facilities. These include:

- to identify the designer's key requirements and core activities to embed flexibility using BIM;
- to explore the combined application of standardisation and flexibility; and
- to explore how designers engage with existing constraints while designing flexible spaces within a healthcare refurbishment project.

The above objectives were achieved by forwarding an interview invitation with a comprehensive guide to the prospective interviewees (see appendix 8). These were provided for:

- introducing the research topic;
- defining the aim and objectives of the interview; and
- identifying the need for flexibility in healthcare facilities.

Tompkins *et al.* (2010) stated nine steps for designing a healthcare facility; the fifth step was to "*generate alternative hospital plans*" while the seventh step was to "*select a hospital plan*". When designing a flexible healthcare facility there is a need to generate alternative flexible plans; it is important to make informed decisions on selecting the most suitable design option. Therefore, a set of flexible design parameters that could aid the selection process were also sent to the interviewees.

7.1.3 INTERVIEW SAMPLING

Architects with vast experience in the AEC industry were contacted. It is important to choose from the best and highly experienced architects to add new knowledge to existing literature. The UK top 100 architectural firms based on the 2010 Building Magazine were the best UK firms with the highest number of UK chartered architects. Out of the 10 architectural firms that responded to the questionnaire survey; eight architectural firms responded to the interview invitations, while two other UK firms within the AEC industry also participated in the interviews. The two firms are both architectural companies with vast experience in healthcare facility design. The firms were suggested by the HaCIRIC team.

Table 7.1: *Details of firms that participated in the research interviews*

Architectural / Construction Firm ID	Top 100 UK Ranking	Number of Chartered Architects	Staff Capacity	UK Offices
Firm A (Architects)	1	384	1032	10
Firm B (Architecture and Construction)	-	-	-	-
Firm C (Architects)	2	247	879	2
Firm D (Architects)	4	226	4611	64
Firm E (Architects)	58	30	`-	1
Firm F (Architect)	7	140	296	4
Firm G (Architects)	-	-	-	-
Firm H (Architects)	52	35	259	9
Firm I (Architects)	33	46	377	8
Firm J (Architects)	9	113	193	6

Detail information for Firm B and G are unavailable. Firms B and G are the two other architectural companies that participated in the interviews.

7.1.4 METHOD OF INTERVIEW ANALYSIS

Face to face interviews were conducted with the various UK architectural firms listed in Table 7.1. All recordings were transcribed. The transcribed interviews had lots of information that this research can analyse. Interview content is usually dynamic with variety of information requiring an analytical analysis (Huberman and Miles, 2002). A robust analysis was conducted to analyse the data. BIM is understood differently by different organisations or individuals. The diversity of information would necessitate a robust analysis of the primary data. The interview analysis was based on the content inquiry approach *coding method.* Content analysis can be used in qualitative analysis to examine words or phrases within collected or available data. It is very important to identify what themes and connections are discovered? They are used to explain findings; attaching meaning and significance to the analysed data. Renner (2003) suggested some questions that should be asked for the interpretation and analyses of primary data. These include: What are major lessons learnt? What are the new findings? And what would people who used the result be interested in finding out? The content analysis method was adopted. Three steps were taken into consideration to prepare the interview data for analysis: interviews were conducted, recorded and transcribed.

Findings

The interview findings were used to identify the designer`s main roles when applying BIM, flexibility and standardisation within a refurbishment projects; the findings were used to show guides, best practices, and the process of developing a flexible design framework. BIM was a subject of interest to many of the interviewees; they highlighted some issues that were noteworthy when applying BIM in the AEC industry. Table 7.2 was used to identify interviewee prefix details to ease the process of analysing the interview data.

Table 7.2: *Interviewee code prefixes detail*

Interview ID	Code Prefixes
Architectural Firm A	AF-1
Architectural & Construction Firm B	AF-2
Architectural Firm C	AF-3
Architectural Firm D	AF-4
Architectural Firm E	AF-5
Architectural Firm F	AF-6
Architectural Firm G	AF-7
Architectural Firm H	AF-8
Architectural Firm I	AF-9
Architectural Firm J	AF-10

7.1.5 INTERVIEW FINDINGS CATEGORIES

The interview findings have been divided into two groups; the first group was based on the *questions category* and the second group based on the *theme category*. This is clearly illustrated in Figure 7.1. The second group has been classified into three phases. These are: the cost effective and cost efficient refurbishment; integrating flexibility and standardisation; and the application of BIM to facilitate the design of a change-ready healthcare facility. The cost effective and cost efficient refurbishment category is sub-categorised into constraints (organisational and technical) and best practices. The process of integrating flexibility and standardisation category is sub-categorised into the standardisation process, flexibility process and the combine application of flexibility and standardisation process. The application of BIM category is sub-categorised into BIM implementation (drivers and challenges) and the BIM maturity levels (level one, level two and level three) which are based on the UK Government Construction strategy (2011).

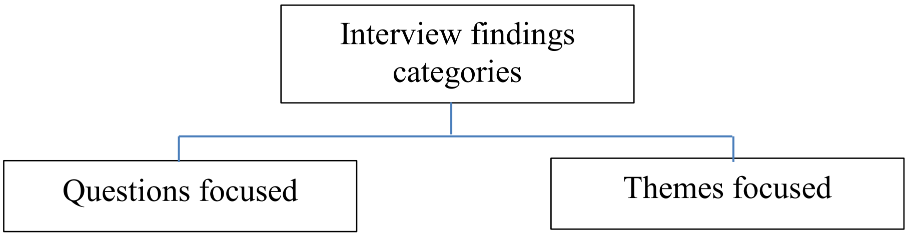


Figure 7.1: *Category of interview findings*

The interview findings based on the questions category

Question focused findings are centred on the responses to specific questions, while the theme focused findings are centred on systematic comparability of common themes, words or phrases within a specified data content. The analysed interview data based on *questions* was used to address specific issues relating to healthcare refurbishment, flexibility, standardisation and BIM. These findings were used to refine a framework for designing a change-ready healthcare facility. Findings of each question with responses from all the interviewees were presented in Tables. Themes, categories and differences were identified.

7.2 THE ROLE OF BIM IN HEALTHCARE

Table 7.3: *Interview responses on the need for BIM in healthcare facility design*

QUESTION 1	INTERVIEWEE THEMES
What will be the need for BIM in healthcare?	1. Information, complexity and general use. 2. MEP Coordination for heavily services. 3. Coordination of information. 4. MEP Coordination , 5. Information management. 6. MEP information management. 7. Visualisation, lifecycle management. 8. Object information modelling and organisation. 9. MEP information management. 10. MEP information management.

Question 1: What will be the need for BIM in healthcare?

Sub-categories of responses

- Information management
- coordination
- MEP management
- Visualisation
- Cost reduction

Table 7.3 presents interview responses of the ten interviewees; the responses were sub-categorised into five groups. The sub categorises were further categorised into using BIM for *management* and *cost reduction*. The similarity between the sub-categories above is the use of information to achieve the benefits of BIM identified in Table 7.3; but sometime visualisation is required to illustrate the scope of work (information) within a BIM environment. For instance, the MEP clash detections, the construction schedule or the outcome of any applied changes could be presented in a virtual environment through views or walk through simulations. The difference between the two categories is the output of the information being produced; this could be figures, patterns, assembling of objects or construction schedule simulation. The most important category is the MEP information management category which is key to detecting clashes and providing the required space for MEP services. BIM has no specific or special application that is unique to healthcare in the opinion of the interviewees. The application of BIM is universal to other sectors in the AEC industry. Perhaps the main application of BIM in healthcare is strongly related to the coordination and management of MEP services due to the 24 hour round the clock services of most healthcare buildings.

This research can conclude that there is no specific application of BIM in healthcare compared to the other buildings sectors such as institutional, commercial and industrial. Nevertheless, healthcare buildings can benefit more due to their complexity, volume and daily services. There is £30 Billion gap that needs to be saved by the NHS in the near future. BBC (2013) stated that "*in a report, NHS England warns that by 2020-21 the gap between the budget and rising costs could reach £30bn*". The noteworthy finding is that MEP services are one of the key elements that makes healthcare buildings complex. Most healthcare buildings are heavily serviced. With the Government push to cut cost and attain cost efficiency, the application of BIM can help with cost reduction. The use of flexibility can also help cut costs by adapting to changes in healthcare facilities and the utilisation of underutilised spaces. Findings show that BIM aids in designing multiple design options. For example, it was found from the interviews conducted that using Revit Architecture, the use of *OPTIONS* allows the use of a single option to be developed into different multiple design options. While the use of *WORKSET* can be used to control the editing of models by different stakeholders while project collaboration takes places. *ASITE* allows information exchange for stakeholders within a given project. This research further looks at the key performance indicators for each flexible design option to develop a decision making parameters that would help stakeholders make informed decisions when choosing a suitable option within the different generated designs. When generating a flexible design option, MEP services should be carefully designed and analysed, the spaces allocated for MEP are technically sensitive and could highly increase the cost of any design option. These spaces can allow increased flexibility when expanding or converting a building.

7.2.1 PROJECT DELIVERY METHODS THAT ALLOW MORE COLLABORATIVE BIM

Table 7.4: *Interview responses on the best project delivery method that allows more collaborative BIM*

QUESTION 2	INTERVIEWEE THEMES
Which project delivery method allows more collaborative BIM?	1. Cross overs. 2. D&B. 3. D&B. 4. D&B. 5. IPD and D&B. 6. IPD. 7. BIM execution plan / IPD. 8. IPD. 9. D&B. 10. D&B.

Question 2: Which project delivery method allows more collaborative BIM?

Sub-categories of responses

- D&B/IPD
- Cross over
- Use of BIM execution plan

Most of the interviewees listed in Table 7.4 were of the view that D&B is the project delivery method that allows more collaborative BIM. Design and Build (D&B) approach is related to the Integrated Project Delivery (IPD) approach; they both encourage collaboration between the designer and contractor at the early design stages. A BIM implementation plan can be used within any project delivery method, but should be more effective with D&B or IPD project delivery method. Interviewee AF-2 stated that

> "*it's always better to work hand in hand with the design and construction team from inception to completion, this way any uncertainties within the project can easily be detected and sorted, while in other methods this detection may be detected and sorted at a later stage*".

Interviewee AF-3 argue that the type of project delivery chosen does not really matter; it is important to understand that whatever method of project delivery chosen, the stakeholders involved have to be organised. Interviewee AF-7 stated that

> "*The biggest issue with traditional contracting is you expect the contractor to be at the same position with the design team when the design team has been on it for over 2 years, and therefore are meant to take all the cost and the risk; so with a contractor on board at the early project stages, the contractor has an opportunity to have a greater understanding of the dynamics of the project. The reason why certain design decisions are made bad is because the contractor always comes to the table with pre-conceived ideas making it more expensive than it needs to be*".

These findings illustrate the importance of collaborative BIM at the early design stages. Most projects leave out the contractor during the design stages (traditional methods). Perhaps collaborative project delivery methods should be appreciated by stakeholders to achieve more quality in projects through the process of making informed decisions throughout the life cycle of a building.

7.2.2 WHICH PROJECT DELIVERY METHOD FACILITATES THE ABILITY TO EMBED FLEXIBILITY?

Table 7.5: *Interview responses on the best project delivery method for embedding flexibility*

QUESTION 3	INTERVIEW THEMES
Which project delivery method facilitates the ability to embed flexibility with BIM more?	1. Difficult to say. 2. D&B. 3. Depends on nature of flexibility type in context. 4. Overlapping of different functions. 5. Brief driven. 6. – 7. – 8. Client agenda. 9. – 10. –

Interview participants from firms with code prefixes AF- 6, AF-7, AF-9 and AF-10 did not respond to this question.

Question 3: Which project delivery method facilitates the ability to embed flexibility with BIM more?

Sub-categories of responses

- Design and Build project delivery method
- overlapping
- brief/client
- depends on the nature of flexibility

Table 7.5 show the interviewee responses which were sub-categorised into four groups. The effective method of embedding flexibility will depend on the nature of the proposed flexibility and Client Brief. D&B project delivery is believed to be effective for collaborative BIM in the opinion of the interviewees. The application of collaborative BIM could help facilitate the process of embedding flexibility. Designers and contractors could work together to analyse the different flexible design options produced by the designers. The advantages of D&B project delivery method when embedding flexibility includes the ability to facilitate collaborative BIM to assess possible constraints within the generated design options. The disadvantages include the complications that come along with organising complex information within the BIM environment. Interoperability is one of the major problems associated with collaborative BIM. Organising the exchanged information from the different stakeholders involved could be a hurdle when dealing with a complex project. It is quite difficult to specify which project delivery will be most effective for embedding flexibility; the type of flexibility embedded could significantly define the project delivery method, but in most cases, flexibility is client driven as it is expected to cost more money to achieve flexible outcomes that could reduce the operational cost of a healthcare facility.

7.2.3 CORE BIM ACTIVITIES TO EMBED FLEXIBILITY

Table 7.6: *Interview responses on the core BIM requirements for achieving a flexible design*

QUESTION 4	INTERVIEW THEMES
What are the core BIM requirements for achieving a flexible design?	1. Understanding the brief and cost. 2. Cost and joint decisions. 3. Modelling and managing information from model. 4. What if scenarios. 5. Organising information for flexible options. 6. Early integration and multiple scenarios. 7. Managing flexibility information. 8. Visualisation and information coordination. 9. Different scenarios and early collaboration. 10. What if scenarios.

Question 4: What are the core BIM requirements for achieving a flexible design?

Sub-categories of responses

- Designing what if scenarios
- Visualisation
- early collaboration/collaborative decision making
- Information management

Table 7.6 show the interview responses that were sub-categorised into four groups. Two categories were derived from the four sub-categories identified above. The first been the process of *generating* a product (flexible design) and the second as *analysing* the product by visualising and managing it`s information. BIM can be used to generate *what if scenarios* using scenario planning schemes, but before the designing process begins, the brief has to be clearly understood by the designer to be able to define the BIM and flexibility requirements for achieving desired project outcomes. The cost involved in embedding flexibility has to be given high priority during the design process. Cost is a major barrier when designing any facility, the project budget has to be justified, and autonomously defining the proposed design features. As a result, the application of BIM can be used to estimate the cost involved in generating each flexible design option and presenting its benefits to clients. Interviewee AF-10 stated that

> "*I cannot speak for all BIM platforms, but within Revit there is a feature called Design Options which allows you to model a building in a particular way that you can save as one particular design option and redesign another option from the same option to model and save it as a second design option; you will be able to flick through them quite easily and quickly*".

Scheduled information relating to project time-frame, cost and amount of materials required for each option are considered when analysing these options. AF-2; AF-5; and AF-7 have mentioned that different professionals are required to conduct different analysis in order to analyse different design options. But while using BIM, there is a problem of information exchange which could be resolved with the use of a well organised BIM protocol or the use of some BIM tool features. It was stated by interviewee AF-1that

> "*Work set in Revit allows ownership; you can clearly see who owns what and who has made any adjustments; this is just to inform colleagues who have got what? And who's editing what? And how that impacts what you are doing; other colleagues would not be able to edit while someone else is working on the model, for instances if someone got the internal partitions, others cannot edit the partitions while someone else is working on it*".

There are different features within the applications of BIM that can facilitate the application of flexibility in any of the AEC sectors. They are different tools that offer different capabilities and most important of all the ability to collaborate can be define as one of the most important feature of BIM.

7.2.4 WHAT ARE POSSIBLE RISK AND UNCERTAINTIES WHEN DESIGNING FLEXIBLE SPACES WITH BIM?

Table 7.7: *Interview responses on possible risk and uncertainties when design with BIM*

QUESTION 5	INTERVIEW THEMES
What are possible risk and uncertainties when designing with BIM?	1. Information sharing. 2. Overlapping BIM protocol. 3. Information management. 4. Early detailed information. 5. Detail information. 6. Information exchange. 7. Organising information. 8. Organising information. 9. Early information and information sharing. 10. -

Interview participant from firm with code prefix AF-10 did not respond to this question.

Question 5: What are possible risk and uncertainties when designing with BIM?

Sub-categories of responses

- Provision of early information
- Detailed information
- Information management
- Overlapping BIM protocol with different stakeholders

Interview responses identified in Table 7.7 were categorised into four groups; they were further sub-categorised into two groups. The first category is the *providing information category* and the second is the *collecting information category*. The similarity between the categories provided is that they are related to issues of information provision, storing, exchange, information detailing and organisation. This is also described as the *information category*. The *collection information category* explores the problem that comes along with BIM implementation. Sometime sub-contractors have their own company or organisational BIM protocol to conduct their various construction services; this causes a major problem. Interviewee AF-2 stated that

> "*There was this project we had in Kent, the MEP contractor produced a BIM model for the building and produces a services BIM model for that, which he can download and send it off to some manufacturers in the factory. So the contractor*

> *is using that in the bottom trying to drive it up, while we the architects are in the middle trying to drive it up and down*".

When the contractor has his own model, and the designers have their own separate model; there is a risk that every consultant might produce separate BIM models, increasing modelling tasks and hindering collaboration.

7.3 EMBEDDING FLEXIBILITY WITH STANDARDS

Embedding flexibility can make healthcare facilities adaptable to future changes, but there is a need to specify some details that would make the design reusable and ease the construction process. To embed flexibility with standards, a design strategy has to be put in place to identify the requirements that could simplify the process.

7.3.1 REQUIREMENT FOR ACHIEVING STANDARDS WHEN EMBEDDING FLEXIBILITY

Table 7.8: *Interview responses on the requirement for achieving standards when embedding flexibility*

QUESTION 6	INTERVIEW THEMES
What are core requirements for achieving standards when embedding flexibility?	1. I Information source. 2. Use ADB & possibly customise. 3. Brief. 4. Spec for user satisfaction. 5. Use brief and customise. 6. Use appropriate information. 7. ADB and right standard. 8. Identify functional spaces, quantity and dimension. 9. Identify information required and customise where possible. 10. Group related standards.

Question 6: What are core requirements for achieving standards when embedding flexibility?

Sub-categories of responses

- Information source / groups / required
- Use design brief / ADB
- Identify function spaces and specifications
- Customisation of standards where required

The interview responses identified in Table 7.8 were categorised into three groups. Information is the central feature associated with achieving standardisation when embedding flexibility. For that reason, these sub-categories were further categorised into three*: information from consultants; information from users;* and *information from healthcare bodies*. Information from all the three categories has to be merged together to develop a standardised and flexible space design. Information from the users and healthcare bodies can help develop the Design Brief with feedbacks and healthcare standards. While information from consultants can be used to further develop the Design Brief into a more effective and efficient design proposal. Interviewee AF-5 stated that

> "*It is important to identify the key factors that need to be flexible, such as spaces, equipment and flow; the standard specifications attached to these key issues could help shape the Design Brief*".

The source of standards can determine its quality; but the availability of numerous standards can complicate the standard selection process and lead to ineffective designs. AF-7; AF-3; and AF-8 interviewees agreed that if specifications are inappropriate, they can be customised to achieve desired goals. Therefore, the appropriate and best standard should be chosen for the design development.

7.3.2 WHO MANAGES THE FLEXIBLE DESIGN WITH BIM?

Table 7.9: *Interview responses on the consultant that manages the flexible design with BIM strategy in a healthcare project*

QUESTION 7	INTERVIEW THEMES
Who manages the flexible design with BIM strategy in healthcare project?	1. Designer, client and contractor. 2. Designer. 3. Contractor. 4. Designer and contractor. 5. Designer. 6. Designer. 7. Designer. 8. Designer. 9. Designer and contractor. 10. Designer.

Question 7: Who manages the flexible design with BIM strategy in healthcare project?

Sub-categories of responses

- Designer/contractor
- Designer/client
- Designer

Interview responses identified in Table 7.9 were categorised into three groups. The designer seems to be the dominant professional agreed to manage the flexibility strategy in a healthcare project in the opinion of the interviewees. But in some cases the contractor is involved in managing the flexible design. In a D&B or IPD projects, collaboration takes place at the early design stages to make informed decisions on further development of a project. Managing the flexibility strategy involves understanding the brief, designing different flexible scenarios and the analysis and selection of the preferable and most suitable flexible design option that is cost effective and cost efficient.

7.4 CORE REQUIREMENTS FOR ACHIEVING QUALITY REFURBISHMENT

Table 7.10: *Interview responses on the core requirement for achieving quality refurbishment when embedding flexibility*

QUESTION 8	INTERVIEW THEMES
What are the core requirements for achieving quality refurbishment when embedding flexibility?	1. Blending function and other features. 2. Decision making. 3. Identify constraints, cost analysis and functionality. 4. Integrating functions. 5. Balance the proposed and existing. 6. Manage the product and process. 7. Ability to switch flexibility on/off. 8. - 9. Manage the process. 10. Avoid disruptions.

Interview participant from firms with code prefix AF-8 did not respond to this question.

Question 8: What are the core requirements for achieving quality refurbishment when embedding flexibility?

Sub-categories of responses

- Blending and balancing new/old building functions
- Making informed decision with cost/other constraints
- Avoid disruption
- Managing the refurbishment process effectively

All the factors identified in the sub-categories in Table 7.10 are drivers for achieving quality refurbishment. They guide the process of conducting refurbishment. Budget is the most important factor to consider when designing for more flexibility within an existing building; while the clients are always concerned with what they can afford to build. Disruptions are also one of the major barriers to refurbishment; they can easily be identified as possible constraint. As a result, refurbishment budgets and possible disruptions are key factors to consider when improving project quality and value. The sub-categories can be grouped under *management*. Three interviewees AF-2; AF-6; and AF-4 are of the view that it is important to blend, integrate and balance the proposed features with the existing features of the facility; these could be spaces, capacity, functions or flow. The constraints that could cause delays and disruptions can be avoided by managing the entire process adequately. The ability to switch the flexibility on and off when required should not be affected by the features of the existing or new facility. This study can conclude that it is important to clearly identify the existing and proposed features of a facility. Both features need to overlapped, overlay or coincides with each other to enable good flow of functions within a proposed design.

7.4.1 TOP THREE CONSIDERATIONS FOR HEALTHCARE REFURBISHMENT

Table 7.11: *Interview responses on the top three considerations for healthcare refurbishment*

QUESTION 9	INTERVIEW THEMES
What are the top three considerations for healthcare refurbishment?	1. Decision making and disruption. 2. Constraints and decision making. 3. Cost, disruption and standards. 4. Interrupting services and cost. 5. Waste management and decision making. 6. Existing information, disruption and asbestos. 7. Cost budget, nature of brief and existing functions. 8. Building type, existing fabric, technical and operational constraints and budget. 9. Asbestos, budget, and identifying constraints. 10. Cost, condition of existing structure and decision making.

Question 9: What are the top three considerations for healthcare refurbishment?

Sub-categories of responses

- Budget cost
- Decision making
- Constraints/disruption/condition of existing structure/waste management

Interview responses identified in Table 7.11 were categorised into three groups. Decision making and cost are highly related to each other; there are both drivers of refurbishment, while the constraints are categorised into the barriers of refurbishment. The constraints raised by the interview respondents include the problem of asbestos within existing buildings, waste management, site limitations, existing spaces and the problems associated with project budgets. These can all hinder healthcare refurbishment processes and eventually affect the quality of a refurbished facility.

7.4.2 MANAGING CONSTRAINTS OF REFURBISHMENT (FUNCTIONS, SPACE AND FLOW)

Table 7.12: *Interview responses on managing constraints of existing factors such as functions, spaces and flow*

QUESTION 10	INTERVIEW THEMES
How do you manage constraints of existing factors such as functions, spaces and flow?	1. Depends on problem nature. 2. Like any other constraints. 3. Depends on context. 4. Creating proper circulation. 5. Using way finding. 6. Connection spaces. 7. Integrating new and existing features for refurbishment. 8. Circulation spaces. 9. Connecting spaces/functions. 10. Overlapping constraints.

Question 10: How do you manage constraints of existing factors such as functions, spaces and flow?

Sub-categories of responses

- Connection/integration
- Way finding/circulation
- Overlapping functions

The interview responses identified in Table 7.12 were categorised into three groups; there are methods of merging functions, spaces and flow together; they are interrelated and will all allow the existing building to flourish into the new building. The sub-categories are centred on *integration*; the existing factors such as function, spaces and flow can be integrated by overlapping each other through proper circulation and effective way-finding. Interviewee AF-2 stated that *"the constraints of existing buildings are like any other problems related to design and construction such as budgets and site limitations*". The nature of the existing function, space and flow has to be considered when integrating the proposed new features to the existing facility.

Interview findings based on themes

Table 7.13:

Table 7.13: *Breakdown of the second Category of the interview analysis focused on themes*

FRAMEWORK COMPONENTS	PRINCIPAL ISSUES	KEY THEMES	SUB- THEMES
Refurbishment	Cost effective and cost efficient refurbishment	1. Project procurement method 2. Constraints 3. Best practices	Traditional procurement process is common. Effective management process. Use of existing information.
Standardisation **Flexibility**	Combine application of: flexibility; and Standardisation	1. Standardising process 2. flexibility processes 3. combine application of standardisation and flexibility	Flexibility is expensive. Use of common spaces with different functions. No specific ratio of combining flexibility and standardisation. Some flexibility features can be standardised
BIM	Applying BIM	1. BIM implementation process: • Drivers; and • Barriers. 2. BIM maturity level: • level one; • level two; and • level three	No specific application of BIM to healthcare. BIM use for more collaboration and virtual analysis. Information exchange challenges associated with BIM. 2D and 3D use. Linking real live data to BIM model.

7.5 THE COST EFFECTIVE AND COST EFFICIENT REFURBISHMENT

Cost is attributed to all the framework components identified in Table 7.13; cost is also one of the main drivers for any refurbishment project, but it is important to refurbish buildings at a reasonable cost and achieve the desired project quality through a cost effective and cost efficient refurbishment process. Interviewee AF-1 stated that "*It is* *important that buildings adapt to future changes, but it is also important to understand that flexibility cost money; the more the flexibility, the more the cost. Therefore, more value for money is required from healthcare designers and planners"*. Perhaps to design a cost effective and cost efficient healthcare facility, an innovative approach is required by all stakeholders involve to collaborate and make informed decisions that will improve the process of designing healthcare facilities.

7.5.1 PROJECT DELIVERY METHOD

The traditional delivery method is the most common procurement method in the opinion of some interviewees. They stated that the project delivery method depends on the Client Brief and the type of project. Bowen *et al*. (1999, p. 92) stated that the "*selection of an appropriate building procurement system are intrinsically important to the attainment of the client objectives*". Cartildge (2004) also stated that the procurement process could affect the quality of the project. A good question is why did most of the interviewees opt for the traditional delivery method? And what is the traditional project delivery method? Dykstra (2011, p. 75) stated that a traditional project delivery method is an approach that introduces the general contractor after the completion of the design; it is suitable for the following:

- small projects such as a private houses;
- standard buildings that are built the same way such as McDonalds;
- projects with limited budgets; and
- public jobs that require competitive bidding.

The traditional project delivery has two contracts, one with the architect and the other with the contractor. Dykstra (2011) further stated that projects with a tight time-frame do not normally opt for the traditional delivery method because of three reasons:

- lack of the contractors expertise at the early design stages could lead to re-designing some aspects of the design;
- Incomplete drawings or detailed information from the architect could allow the contractor to increase the time-frame; and

- the architect always oversees the contractor`s work; this could create a tension between the architect and the contractor which could also affect the outcome of the project.

Despite the problems associated with the traditional project delivery method, it is the most common procurement approach towards refurbishing buildings in the opinion of most of the interviewees. Perhaps it is frequently used in healthcare refurbishment projects as the UK NHS are considering lowest tender, competitive bidding and demand more value for money due to the tight budgets available for their projects.

7.5.2 CONSTRAINTS

There are different constraints affecting the functional flow of healthcare refurbishment processes; all possible constraints should be identified at the early design stages to guide and enable designers and healthcare planners to make informed decisions when refurbishing existing buildings. There are various factors affecting a cost effective and cost efficient refurbishment project; the interview findings showed two type of constraints which are categorised into the *organisational* and *technical* category.

Organisational constraints

These are factors involving the management personnel making decisions on behalf of the entire project team, to set regulations to managers for organisational performance in order to achieve desired standards and code of practice. The organisational system could be affected by change, which is one of the key drivers for this research. Interviewee AF-4 stated that "*Cost is the main challenge of our organisation, to produce quality healthcare refurbishments within budgets. The need to apply BIM in our projects is also a cost issue rather than a technical issue; there is a need to train staff, purchase software and also bring in a BIM manager into the project*". Interviewee AF-3 was of the view that "*change is one of the challenges of our company, we need to adapt to all these changes such as the need for the application of BIM and the changing needs of healthcare buildings; these changes leads to higher budgets*". The two interviewees agreed that cost is one of the main factors affecting the organisational constraints, but interviewee AF-3 was on the view that change leads to budget increments. Decision making and the type of policies described by company management can promote the quality of projects.

Technical constraints

Technical activities support the process of healthcare refurbishment projects, but they could also affect the time and cost scheduled for the completion of a project. Technical barriers are one of the most common constraints involving practical undertakings and use of standards within a refurbishment. The structural work within a construction process comes along with lots of difficulties such as possible disruptions, noise disturbance, lack of proper public access, inadequate waste control, site limitations, space restrictions and environmental conditions when existing spaces are fully operational. Interviewee AF-8 stated that "*many technical constraints exists that can obstruct, hinder or delay the refurbishment process, it is vital to understand that time is money, the more the delays and obstructions the more the cost to complete the project*". Interviewee AF-5 argued that "*I believe that some constraints force consultants to be more creative in solving their project tasks rather than affecting their ability to produce quality project outcomes*". The aim of this research is to produce a framework that can guide the process of designing a change-ready healthcare facility that is cost effective and cost efficient. Therefore, it is important to identify all possible constraints at the early design stages to enable designers and healthcare planners to make informed decisions. The technical constraints should also be documented so that the solutions can be re-used when required to achieve optimum project outcomes.

7.5.3 BEST PRACTICES

These are guides that unfailingly support decision making and the process of achieving desired project outcomes through strategic use of methods/techniques/tools or any other suitable resources. It also simplifies the ability to achieve desired project outcomes by providing processes that can be further developed and applied in various contexts. Interviewee AF-1 stated that "*to reduce the cost of refurbishment and get more value for money, the entire refurbishment process has to be managed in such a way that cost reduction is the key concern*". To cut the cost of healthcare refurbishment, interviewee AF-3 stated that "*the use of evidence based design should be encouraged in refurbishing* *healthcare facilities by using ADB standards to design"*. Standardisation helps in cutting the cost of buildings by re-using design layout, dimensions and model objects. Besides reducing the cost of healthcare refurbishments, it is important to keep value for money in mind. Therefore, during any healthcare expansions, contractions, conversions, or structural alterations; many factors comes to into focus, such as health and safety, waste control, recycling and the circulation of the occupants while the facility is partially or fully operational. Apart from cost reduction issues, there is also a need to improve quality during healthcare refurbishment. It is essential to collect existing stored information to analyse existing features and propose new improvement. The refurbishment information should also be stored for future development. It is fundamental to plan for reuse and recycling of building elements during refurbishments to cut costs and manage the waste generated. Interviewee AF-8 stated that a good practice is the "*optimum utilisation of current/existing/available spaces and resources that will enable healthcare planners and designers to provide efficient refurbishment"*. When existing spaces are fully utilised, the new proposed space functions can clearly respond to the new challenges of healthcare refurbishment. Utilising existing space functions helps in excluding the possibility of attaching a similar function to existing spaces. Therefore, for a strategic distribution of functions to specific spaces, the existing space functions have to be entirely explored at the early design stages. Table 7.14 presents findings from the interview participants.

One of the important lessons learnt from the interview findings is that all possible constraints should be identified at the early design stages to enable designers and planners to make inform decisions in all refurbishment project phases. To achieve cost reduction and value for money, good practices should be put to use. Another proposed method of cutting cost for the purposes of this research is the combined application of space flexibility and space standardisation which is discussed below.

Table 7.14: *Cost effective and cost efficient refurbishment*

Cost effective and cost efficient refurbishment		AF-1	AF-2	AF-3	AF-4	AF-5	AF-6	AF-7	AF-8	AF-9	AF-10
Project delivery method		Bottom –up.	Traditional method.	Traditional method.	Depends on the client brief.	-	Traditional method.	Traditional method.	Depends on the type of project.	Traditional method.	-
constraint	**organisational**	Lack of required skilled workers. Cost.	Inadequate project planning. Cost.	Poor communication between the designer and contractor.	Need for effective roles, polices, procedures and standards.	Financial capability to allocated funds for implementing various standards.		Organisational change. Decision making. Budget.	Budget.	Budget.	-
	Technical	Site and space restrictions.	Project team communication and time planning. Space limitation.	Existing occupants causing interruptions. Tasks inspections.	Environmental conditions. Task sequence, completing a task before going to the next.	Lack of public access can cause difficulties during refurbishment.	Lack of relevant or appropriate information. Size and scale of a project.	Blending existing features with the proposed.	Disruption due to lack of circulation or way finding.	Noise and dust could cause disruption. Complex shapes. Location and time of conducting project.	Cost, location, size and type of project in context.
Best practice		Quality refurbishment requires managing the product and the process. Collective involvement of stakeholders.	The complete information of the existing structure should be collected and analysed. All projects should store existing information for achieving excellence in future refurbishment.	Evidence based research should be encouraged in refurbishing healthcare facilities by using ADB standards. Identifying an organisation framework for refurbishment.	Safety is one the most vital considerations for any healthcare refurbishment process. Identify any structural considerations.	The facility`s operational history records should be analysed and evaluated for cost reduction.	Plan to reuse and recycle any reusable building element. Use of connecting corridors for facility expansions.	Refurbishing buildings to specification can save cost. Good leadership. Identify constraints of existing function, flow and space.	Generally refurbishment generates a lot of waste. Waste management can cut budgets. Integrate user feedback into the refurbishment process.	For quality refurbishment; time, cost, health and safety checks should be given high priority. Attach high priority to way finding and circulation when designing for refurbishments.	Controlling or managing constraints can lead to cost control.

7.6 INTEGRATING FLEXIBILITY AND STANDARDISATION PROCESSES

Standardisation and flexibility processes support the designs of healthcare facilities. They can also influence the process of cost reduction and cost efficiency in healthcare refurbishment. The combined applications of standardisation and flexibility can improve the design of a change-ready healthcare facility and reduce the cost of its refurbishment through the use of a standard design process (design re-use) and the use of universal healthcare spaces using generic space features such as space layout, dimension, door and window openings, door and window sizes and so on.

7.6.1 STANDARDISATION PROCESS

The application of standardisation in healthcare is getting more acknowledgements for improving healthcare design, construction and delivery (Hignet and Lu, 2008; and Joint Commission Resources 2004). A standardised process is the progression of developing and using procedures and products that can bench mark the level of quality required from designers and healthcare planners to improve efficiency, effectiveness and the performance of healthcare spaces. Standardisation in healthcare can be a gauge, average, mean, benchmark, quantity or quality required by healthcare governing bodies such as the NHS in the UK. Some average users can use standards as solutions to some design problems. Interviewee AF-9 stated that *"there is a need for standardisation in the healthcare sector due to the immediate need for cost reduction proposed by the UK Government; but there is a need to provide updates for existing standards to improve the quality of care"*. Findings of the interviews show that the process of applying standards involves use of reliable source of information, selecting appropriate specification from bunch of available standards, categorising relevant information, reviewing existing information for possible updates and adopting specifications that would easily adapt to the proposed business case of the project in context. Interviewee AF-1 suggested that

> "S*tandards from Government bodies or private healthcare advocates provide specifications that are used as guides, but they need frequent updating. With the current BIM trend, HTN guidelines can be copied and pasted, monitored and manage within a BIM platform to improve the use of standards in the healthcare sector".*

Interviewee AF-8 stated that

> "*The information required for linking real live information to the BIM model for life cycle analysis should be identified and updated; I think this will support the modelling process and produce accurate estimates".*

With accurate information provided for modelling; cost estimates for managing a building over a short-term or long-term can be extracted from a BIM model. There is always a major concern of outdated standards due to the changes in space requirement, development of new standards, emergence of new technologies, adapting to modern designs/aesthetics, managing a growing and aging population, Government policies and so on. Standards should not be too rigid, they should be flexible to adapt to different or a number of contexts. A standard that addresses the socio-cultural values envisioning future policies and user requirements would enable the development of healthcare facilities. It is vital to always lookout for updates when designing new or refurbishing existing healthcare facilities to improve their current situation. There is a need to use standards during the design, construction and operation of healthcare facilities to achieve a systemic interoperability that could ease the application of flexibility.

7.6.2 FLEXIBILITY PROCESS

Flexibility is required to cut the cost of designing, refurbishing or managing healthcare facilities. The use of multi-functional spaces for multi-use can help solve the problem that comes along with a rapid changing healthcare facility. The design of a facility cannot be separated from its operations. Flexibility has to be embedded into the design of a facility at the early stages to flourish into its operations. Flexibility in healthcare will see buildings expand to suit users' needs and then contract back to their original capacity. For example, single bed units can be changed into multiple bed units; and offices converted into consulting units with the application of universal space designs and open space planning. Flexibility can increase the life span of a facility by decreasing the running cost and adapting to changes. But interviewee AF-6 argued that "*even if you* *make your structure flexible you still can't guarantee flexibility, to make buildings truly flexible in the future is expensive; nine out of 10 you won't use it*". Cost is a major driver associated with flexibility, there could be a risk that the embedded flexible might not be *switched on*; flexibility in this case can be seen as an *insurance strategy*, that is effective only when it is required. There are short-term flexibilities that are widely used, such as the use of flexible furniture or equipment within an open space. Interviewee AF-1 stated that

> "*Flexibility cost money; some things will be flexible. For example, some places can be flexible that they can be used as bedrooms in the future; but generally if you are saying you want to be flexible, you are increasing the floor area of the building or the height or increasing the span and poles. So flexibility becomes difficult if you are on a tight budget*".

The process of adapting to future changes is a key driver that could increase the operational running cost of healthcare facilities, as the facility management team tries to adapt to uncertain changes, the cost increases. Over the years, the UK Government has been frequently cutting down budgets within the different industry sectors that includes healthcare; the capital funding of the UK NHS has been on a very tight budget over the years. There is a need for flexible approaches in the design of healthcare facilities. All stakeholders involved need to come up with adaptable features and strategies that could improve healthcare facility to be change-ready when systematically designed. The lesson learnt regarding the application of flexibility is that, it is client driven, as the client always signs off to allow the project to progress, and when designing for flexibility, the client has to be specific on the flexibility required.

7.6.3 THE COMBINED APPLICATIONS OF FLEXIBILITY AND STANDARDISATION PROCESSES

Standardising the flexible parts that make the whole flexible space can be a simple process. Sometime complete facility flexibility may not be required. Allison and Battisto (2002) categorised flexible spaces into three. Each category has a different amount of standardisation. A flexible space that has standardised dimensions, equipment, staffing, and a diversity of patient conditions aiming at improving healthcare facilities can be a space that is standardised and flexible. With standardised flexible designs, the decision makers can have ease in assessing the cost of projects at the early design stages. The use of standards in healthcare simplifies the planning and procurement of constructing healthcare facilities through the use of standardised grids patterns. Perhaps a standardised flexible plan can lower the construction cost and cut the design fees through design re-use; waiving the process of re-designing; eliminating the cost of redesign within a project. It was stated by interviewee (AF-3) that

> "*The first step towards producing a standardised process is to draw up a process flow map which shows what needs to be done from one step to the next, this way everyone understand what is expected from the process; it will be easy to come up with any sort of development that will see the standardisation process advances and improves".*

To combine flexibility and standardisation, a specific modification process can help the combination. Customisation would be a clearer and simpler way to define the combined application of flexibility and standardisation. A standard design is altered to suit a specific context through the use of varied and alternative specifications to make designs more flexible. Ahmad *et al*. (2011) (appendix 1) agrees that there is no standardised ratio of combining flexibility and standardisation. As a result, different flexible components can be standardised at the early stages of combining flexible and standardisation. In the experience of more findings through further research, a ratio of what should and can be standardised for best practices could be identified to further improve the combination process. The interview findings further described the possible tensions that exist between space flexibility and space standardisation. Despite the advantages of space standardisation and space flexibility, they both have major differences and similarities. These could be found below in Table 7.15. Table 7.16 which show present responses of the interview participants.

Table 7.15: *Tension within the combined applications of flexibility and standardisation (interviewees: AF-1, AF-2, AF-5, and AF-8)*

Space flexibility	**Space standardisation**
Easily focused on context	Not always focused on context
Developed in isolation mostly (reductionism)	Developed in forums mostly (Holistic)
Easier to adapt to	Harder to adapt to
Flexibility is not free	Standards are a time free
Mostly applied before standardisation (absence of interoperability)	Always standardised before applied (presence of interoperability)
Focus on specific issues	Focus on general issues
Responds to changes	Repeatability
Adjust processes	Constant and regular

Table 7.16: *Integrating flexibility and standardisation*

Integrating flexibility and standardisation	**AF-1**	**AF-2**	**AF-3**	**AF-4**	**AF-5**	**AF-6**	**AF-7**	**AF-8**	**AF-9**	**AF-10**
Standardisation process	Identifying specifications required to support the business needs. HTN and guide lines can be copied and paste, monitored and manage with a BIM process.	Identifying the source of information. Identify information required for linking real live information to model for life cycle analysis.	Using the design brief for design specifications.	Identifying the right information to achieve user needs.	Categorising relevant data. Attaching specification to design components.	Identify source of information for product and processes.	Review standards for possible new updates.	Standards have to be organised for planning permission application.	Identify required BIM object with specifications for modelling different design options.	-
Flexible process	Flexibility is cost driven. Flexibility should be designed with cost in mind. Identify flexibility approaches. Identify possible future changes through scenario planning.	Advice client on facility life cycle management.	Define and identify flexibility requirements. Evaluate the input and output of the flexibility requirements.	Integrate user feedback into the design.	Advice client on benefits of flexibility. Agree on long-term, mid-term or short-term flexibility approaches Finalise assessment of the preferable flexible design option.	Estimate the cost of embedding flexibility.	Identify responsible flexible design team. Organise project information within the BIM model.	Identify key flexibility components.	In the conceptual stage short-term flexibility can be achieved by use of open planning, use of standard equipment and universal rooms. At the mid-term level interstitial floors and modular designs are used. Whilst long-term flexibility is achieved using open-ended corridors. Flexible foundations create space for expansion and zoning.	-
Combine application of flexibility and standardisation process	-	Provide flexible spaces that are standardised.	Standardising columns, beams, windows, doors, furniture, grids. Integrate components (prefabrication) spaces involved in designing flexible spaces.	Standardising elements or components of the flexible designs.	Standardising parts or entire designs.	This involves the use of modular grids, sizes and components.	Attaching standards to proposed flexible spaces.	Combining the standardised parts into a single element. For example, a room	Flexibility and standardisation both tend to reduce cost and maintenance effort to improve quality. Standardised components can be flexible by been interchangeable.	When combining flexibility and standardisation it is important to consider standards` characteristics such as the degree of specificity and simplicity

7.6.4 APPLYING BIM PROCESS

BIM use is undoubtedly growing and important in the AEC industry; its application has lots of challenges which could hinder its use. The use of BIM for the purpose of this research focuses on the design of flexible healthcare spaces during healthcare refurbishments. BIM in this context is important for coordinating the information used for the flexible design components to be standardised and evaluated for different design options to be generated using BIM. The application of BIM for the purposes of this research focuses on BIM implementation and the BIM maturity levels addressed by the UK Government construction strategy.

7.6.4.1 BIM implementation

The implementation of BIM in an organisation, office, team or project is required before achieving its benefits. There are drivers that inspire the use of BIM; most of these drivers are the benefits that BIM implementation comes along with. In spite of the benefits of BIM, it is associated with challenges which could delay, hamper and disrupt the use of BIM in the entire AEC industry. The drivers and challenges of BIM are discussed below.

Drivers

The most important consideration for using BIM in this research was to reduce the cost of designing and running healthcare buildings with the combined applications of flexibility and standardisation. Some of the information associated with a standardised flexible design can be stored as an object that can easily be re-used; cutting the cost of redesigning healthcare spaces. Another main driver of BIM is that the user gets to define his/her personal BIM goals when implementing BIM. This depends on the capabilities of different BIM tools and the experience of the users. The users of BIM have to differentiate between BIM reality and BIM fantasy. Interviewee (AF-7) stated that "*you need to illustrate what BIM can do for you and what it is already doing. BIM can illustrate the consequences of each decision you make, the appearance, the changes and the final product expected at the end of the day*". BIM simplifies the tasks conducted by architects, quantity surveyors, MEP consultants, and structural engineers through automation. Other benefits of BIM will be discussed below in the BIM maturity levels developed by the UK construction strategy approach which clearly defined the levels and benefits of BIM at each stage.

Challenges

The main challenges of implementing BIM addressed by some of the interviewees are the economical, technical, and operational barriers. The economic challenges revolves around cost or budgets. BIM is associated with training staff, purchasing hardware and software, recruiting a BIM manager and so on. Firms within the AEC industry can develop business cases with the implementation of BIM; this could be for cost reductions or the initiative to secure more projects due to their BIM capability. The technical challenges include the complex problem of interoperability which can impede the ability to exchange information when using different BIM software. The operational barriers are mostly the problems that come along with all stakeholders involved when collaborating; this could be during the design, construction or facility management phases to reduce errors and allow the design to flourish in a 3D environment. Other challenges of BIM include people problem, technical issues and the ability for organisations to accept change.

7.6.4.2 BIM maturity levels

BIM maturity levels were clearly described in the UK Government Construction Strategy report that was published in 2011; four different levels have been identified, starting from level zero to level three, but for the purpose of this research, three levels were identified; that is level one to level three. Level zero was not used in this research as the interviewees did not focus on it. The BIM maturity levels are presented as they can be used to facilitate BIM implementation within an organisation. The UK BIM mandate in 2016 requires level 2 BIM implementation on certain projects (UK Construction Strategy 2011; PAS 1192). The four UK Government maturity levels are described by the UK Construction Strategy Report (2011:96) in Figure 7.2.

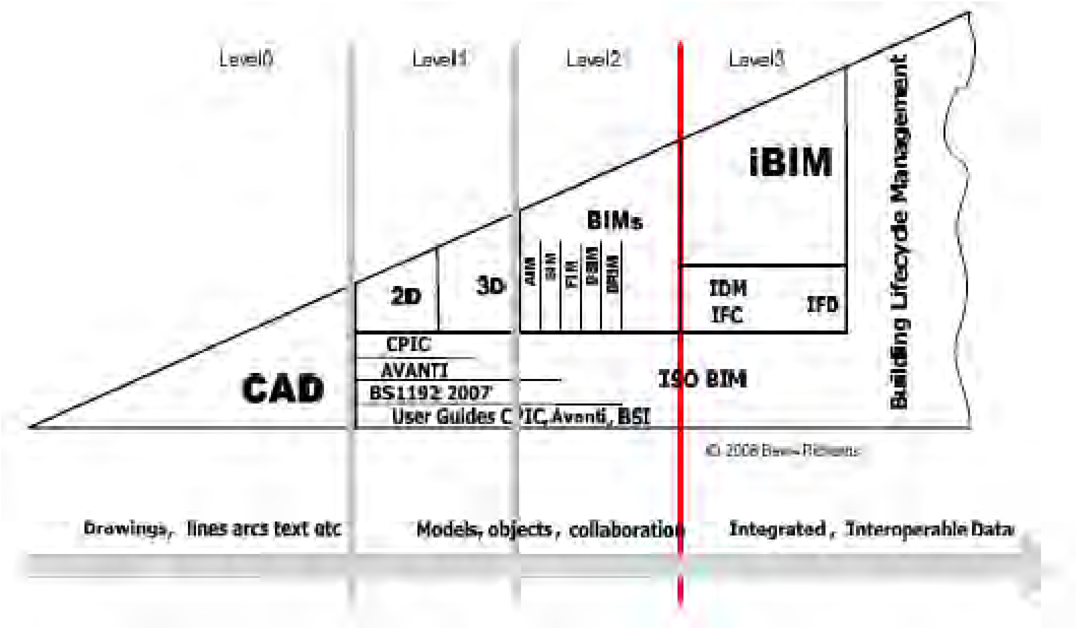


Figure 7.2: *UK Government BIM maturity levels. Source UK Construction Strategy Report (2011, p. 96)*

Level 1

The UK Construction Strategy, (2011, p. 16) defined level one BIM as "*managed CAD in 2 or 3D format using BS1192:2007 with a collaboration tool providing a common data environment, possibly some standard data structures and formats. Commercial data managed by standalone finance and cost management packages with no integration*". Some of the interviewee`s findings on BIM were grouped as level one BIM. These include the use of 2D and 3D applications, with the production of all documents in electronic data, and also informing clients the benefits and challenges of implementing BIM.

Level 2

The UK Construction Strategy (2011, p. 16) described the level two as a "*managed 3D environment held in separate discipline "BIM" tools with attached data. Commercial data managed by an ERP. Integration on the basis of proprietary interfaces or bespoke middleware could be regarded as "pBIM" (proprietary). The approach may utilise 4D programme data and 5D cost elements as well as feed operational systems*". The interview findings grouped as level two BIM were the process of recognising what and when to share, standardising the information exchange process, attaching detail information to the model at early project stages. The use of time and cost scheduling is another feature appreciated at level two BIM

Level 3

The UK Construction Strategy (2011, p. 17) described level three as a "*Fully open process and data integration enabled by "web services" compliant with the emerging IFC / IFD standards, managed by a collaborative model server. Could be regarded as iBIM or integrated BIM potentially employing concurrent engineering processes*". The interview findings categorised as level three BIM include, the linking of real live data to models for operational management analysis; promoting life cycle assessment. This process requires all stakeholders involved to collaborate using specified BIM protocols. Interviewee (AF-10) stated that the use of a web based service called *Asite* is used for storing and sharing project information with all associated stakeholders. The website was understood to be accessible to only project member. However, Level 3 is currently not applied in the AEC industry yet (interviews). Table 7.17 shows the responses for the interview participants.

Table 7.17: *The process of applying BIM*

APPLYING BIM		**AF-1**	**AF-2**	**AF-3**	**AF-4**	**AF-5**	**AF-6**	**AF-7**	**AF-8**	**AF-9**	**AF-10**
`	**Drivers**	Cost reduction. Automation. Information sharing, storing, analysing and evaluation.	3D visualisation allows decisions to be easily made. Cost reduction. Making joint decisions.	Information about existing materials can help reduce risk of asbestos.	BIM helps with editing, automating changes, exploration, visualisation and decision making analysis. Generating what if scenarios.	BIM implementation has both short-term and long-term goals. Organising information for generating flexible design options.	Early collaboration. The generation of multiple design options.	3D visualisation capability. Ability to managing information for designing flexible spaces.	Early collaboration within the project delivery approach.	Generating different flexible design options.	Information coordination. BIM is used for MEP coordination.
	Challenges	To apply BIM it has to be implemented first; Implementing means changing the traditional delivery approach.	Choosing/developing a BIM protocol.	Interoperability. Cost.	Training the entire office is expensive.	The software is very expensive.	Early information is required for tendering purposes. A higher budget is required for BM implementation.	The need to generate a BIM maturity guide protocol, to develop systematically.	Information exchange problems. Cost.	Organisational cultural change. Additional cost.	The need to comply with the contractor`s prescribed software.
BIM Maturity Levels	**Level one Modelling**	Identify key elements specifications. Identifying what and when to model?	2D and 3D use.	Identify the importance and challenges of using BIM.	-	Producing electronic documents, (2D and 3D).	-	2D and 3D application.	-	2D and 3D BIM use.	Generating different design options. Visual design decision capabilities.
	Level Two collaboration	Identify what and when to share?	Standardising data sharing process.	Introducing the contractor at early design stages.	Information exchange.	The process of Naming convention; it simplifies information exchange with collaborators.	MEP collaboration for clash detections.	Designer, contractor and sub-contractors get involved at the early project stages for analysis of various project issues.	Linking model with live data.	-	Asite can be used for information sharing with collaborators. WORKSET in Revit can be used for information input and output management.
	Level three integration	Materials and equipment information can be linked to model.	Facility operational management capability.	Building performance analysis and evaluation.	Integration of user feedback into a model.	Facility management capability.	Facility management tends to reduce risks due to operational management.	Linking model to real live data.	Life cycle asset management can help cut the cost of future refurbishment.	Collaboration promotes informed decision making.	The application of *options* in Revit allows quick performance analysis of models.

7.6.5 FLEXIBLE DESIGN PARAMETERS

Decision making is important. Different flexible design parameters can be used to facilitate decision making when dealing with different flexible design options. As a result, 15 different flexible design parameters were developed from literature review and forwarded to the potential interviewees. They were asked to identify the most important parameters that can facilitate the selection process when dealing with different flexible design options in a hierarchy order; with one been the most important and 15 as the least important. Table 7.18 was tabulated by calculating the mean. The top five parameters indicated were: the cost of embedding flexibility; the cost of the entire facility; the area of income generating space; the type of flexibility; and the classification of flexibility.

Table 7.18: *Change-ready design parameters that could facilitate the decision making process*

Flexible design selection parameters for cost effectiveness and efficiency				
Parameters	**Reference**	**Mean**	**Ranking**	**Focus**
Cost of embedding flexibility	Cleveland Clinic	1+ 1+1+1+1+1+1+1+1+1 / 10 =1.0	1	Design
Cost of entire building option	Cleveland Clinic	2+2+2+2+2+2+2+2+2+2 / 10 = 2.0	2	Design
Area of income generating space	Ahmad	3+3+3+3+5+4+4+4+4+4 / 10 = 3.7	3	Operational management
Classification of flexibility: Long-term/mid-term/short-term	Pati *et al.* (2008)	4+ 5+5+5+12+3+12+3+3+3 / 10 =5.5	4	Design
Type of flexibility e.g expanding, contracting and adapting	Pati *et al.* (2008); Cleveland Clinic	5+4+4+4+4+8+13+8+8+ 8/ 10 = 6.6	5	Design
Area of secondary space (serving area)	Kazanasmaz (2006)	14+8+8+8+13+5+5+5+5+5 / 10 = 7.6	6	Operational management
Area of primary space (served area)	Kazanasmaz (2006)	15+7+7+7+7+7+7+7+7+7 / 10 = 7.8	7	Operational management
Area of non-income generating space	Ahmad	9+6+6+14+6+6+6+6+6+13 / 10 = 7.8	7	Design
Design efficiency= core area/total building area	Ilozor (2001); Hofer and Schendel (1978); Hardy and Lammers (1986)	6+10+9+6+8+13+8+12=13+6 / 10 = 9.1	9	Design
Number of functions a design options adapts to (variety of scenarios)	Ahmad	11+12+12+12+3+9+9+9+9+9 / 10 = 9.3	10	Operational management
Area of core spaces (primary + secondary)	Kazanasmaz (2006); Ilozor (2001)	10+13+15+10+10+10+10+10+10+12 / 10 = 11.0	11	Operational management
Population capacity of a building	Ahmad	7+15+10+11+11+14+3+14+14+14 /10 = 11.3	12	Design
Area of non-core spaces (circulation)	Ilozor (2001)	13+9+14+9+15+11+11+11+11+11 / 10 = 11.5	13	Design
Number of flexible partitions	Ahmad	12+11+11+15+14+12+15+13+12+10 10 = 12.5	14	Design
Percentage of incoming natural lighting	Ahmad	8+14+13+13+9+15+14+15+15+15 /10 = 13.1	15	Design management

7.7 DISCUSSION

Renner, (2003) stated that three features should be presented after conducting an interview. These are:

- What are major lessons learnt?
- What are the new findings that can be added to literature?
- What the reader of the interview might be interested in finding out?

What are major lessons learnt?

- The constraints of refurbishment stated by the interviewees were mainly focused on the management process.
- Cost is a major issue relating to flexibility. It is arguably increasing the capital cost of a building and reducing the operational management cost. While some interviewees were of the view that flexibility does not necessarily increase the capital cost of a building.
- Despite the problems associated with the traditional project delivery method, it is the most common procurement approach towards refurbishing buildings in the opinion of the interviewees. Perhaps it is frequently used in healthcare refurbishment projects as the UK NHS is considering lowest tender, competitive bidding and demand more value for money due to tight budgets available for their projects.
- Strategies of dealing with existing features such as function flow and capacity within a healthcare facility requires integration; the existing and proposed features can be integrated by overlapping each other or through proper circulation and way-finding.
- When dealing with healthcare refurbishments using BIM application, it is important to store the existing and proposed BIM model data for future use.
- This research can conclude that there is no specific application of BIM to healthcare compared to other buildings such as offices, schools, or commercial structures. However, healthcare buildings can benefit more due to their complexity, volume and 24 hour round the clock services. The noteworthy

finding is that MEP services are one of the key factors that makes healthcare buildings complex. Most healthcare buildings are heavily serviced.

- When designing different flexible options, MEP services should be carefully designed and analysed; the spaces allocated for MEP services could highly increase the cost of any design option, and these specific spaces can also allow flexibility when expanding or converting a building project. MEP clashes can also increase the cost of newly or refurbished healthcare facilities.
- With the Government push to cut cost and attain cost efficiency, the application of BIM can help with cost reduction, while the use of flexibility can cut the operational cost of running a facility by adapting to change. Findings show that BIM aids in designing multiple design options using Revit Architecture, the use of *OPTIONS* allows one design option to be developed into different multiple scenarios; the use of *WORKSET* is used to control the editing of models when collaborating with various stakeholders, while ASITE, an online service, allows information exchange for stakeholders within a given project.
- BIM can be used to analyse the operational phase of different flexible design options by analysing operational cost and performance from the working model.

What are the new findings that can be added to literature?

- The most important parameters that can be used to facilitate decision making when selecting the most suitable design option from different flexible design options were identified. Figure 7.2 illustrates the top five parameters. These include: the cost of embedding flexibility; the cost of the entire facility; the area of income generating space; the type of flexibility; and the classification of flexibility been embedded into a facility.
- The combined application of flexibility and standardisation in healthcare facilities is used in redesigning spaces. Standardised spaces, such as nursing stations and patient rooms can be re-used by storing/saving: size (dimensions), layout, components, equipment as objects in a BIM environment to easily re-use.

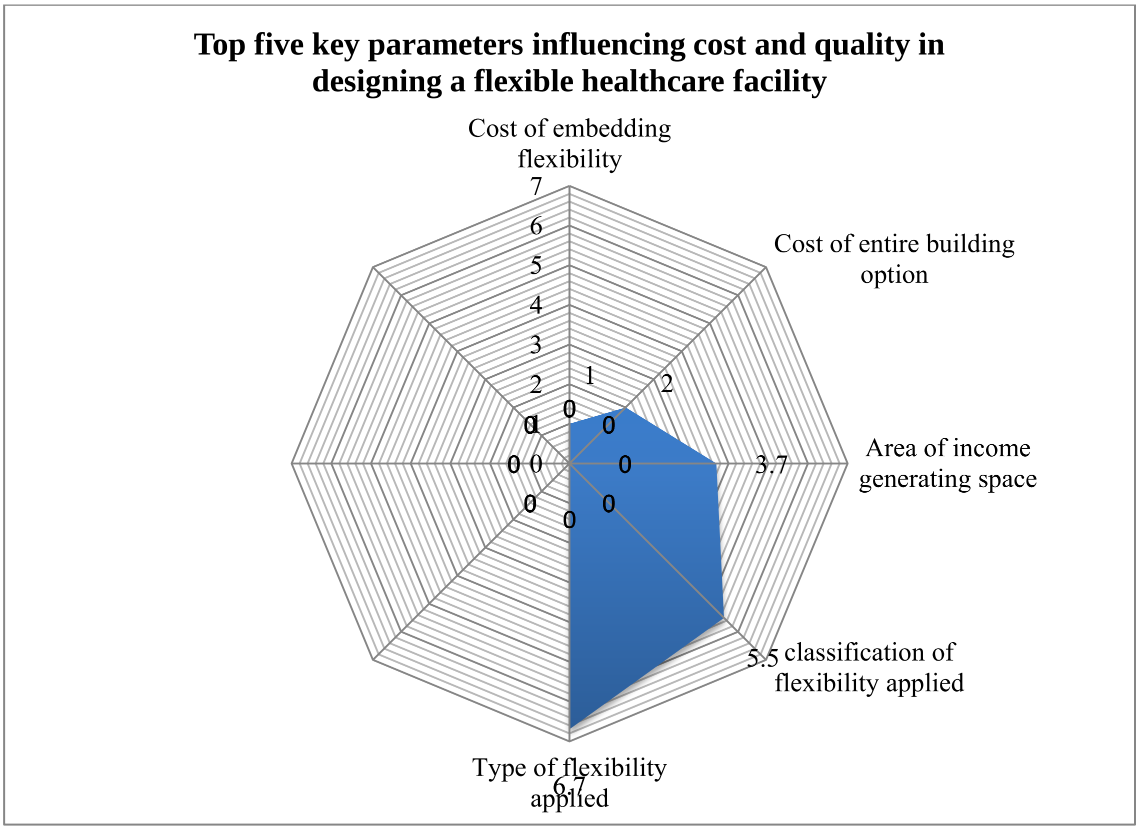


Figure 7.3: *Top five key parameters for making informed decisions before selecting a change-ready facility*

What the reader of the interview results may be interested in finding out?

- the process of applying standards involves identifying the source of information, selecting appropriate specification from bunch of available standards, categorising relevant information, reviewing existing information for possible updates and the use of specifications that can easily adapt to the proposed project business case;
- the reader of the interview findings might want to know how to combine flexibility and standardisation? There is no specific ratio of combining flexibility and standardisation. Therefore, all flexible parameters could be standardised. For example, flexible space, equipment, function can all be standardised and customised were appropriate;
- the BIM requirements for designing a *flexible* space include planning and implementing BIM through the process of choosing and developing BIM protocol, identifying what and when to model, what and when to share, file

naming convention and so on. After the implementation of BIM, different design options can be generated using BIM. It is also required to link the BIM model with real live data through 4D and 5D modelling. Design coordination requires the introduction of the contractor at early design stages to collaborate with the design team when analysing the various flexible design options generated; to explore their impact on the services systems, site landscape, cost and energy performance to improve flexible design outcomes; and

- There reader might also want to know how the findings were used to revise the framework. These are presented in section 7.8.

7.8 FRAMEWORK REVISED FROM INTERVIEW FINDINGS

The framework was revised from a combination of findings from literature review, questionnaire survey and interviews. The findings were collected from healthcare designers. Table 7.19 presents the different features included into the framework and their information sources. *The RIBA Plan of Work* (2013) Stages and their *Additional Information* were merged into a single flow in order to focus the framework on the design process. The strategic definition Stage is the addition to the previous RIBA Plan of Work; it requires more detail of clients business and project requirement, theses were further added into the revised framework. Additional information is also available for each of the sequential design tasks. The interview findings used in the framework included the following:

- The need to identify possible uncertainties when conducting a refurbishment;
- Identifying the need for applying flexibility strategies with BIM support;
- Interview findings also showed that the framework could be applied in both new build and refurbish projects;
- Identify core requirements for achieving quality refurbishment. These include: managing new and proposed features of a healthcare facility; managing constraints of refurbishment such as function, space and flow. There is a need to integrate or overlap the constraints through proper circulation and way-finding design;

- Some projects could be new while some could be refurbishments. Therefore, an option was created to choose from the two depending on the project in context;
- Questionnaire survey findings showed that it was important to identify possible changing spaces. However, interview findings showed that in order to do this existing and proposed features have to be identified at the early design stages; and
- Interview findings showed that different stakeholders can collaborate by exchanging their specific design information with other stakeholders.

The revised framework was revised using interview findings. The main tasks involved in the revision include collecting, analysing and evaluating data; each finding was inserted into the appropriate Design Stages of the RIBA Plan of Work (2013) and presented in a sequential order. For example, identifying project needs takes place in the appraisal project phases. Holistically, these steps can work in the pattern there are presented. Therefore, the links between the steps are interrelated; step 2 cannot take place before step 1. This applies throughout the process. The 13 steps are:

1- Set project goals;
2- Identifying possible uncertainties or constraints;
3- Set project target;
4- Identify existing features;
5- Identify new-proposed features;
6- Identifying features of possible changing spaces;
7- Integrate the features of the possible changing spaces;
8- Proposed flexibility building elements;
9- Propose standards/specification of building elements;
10- Organise information into a BIM model;
11- Analyse flexible design options generated;
12- Collaborate with different stakeholders; and
13- To verify project target using the decision supporting parameters tabulated in Table 7.18.

These findings are grouped into the following: 1 and 2 (Stage 0); 3, 4 and 5 (Stage 1); 6, 7, 8 and 9 (Stage 2); and 10, 11, 12 and 13 (Stage 3). Stages are linked through RIBA Plan of Work Procedures.

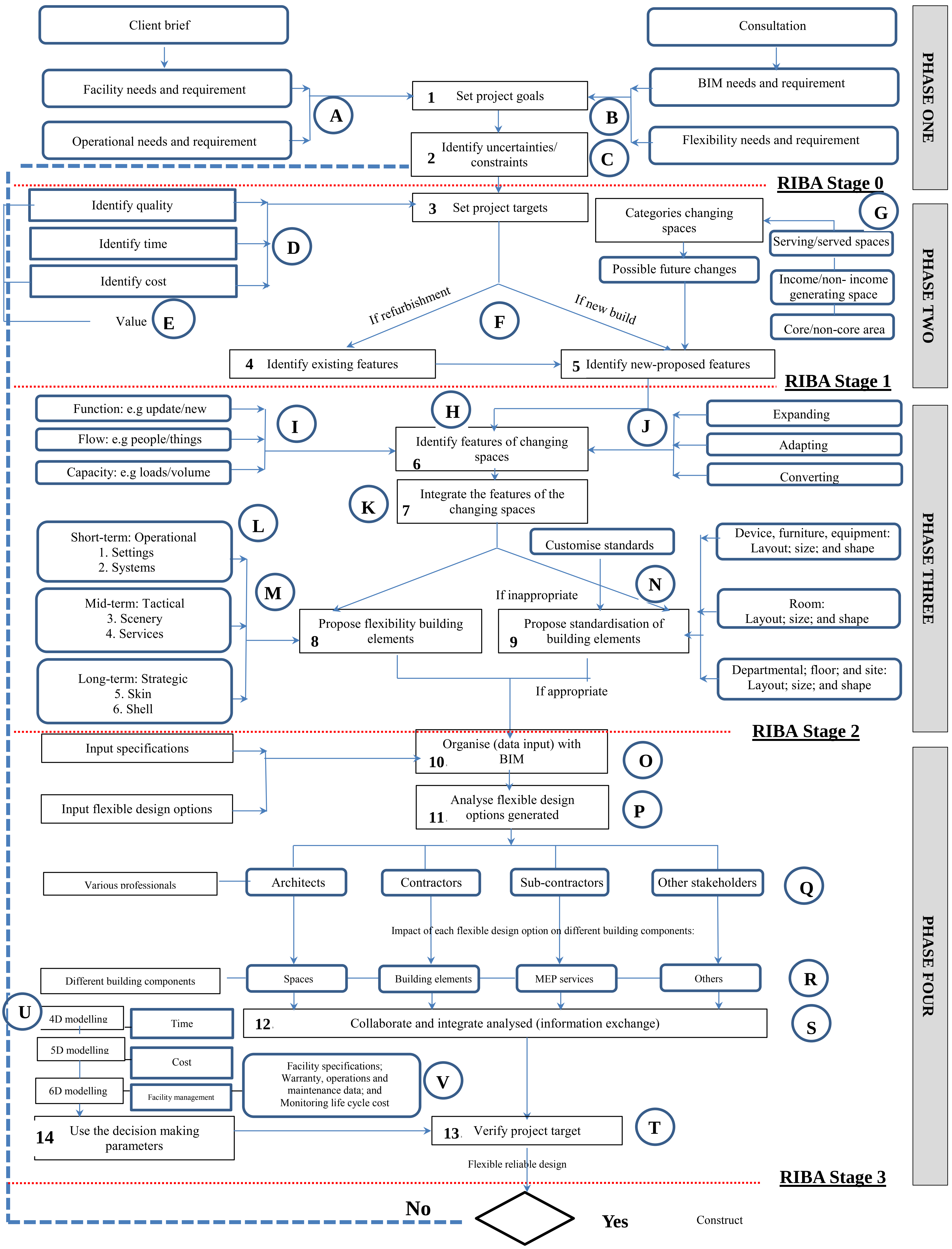


Figure 7.4: *Framework for designing a change-ready healthcare facility generated from literature, questionnaire survey and interview findings*

Table 7.19: *Framework keys and references*

REFERENCES	RESEARCH METHODS	DESCRIPTION OF REFERENCE WITHIN THE THESIS
A	AL	Described in the analysed flexible frameworks. For example, Allahaim, (2010); Vorel, (2009); Ajah *et al*., (2005); Kunders, (2004); Fien *et al*., (2007).
B	AL & I	Described in *core BIM activities to embed flexibility (7.2.3*). Participants agreed to identify the need for flexibility and BIM.
C		Described *in core requirements for achieving quality refurbishment. (7.4).* Identifying possible uncertainties. 3 out of 5 frameworks had agreement that identifying uncertainties is important.
D	LR	Goodpasture, (2002:6): Oisen, (1971); Sureshi and Babu, (1996).
E	LR	Simm and Masters, (2003:46): Rogers and Duffy (2012:200)
F	I	Described in *Core requirements for achieving quality refurbishment (7.4).* Managing new and proposed features. 7.4.2 Managing constraints of refurbishment (functions, space and flow). Integrating and overlapping functions and features.
G	LR	Hardy and Lammer (1986)
H	Q	Described in healthcare spaces that rapidly changes and their features. (6.2.1).
I	L	Slaughter, (2001).
J	AL	Described in exploring concepts and planning approaches for flexibility. (3.4.2). Analysis various flexibility definitions, planning processes and concepts.
K	I	Described in core requirements for achieving quality refurbishment (7.4) and Managing constraints of refurbishment (functions space and flow). (7.4.2) Integrating and overlapping functions and features.
L	Q	Brand, (1994).
M	Q and I	Carthey, J., Chow, V., Jung, Y. M. and Mills, S. (2010).
N	I	Described in *Requirement for achieving standards when embedding flexibility (7.3.1).* If inappropriate; customise.
O	I	Described in the role of BIM in healthcare (7.2)
P	Q	Described in *core BIM activities to embed flexibility (7.2.3*). Producing and analysing *What if scenarios with BIM (6.4.2)*
Q	LR, SQ and I	Described in core BIM activities to embed flexibility (7.2.3). Three respondents AF-2; AF-5; and AF-7 agreed the analysis of different scenarios by different stakeholders. Eastman *et al*., (2011:584), Weygant, (2011:102)
R	LR and Q	Described in core BIM activities to embed flexibility (7.2.3). Eastman *et al*., (2011:584).
S	Q and I	Describe in *core BIM activities to embed flexibility (7.2.3).* Collaborating information from various BIM professionals.
T	LR and I	Allahaim, (2010); Vorel, (2009); Ajah *et al*., (2005); Kunders, (2004); Fien *et al*., (2007).
U	LR and I	UK Government construction strategy, (2011).
V	LR and I	UK Government construction strategy, (2011).

Key: LR: Literature Review; AL: Analysis of Literature; QS: Questionnaire Survey; I: Interviews; SQ: Secondary Questionnaire.
Relationship: → Next processes task —
; RIBA Stages: A: Appraisal; B: Design brief; C: Concept; D: Design development.
○ : Reference; ▭ Process task; ▭: Additional information; :

7.9 LIMITATION OF INTERVIEWS

The conducted interviews lasted a range of 25 to 60 minutes. Among the 10 interviewees; three interviews lasted more than 45 minutes. Some of the interviewees were very passionate about the application of BIM in the AEC industry; they raised some of their organisational concerns regarding the development of BIM in the AEC industry, such as fee issues, who manages the model? Who drives the BIM implementation in the AEC industry? And so on. These are all important issues to consider when applying BIM, but they were changing the focus of the interviews. Therefore, these conversations were moderated to focus on the aim and objectives of the interviews. A limited number of interview participants were recorded (10 participants).

7.10 CHAPTER SUMMARY

This chapter presents the role, best practice and important considerations towards achieving RFSB in healthcare. Interview findings show that: it is important for spaces to be flexible and standardised to adapt to future changes; information can be shared with the use of specific websites that allow information to be uploaded, edited, and shared between specific authorised stakeholders; the use of certain BIM tools allow designs to be edited, analysed and evaluated virtually to facilitate decision making when different design options are generated; there is no specific application of BIM in healthcare compared to the other sectors of the AEC industry; and there is also no specific ratio of combining flexibility and standardisation. This research also explored the flexible design parameters that can facilitate decision making when selecting the most suitable design option from different flexible designs. The interview findings were used to further revise the framework presented from literature review and questionnaire survey findings. The next chapter presents the development stages of the revised frameworks in detail. A validation exercise was also conducted for reliability and validity of the framework revised. Architects, facility managers, RIBA and the NHS trust were interviewed.

8 CHAPTER 8: FRAME WORK DEVELOPMENT, VALIDATION AND DISCUSSION

8.1 INTRODUCTION

It is important to consider the environment, technology and facility users when developing a framework for designing a change-ready healthcare facility. Jen (2009) described the strategy for designing a framework to include the need to combine the application of the physical space; technology; and quality of living environment by focusing on social and environmental factors to achieve efficiency. As a result, proposed design features in the framework developed should consider the three factors above. The *aim* of the framework is to guide healthcare designers and planners in applying BIM when designing a change-ready healthcare facility to improve the existing situation of healthcare facilities during refurbishment or new builds. The required capacity of a healthcare building can be forecasted to increase in the future with the rapid change in population around the UK. It can also be forecasted to reduce with the vast changes in technological advancement, such as e-health, mobile healthcare, advance healthcare treatment and equipment etc. It is therefore challenging for existing healthcare facilities to adapt to these changes. The combined application of flexibility and standardisation is meant to improve value for money when designing healthcare facilities. The application of BIM was introduced to influence the process of reusing designs, simplifying the process of generating various flexible *design options.* The designed framework is meant to aid healthcare facility planners and architects to manage change by providing carefully designed processes with a detailed sequence of applications. The framework can be used for designing new facilities or to conduct refurbishment projects. Another advantage of the framework is its ability to be applied to other building sectors in the AEC industry with minor modifications. *What is a framework?* Arora and Johnson (2006) stated that a framework is a set of processes laid down to accomplish set of goals. They identified four steps within the process. These are:

- defining the project confinements or boundaries;
- the first boundary becomes the first step of the process;
- the last boundary becomes the last step of the process; and
- identifying all major steps between the first and the last step.

They further stated the reasons for creating a process sequence within a framework include the need to: describe and document the process; develop with improvement ideas; determine best methods; and train others to conduct a process adequately and appropriately for best practices. However, this study understands a framework as a set of guidelines that can sequential guide a process to achieve desired project outcomes.

8.2 FRAMEWORK DEVELOPMENT PROCESS

The framework for designing a change-ready healthcare facility is set to guide the design of new or refurbished projects that deals with known/expected future changes. it identifies how to embed a flexible design option in a building`s system. A long-term, mid-term or short-term flexibility option can be triggered in the future when required. Some basic attributes of the proposed framework include compatibility and a clear structure; it was crucial that the framework works in line with the RIBA Plan of Work as it is accepted widely in the UK. RIBA Plan of Work (2007) was used to revise the framework from literature review and questionnaire survey. The RIBA Plan of Work (2013) was used to revise the framework using interviews and the validation outcome.

The methodology for the framework development process had three sequential steps. The first step was through a robust analysis of literature; the second step was through the use of a questionnaire survey; and the third step was through the use of interviews. The sequential development of the framework is presented in details below. The methodology for the entire research is centred on mixed methods; this involves both qualitative and quantitative methods, but strongly centres on deductive research. This is described as starting from a more generalised set up to more specific; that is (literature – questionnaire survey – interviews). Literature was required to explore the context of existing flexibility frameworks; statistical evidence for applying BIM within the framework was essential in order to have a strong basis for the research. Detailed and in-depth information was also required to explore what? How? When? And why the framework is required? As a result, the framework developed from literature review was revised with analysed data collected. These are:

- framework generated from literature review;
- framework revised from questionnaire survey; and
- framework revised from interviews.

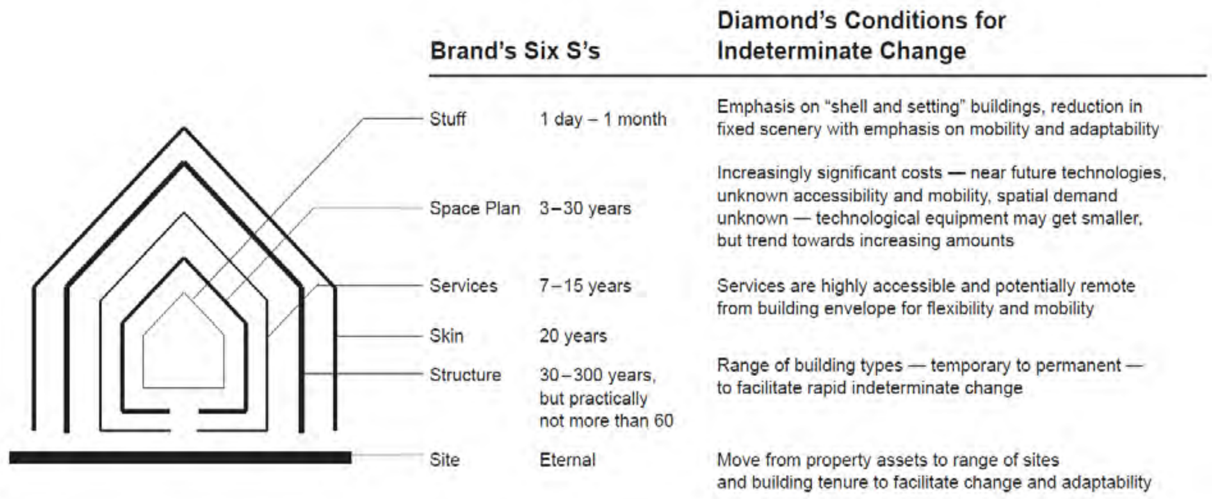
8.2.1 FRAMEWORK REVISED FROM LITERATURE REVIEW

A state of the art analysis was conducted to review current literature on the components of designing a framework. Literature was used to develop the framework for designing a flexible healthcare facility that could adapt to future known changes. The features identified include: literature on flexibility; standardisation, BIM and RIBA Plan of Work (2007). Also the sequence pattern of tasks (steps as subsections of phases) used when developing a healthcare facility were adopted from Tompkins *et al*. (2010). However, the framework did not use the phasing method adopted by Tompkins *et al*. (2010); they divided tasks into three phases while the RIBA Plan of Work (2007 and 2013) had more than 3 phases and is accepted nationally. Despite this, lessons learnt and applied in the framework include: the sequence order of activity flow; the grouping and flow of activities with a principal theme. For example, all appraisal tasks were grouped and arranged under the Appraisal Stage of the RIBA Plan of Work (2007).

Literature on flexibility

Different existing flexibility frameworks were analysed. The different flexibility processes and the concepts and planning approaches for designing flexible spaces expanding or contracting were identified. Taylor *et al*. (2011) stated that the British architect Frank Duffy identified six S`s that can be considered when designing a flexible and adaptable design framework. These included: site; structure; skin; services; space plan; and stuff such as furniture. Battisto and Allison (2002) and Taylor *et al*. (2011) complemented the theory described by Brand (2004). Figure 8.1 was used to categorised the Brand`s Six S`s into three groups. These are: (site and structure) long-term flexibility; (skin and services) mid-term flexibility; and (stuff setting and space plan system) short-term flexibility. As a result, three options were presented to the framework users;

- for long-term changes the site or structure is altered;
- for mid-term changes the skin and services layout are adjusted; and
- for short-term changes that take places frequently or adapts to changes within a short notice; space and equipment settings are considered.



Brand's Six S's		Diamond's Conditions for Indeterminate Change
Stuff	1 day – 1 month	Emphasis on "shell and setting" buildings, reduction in fixed scenery with emphasis on mobility and adaptability
Space Plan	3–30 years	Increasingly significant costs — near future technologies, unknown accessibility and mobility, spatial demand unknown — technological equipment may get smaller, but trend towards increasing amounts
Services	7–15 years	Services are highly accessible and potentially remote from building envelope for flexibility and mobility
Skin	20 years	
Structure	30–300 years, but practically not more than 60	Range of building types — temporary to permanent — to facilitate rapid indeterminate change
Site	Eternal	Move from property assets to range of sites and building tenure to facilitate change and adaptability

Figure 8.1: *The Brand`s Six S`s. Source: Taylor et al. (2011) adapted from Brand (2004)*

Literature on the RIBA Plan of Work with BIM Overlay

The RIBA Plan of Work (2007 and 2013), RIBA Plan of Work BIM Overlay, and design management process from Gray and Hughes (2001) was used to present the scope of this research. The design process is the main focus. The applications of refurbishment, flexibility, standardisation and BIM were also applied within the design process in order to achieve a change-ready healthcare facility that is cost effective.

Literature on BIM

To define the key BIM features that can be applied to the framework design, state of the art desktop study on literature was conducted through the analysis of the different definitions of *BIM* by different individuals and organisations. There is no one definition of BIM; it is defined and understood differently by different building professionals.

The Framework generated from literature (Figure 3.17) had a total of nine steps. Step 1 is to *identify needs and* conduct *feasibility studies*. These include: defining facility goals; describing the facility design criteria; and BIM use protocols. To design a framework that can guide healthcare designers and planners to design a change-ready healthcare facility, it is important to identify the facility goals at the early design stages; these are collaboratively made by clients, designers, contractors and other relevant decision makers. The facility goals revolve around users` needs. Step 2 involves assessing options to achieve users` needs and working around client`s budget. Step 3 cost appraisals should be conducted and could be identified as a possible constraint. However, the needs of a facility can define the magnitude of a project. Step 4 is the process of *identifying and selecting the proposed time-frame of the flexibility option* in context. Long-term flexibility is conducted through a strategic approach that involves structural expansion or contraction of a facility; mid-term flexibility is conducted through a tactical approach that involves conversion within a facility; while the short-term flexibility is conducted through an operational approach that involves adapting spaces. For example, moving furniture or equipment within a given space or unit. Despite the three types of flexibilities identified by Carthey *et al*. (2010); the planning and conceptual approaches of two flexibility types were taken into consideration. These include *short-term* and *long-term* flexibility; in-between can be described as mid-term flexibility. Step 5 is *to identify the flexible concept*. Step 6 is *the process of identifying flexibility planning sequence*. Step 7 is *the process of applying BIM*; it is used as an analysis tool, a process and an information manager for the effective utilisation of flexible healthcare spaces. When using BIM as a tool, information can be shared between stakeholders within an organisation and with external organisation to achieve desired healthcare outcomes. The use of BIM as a process, involves the collaboration of responsible stakeholders to make informed decisions before a suitable and appropriate design option is selected for construction. Step 8 is *to select an appropriate plan* that the project would proceed with. Step 9 *is the use of the BIM model to generate detailed design information*. A questionnaire survey was used to further develop the framework. The need for a questionnaire was required to verify the use of BIM in designing flexible healthcare spaces and the impact of using BIM tools with standards. For example, the use of BIM objects which are standardised for manufacturing purposes. It is important to embed space flexibility during the design stage, this way, the operational strategies suggested by the facility managers can be introduced at the early design stages.

8.2.2 FRAMEWORK REVISED FROM QUESTIONNAIRE SURVEY

The framework generated from state of the art desktop study on literature was further revised using a questionnaire survey. Chapter 6 presents a detailed analysis of the survey. The survey findings have identified some key issues. These include: the key spaces that rapidly change within a healthcare facility; the design principles for achieving flexibility in practice; the effectiveness of some flexibility concepts; the effectiveness of *what if scenario*s with BIM: the effectiveness of BIM use for analysing and evaluating flexible healthcare spaces; the important considerations for embedding flexibility within a healthcare facility; the important considerations for using standards within a healthcare facility; the opinion of questionnaire respondents on the impact of BIM tools on design creativity; and the effectiveness of BIM use when relocating, adapting, expanding or contracting a healthcare facility space.

Further literature suggested setting *the facility goals* required to accomplish a change-ready healthcare facility during refurbishment or new builds. These include: operational; facility; flexibility; BIM; and financial goals and requirements; and possible uncertainties towards achieving a change-ready healthcare facility. The findings from the questionnaire survey were used to revise the framework generated from literature review. The findings were categorised into four steps. These include: dealing with uncertainty when forecasting how healthcare facilities will operate or function in the near future; the more a facility adapts to future changes, the more quality and value achieved. Value can be achieved when more productivity is achieved in healthcare delivery. For example, when a consulting room has the capability to be used as an x-tray unit when required; fragile patients will not have to be moved. The possibility of any uncertainty occurring within a change-ready health facility should be identified and analysed. It could be identified through the probability approach or precedent studies. The prediction of disruptions or known future operational changes within a facility can be explored using evidence based design. For example, Accident and Emergency (A&E) experience high pressure during the weekends (Interviews).

The questionnaire survey findings were used to revise the framework into 13 steps. All steps were either suggested from literature or questionnaire survey respondents. This study took each task and grouped them under their appropriate RIBA Plan of Work (2007) Stages. For example, the BIM Overlay on the RIBA Plan of Work in appendix 10 shows how suggested BIM tasks were added into the different Work Stages.

Step1 is to *identify needs and feasibility study*. Step 2 is to *identify cost targets and assess possible options to consider at the early design stages*. Step 3 is to *identify possible constraints/uncertainties and cost involved*. Step 4 is *identifying spaces that rapidly change*. It is imminent to the design of any change-ready healthcare facility. Step 5 is to identify flexibility approaches with possible time frames. Step 6 is *to identify conceptual and planning approaches relating to embedding flexibility*. Step 7 is *to apply standards when embedding flexibility* on either a short-term, mid-term or long-term basis. Step 8 is the process of integrating flexible design features into a BIM model. Step 9 is the process of *creating and analysing different scenarios or design options with BIM support*. Step 10 is the process of collaborating with different stakeholders while *analysing and evaluating flexible spaces with BIM*. Step 11 is to *share information*. Step 12 is to *select a flexible design option from the generated design options*. Step 13 is to *generate detail information from the BIM model*.

When building flexibility into a facility, the use of standards is important, it is recommended to carefully use standards; some of the questionnaire survey respondents had concerns that the use of standardisation could impede the opportunities to embed flexibility within a facility in three different cases which are: *creating spaces with rigid design layouts*; *producing interrelationships of spaces that are highly complex*; or *hindering modularity layout concepts*. Dealing with space specifications can be complex; there are many functional spaces in healthcare facilities. Other considerations of the questionnaire survey respondents were: dealing with standards that could be complicated due: to the need of frequent update when required; the need to select a standard from the different available standards; and the impact of BIM tools on design creativity when designing a facility. There were split opinions on BIM tools hindering or facilitating design creativity. Therefore, a solution was prescribed in Ahmad *et al*. (2012b) see appendix 3. It is important to understand the limitations of BIM tools; and differentiate what is BIM reality from what is BIM fiction.

There is a need to further develop the framework generated from questionnaire surveys; the findings verified that the application of BIM, flexibility, and standardisation can reduce the cost of designing a facility and improve its value on both short-term and long-term basis. Their applicability in the design process needs to be described with more practicality. This was identified through the use of in-depth interviews with architects in the healthcare sector.

8.2.3 FRAMEWORK REVISED FROM INTERVIEW FINDINGS

The framework revised from the interviews findings was a development on the previous frameworks (revised from both literature review and questionnaire survey). The framework described in Figure 7.4 of chapter 7 was developed to provide guidance that could foster the design of a cost effective and cost efficient healthcare facility design using BIM. The framework presented consists of four phases as shown in Table 8.1.

Table 8.1: *Phases of the framework generated from interviews*

Framework Phases			
Phase 1	**Phase 2**	**Phase 3**	**Phase 4**
Set Goals For a cost effective and efficient change-ready healthcare facility	**In** Healthcare Refurbishment	**Combining** space flexibility + space standardisation	**Using** Building information modelling (BIM)
Steps 1 and 2	**Steps 3, 4 and 5**	**Steps 6, 7, 8 and 9**	**Steps 10, 11, 12 and 13**

The findings from the conducted interviews were used to further develop the framework. The findings are used to describe the four phases identified above. It is important to note that the interviews findings were used to improve the framework generated from literature analysis and questionnaire survey analysis. The interview findings are explicitly presented in chapter 7. The sequential arrangement of the steps in the framework was taken from the analysis of the existing flexibility frameworks and was later improved with findings from the analysed primary data.

Phase one: *Setting goals for a cost effective and efficient change-ready healthcare facility*

Phase one consists of steps 1 and 2. Step 1 is to *set project goals*; this is the first step which clearly defines the intended goals of developing a change-ready healthcare facility. It ensures the right procedures are adopted to achieve the desired facility outcomes. These include: the facility; operational; flexibility; and BIM needs and requirements. Step 2 is to *identify possible uncertainties* that could disrupt or delay the process of designing a change-ready healthcare facility.

Phase two: *Identify the key healthcare refurbishment features*

Phase two consists of three steps 3, 4 and 5. Step 3 is *setting project targets* for achieving a change-ready healthcare facility to be cost effective and to achieve more value for money. Step 4 is *to identify the existing design features* and step 5 is *to identify the new-proposed facility features.* These design features include: the existing and proposed/expected facility capacity; the existing and proposed functional operations; and identifying possible spaces that needs to expand, contract, convert, relocate or adapt to changes. The integration of existing and proposed features would stimulate the need to organise these features when refurbishing a building. There are other design features that can help the design team with informed decisions when proposing for facility improvements. For example, the proposed future changes can be categorised around three functions to achieve efficiency in space design. These are: serving area/serve spaces (Kazanasmaz, 2006); income/non-income generating spaces (Ahmad); and the core/non-core spaces (Hardy and Lammers (1986); Ilozor (2001); and Hofer and Schendel (1978). This categorisation is conducted to utilise the existing features and recommend suitable and appropriate design features in the future. It also helps in setting priority to certain possible changings spaces. For example, large budgets should not be spent on non-income generating spaces, while it is feasible to spend on income generating spaces.

Phase three: *The combined application of flexibility and standardisation*

Phase three consist of steps 6, 7, 8 and 9. Step 6 is to identify *the features of the possible changing spaces.* These spaces could be converting, adapting or expanding. When embedding flexibility into the facility, one or two of these features are designed to be flexible. For example, when the *flow, function or capacity of a facility* is identified as a design feature that should be considered when embedding flexibility into a facility; *space* can be identified as one of the design component in focus. To embed flexibility into a desired facility space, different design scenarios can be considered by applying different methods; this can be conducted by overlapping the features identified in Step 5. For example, during the night shift (flow), certain day shift office *spaces* could be used as treatment rooms (functions) when some administrative staff have finished their day shifts (flow). This can be a flexible approach due to a possible high use of A&E on the weekends to adapt to any change in the capacity of a facility. Therefore, it can be understood that by overlapping components such as flow, function and capacity; flexibility can also be achieved. Others factors have to be considered when designing universal spaces. Step 7 is *the process of integrating the features of the changing spaces*. Step *8 requires the proposed flexible building element in focus to be set on short-term, mid-term or long-term basis*. Flexibility can be facilitated through the application of standards. Step 9 is to *apply standards,* the attributes attached to each standard has to be explored based on their international, organisational, industrial, or the type of facility being managed. Standards should be based on specific needs; the decision makers should collaborate and select the standard that is deemed wholly appropriate and can be adopted within the context of the task in focus. Some of the questions to ask when dealing with standards are: what are the standards available for the facility design purposes? How many standards are available and when last were they updated? Standards can also be customised to suit immediate needs.

The combined application of standardisation and flexibility in the framework design can be used to achieve many key factors, but two key factors have been identified from the interview findings. The application of standardisation can aid the process of: redesigning and replication of healthcare spaces using BIM; and for restructuring equipment/furniture/curtain walls within an open space. Standard specifications will allow components such as furniture or equipment to be saved as an object within a BIM environment. Flexible equipment or furniture can be used in different places if they are standardised. Under standardisation can lead to lack of compatibility in open spaces.

Phase four: *The process of applying BIM*

Phase four consist of steps 10, 11, 12. Step 10 is the process of *organising (data input) with BIM* in the framework design. Project data can be processed and organised within a BIM environment. The entire project information can be saved electronically; all project data including (geometric and non-geometric) can be put into BIM to facilitate the design process. Detailed specifications are required to be organised for accurate models to be generated within a BIM environment. Step 11 is the process where *all stakeholders involved, analyse and evaluate the different flexible design options with BIM*. Step 12 is the process of *collaborating and integrating analysed data*; this includes collecting and organising the analysed and evaluated information from the different flexible design options generated in order to choose a suitable and appropriate design. An IPD project should favour this step where collaboration by different stakeholders is conducted to achieve harnessed desired project outcome; stakeholders should seek to achieve similar project goals. The next is Step 13 which is *verifying project target* through the use of the decision making parameters. The chosen design is to be verified against the *business case* set at the beginning of the design stage in Step 3. If the project target is verified as suitable, reliable, cost efficient and cost effective, it is constructed. If the design project target is verified as inappropriate, one returns to step two *identifying uncertainties/constraints*. The process is followed systematically down to Step 13 again.

8.3 COMPONENTS OF COST EFFECTIVE AND COST EFFICIENT CHANGE-READY FACILITY DESIGNS

It is certain that healthcare facilities designed today will change in the near future; these changes will increase the cost of managing healthcare facilities and also reduce the value of a facility on a long-term basis. Modern healthcare facilities are expected to improve delivery time, staff performance, staff and patient safety; adapt to future changes, and manage the whole life cost of a facility (Purves, 2009). The cost of design, construction, and management should be considered at the early design stages when modelling different design options (interviews). To achieve a cost effective and cost efficient change-ready healthcare design, two key issues should be taken into considerations which include modelling different *design options* with BIM; generating options with cost as a primary focus, and using parameters that could facilitate decision making when selecting the most appropriate design option. However, to achieve different project goals different delivery mechanism could be required such as IPD.

8.3.1 MODELLING DIFFERENT DESIGN OPTIONS WITH BIM

The questionnaire survey respondents in chapter 6 verified that BIM can be used for generating different design options. Some interviewees in chapter 7 also suggested that the use of BIM tools can facilitate the analysis of different design options generated. Different BIM tools can be used to design different options but there is a need to analysis these options for efficiency and effectiveness. The performance outcome of each design option generated can be analysed and considered during the selection of the most appropriate design to progress with. As a result, BIM modelling can help with optimisation of cost, improving project productivity. Uncertainty is a barrier towards the generation of different design options. It is difficult to deal with uncertainty in healthcare, it is expensive and inevitable. Change is the only certainty in healthcare with new Government policies, modern treatment and demand for more value. The existing healthcare services and methods of delivery have to improve in order to respond to changes.

To generate different design options that are cost efficient and cost effective; best practices have to be put to use. Some key issues were identified from the interview findings which are: effective choice of a project delivery method; managing the procurement method; the identification of possible constraints at early design stages; utilising the features of existing spaces and the application of EBD.

8.3.2 PARAMETERS THAT FACILITATES DECISION MAKING (DESIGNER AND CLIENT)

Designers need to provide cost effective designs that are flexible and can increase the value of a facility on short-term, mid-term and long-term basis. Clients need to collaborate with stakeholders involved to make joint decisions on the most preferable and suitable design option. Table 7.18 in chapter 7 show the design parameters that could foster the decision making process when designing a flexible facility. There is a need to verify the cost of embedding flexibility and to estimate the value of the facility in the near future when certain changes take place in the future. For example, it is important to know that a facility can expand when its capacity increases in the future. It is also vital that a facility can quickly adapt to some basic users' needs on a short notice. Therefore, it is important to identify the number of flexible functions a facility can provide. This can increase the quality and value of a facility. Sometime the cost of a facility can be justified by its quality and value over a specified period of time.

8.4 THE FRAMEWORK VALIDATION

To design a healthcare facility that is effective and efficient all stakeholders involved in the design, construction and management process should collaborate to make informed decisions in order to avoid designs that could affect staff productivity or patient needs. As a result, different organisations were selected as a possible sample group to improve the framework. Four samples were considered for the framework validation interviews. These include: some previous interview respondents from the top 100 UK architectural firms (architects) were considered to improve the validity of the framework, the respondents have participated in this study from inception to completion; list of RIBA registered and awarded healthcare architectural firms described as the best British architectural firm with healthcare experience suggested by Britain`s Best Architects (BBA); RIBA; and facility management associations; and the UK NHS estates. The respondents were contacted through telephone and e-mail.

8.4.1 EVALUATION OF THE FRAMEWORK

This was conducted to identify the impacts, quality and effectiveness of the proposed framework developed for the purpose of this research. A validation was proposed to elicit the opinion of four different sample groups in order to achieve quality in the framework design and add knowledge to existing literature. The advantages and disadvantages of the framework are presented in the discussion section. The objectives for the evaluation of the framework were based on reliability and validity, and to identify further gaps that can improve the revised framework. These objectives are:

- to verify if the framework is valid and reliable;
- to describe the best circumstances to use the framework;
- to identify possible gaps in the framework;
- to understand who is the best person to own the framework;
- to relate existing flexibility approaches with the developed framework; and
- to elicit findings that can improve the framework.

8.4.2 BACKGROUND OF THE INVITED SAMPLES

Apart from the previous respondents from the UK top 100 architectural forms, other samples were included to add diversity and quality to the collected data. The four samples invited to take part in the validation of the framework for designing a change-ready healthcare facility are part of the design, construction and facility management groups.

8.4.2.1 Sample One

It is logical to elicit the opinion of the previous respondents from the UK top 100 architectural firms based on the Building Magazine 2010. Their responses were used to develop the framework. The relevance of Sample One to this research is significant. Three frameworks were revised to generate state of the art framework; findings from Sample One were used to facilitate three revised frameworks revised from questionnaire survey, interviews and validation exercise. There were contacted three times as there opt to be contacted when required. Furthermore, their consistent participation would improve the validity of the framework; registering their contribution from inception to completion. Out of the 10 contacted respondents from Sample One, only three respondents participated in the validation interviews.

8.4.2.2 Sample Two

Britain`s Best Architects (BBA) provide lists of different building sectors in the AEC industry. The healthcare building types were relevant to this research. The website is published by Extonet Ltd and edited by Dr Alex Reid, a former Director General of the RIBA. The architectural firms listed on the Britain`s Best Architects (healthcare sector) are Chartered RIBA firms, and have won at least three RIBA awards within the last decade (Britain's Best Architects, 2013). A total of 11 architectural firms were identified, four of the architectural practices listed above are part of the top 100 UK architectural practices based on the Building Magazine, (2010). It is important to elicit their opinion on the framework developed. The architectural firms were contacted through the telephone and via email. However, out of the 11 contacted firms, no response was recorded. As a result, this sample was not used for the purpose of the framework validation.

8.4.2.3 Sample Three

The NHS Trust Foundation and NHS estates was also chosen as a possible sample, key members and main contributors of the NHS Estate and facility management conference group were invited to participate in the interview. These members include:

- Managers in Partnership (MIP);
- Community Health Partnership (CHP);
- NHS Sustainable Development Unit;
- Health Estate facilities Management Association (HefmA); and
- NHS Foundation Trust; *Guy`s and St Thomas` NHS Foundation Trust*

Architects for health are also part of the NHS Estate and facility management group. However, they were previously contacted twice, but no response was recorded. Therefore, architects for health were not contacted during the validation process. This research has acknowledged that the architects for health (AfH) administrative department have put up both questionnaire survey and interview invitations (for this research) on their website on two different occasions; no response was recorded. HefmA, (2013) supports the need for greater standardisation and collaboration with neighbouring trusts. The NHS foundation trust (Guy`s and St Thomas NHS foundation trust) responded and participated in the validation process.

8.4.2.4 Sample Four

The RIBA BIM working group were contacted to participate in the validation of the framework for designing a change-ready healthcare facility. The RIBA BIM working group are made of six chartered architects who are members of top UK architectural firms and two members of the RIBA practice department. The framework designed prescribes an area for further research; to develop add-ons using BIM, it would be important to elicit their views on the compatibility of the framework with the RIBA Plan of Work and the BIM Overlay. One individual represented the RIBA.

8.5 DISCUSSION

This section presents detail findings of the framework validation from the different interviewees that participated. The framework has not being applied in any live project. The findings are solely on the overview of the framework details presented to the interviewees during the validation interviews. Different concerns have been raised by the participants. These issues have been addressed in some details. The main challenge of a change-ready healthcare facility is uncertainty. Kagioglou and Tzortzopoulos (2010, p. 47) were of the view that when dealing with uncertainties in healthcare "*it will mean moving away from the idea that models of care are static and that space is a fixed commodity*". Other findings associated with the framework are related to the application of BIM.

8.5.1 VALIDATION PARTICIPANTS

A total of six interviews were conducted with representatives from three different samples. Focus group was considered, but it was difficult to get all participants to meet at the same time. Therefore, this study opted for interviews. The framework in Figure 7.4 was sent out to the participants with Tables 8.3 and 8.4 without the responses. There was no response from Sample Two, although some architectural firms listed in the sample are also listed in Sample One category. The entire validations responses include: Sample One with three interviewees; Sample Three with two interviewees; and Sample Four with one interviewee. Table 8.2 provides a summary of the validation responses.

Table 8.2: *Background of the validation participants*

Participants	Experience	Background	Sample group
P1	17 years	Architect	Sample one
P2	20 years	Architect	Sample one
P3	30 years	Architect	Sample one
P4	15 years	Facility management (NHS trusts)	Sample three
P5	20 years	Facility management	Sample three
P6	15 years	RIBA	Sample four

8.5.1.1 Findings from interviewees

The interview approach was semi-structured. The uses of both open-ended and close-ended questions were applied for statistical analysis and in-depth data that this research can analyse to improve the framework. The validation interviewees were asked to state yes (1) or no (0) in the questions provided. Table 8.3 shows the summary of the validation responses. There was agreement that the framework is useful for designing of a change-ready healthcare facility that can improve cost effectiveness and project value.

Table 8.3: *Summary of the results from validation of the framework*

Questions	P1	P2	P3	P4	P5	P6	TOTAL
Does the Framework facilitate refurbishment or reconfiguration of a healthcare facility?	1	1	1	1	1	1	6
Do you agree that the Framework enhances the RIBA Plan of Work (2013) by providing more details and specifications on the key considerations of refurbishment or reconfiguration, optimising flexibility, maximising standardisation and optimisation of BIM?	1	1	1	1	1	1	6
Does the Framework facilitate the implementation of Building Information Modelling (BIM)?	1	1	1	1	1	1	6
The Framework has the potential to address the problems of underutilisation of a healthcare facility as an asset by offering options in terms of spatial reconfigurations and spatial flexibility.	1	1	1	1	0	1	5
The Framework enhances compliance with health and safety regulations/legislation, requirements which support Government health policy and BIM strategy.	1	1	1	0	1	1	5
Does the Framework maximise standardisation in the design and creation of a healthcare facility?	1	0	1	0	1	1	4
Challenges for the Framework are using both measurable and non-measurable factors which define efficiency, effectiveness and quality of the healthcare facility	1	0	1	0	1	1	4
The Framework informs health planning information by generating criteria that can be used for its evaluation	0	1	1	1	1	0	4
Does the Framework optimise flexibility of a healthcare facility such as an A&E Centre?	0	1	1	0	1	1	4
Implementation of the Framework will help achieve NHS cost savings and aid the delivery of £15-20 billion in efficiency savings by 2014	0	X	1	1	1	0	3
Integrating the Framework into the RIBA Plan of Work (2013) clarifies the capacity of design teams to deliver quality healthcare projects which ensure better patient and staff outcomes.	0	1	0	1	0	1	3
Do you agree that the Architect has a leading role in implementing the Framework if it is to be successfully integrated within the RIBA Plan of Work?	0	1	0	1	0	0	2
Key P1= Participants (architects, facility estate managers and BIM specialist) Yes = 1 and No = 0							

Table 8.4: *Validation Questions and results (interviewee P1)*

Validation (Interviewee) Findings						
Does this framework look potentially useful to you? Please state reasons.	**Under what circumstance would you use this framework?**	**Who is the best person to take ownership of this framework?**	**How would you compare this framework to current approaches towards embedding flexibility?**	**Is there anything missing in the content of refurbishment, flexibility, standardisation or BIM process? If yes, please state.**	**In what ways can this framework be improved**	**Points to consider**
Yes It provides guidance for achieving quality in design.	To present the process to the entire team.	Design team.	Flexibility is embedded by architectural designers from their work experience. There is no specific flexibility process. Flexibility can be embedded into a facility by first designing the best option and at a later stage different flexible option are generated from the best.	Flexibility: You need to state if the flexibility can be embedded by in-house staff or flexibility experts. You need to give at least three different examples, minimum, medium and maximum. Building Information Modelling (BIM): You need to define what you understand by BIM. Who owns the BIM model? Who manages the model? Identify the integration of BIM electronic data (COBie data).	Identify who executes the framework. Identify who pays for the framework tasks. Identify how it fits into the contractual arrangement. Identify precisely what the framework does.	Reducing travelling distances could lead to deep planning; Multi-purpose uses of spaces could lead to over utilisation; Does the framework responds to future changes, such as policies? Identify why you have not included non-measurable aspects; 65% of hospital design is centred on the mechanical electrical and plumbing services (MEP); There are three key stages within the project delivery process. These are the pre-project, project and post-project stages. Are you trying to educate the architect / contractor / client? This framework can be used to teach students the concept of flexibility and standardisation (suggestion).

Table 8.5: ***Validation questions and results (interviewee P2)***

Validation (Interview) findings						
Does this framework look potentially useful to you? Give reasons please	**Under what circumstance would you use this framework?**	**Who is the best person to take ownership of this framework?**	**How would you compare this framework to current approaches towards embedding flexibility?**	**Is there anything missing in the content of refurbishment, flexibility, standardisation or BIM process? If yes, please state.**	**In what ways can this framework be improved**	**Points to consider**
Yes. It is good if used as a design guide or check to enable value in design.	I would use it as a design tool from stages A to D.	I think the lead designer or the project manager should take ownership of the framework but it is reviewed by the team at several critical gateways and all parties' sign off decisions made at pre-determined stages.	There is no specific flexibility schemes used for embedding flexibility. Flexibility is normally designed from the experience of the design team.	Building Information Modelling (BIM): Government requirement for BIM levels should be included.	There should be collaboration at each stage. There has to be agreement at each stage before proceeding to the next. There should be cost implication at each stage. Describe the three vertical lines of the framework.	There has to be collaboration at each stage. Don't leave people out too late. You can get a project cheap and good, but at a very slow rate. You can get a project fast and good, but at a very high cost. Flexibility is expensive. There should be: option generation; option analysis; and a decision needed. Start with the best option and different options can be generated from the main design option. It might be cheaper to design two different rooms than to design a multi-purpose room. Worst designers are the surgeons, brilliant around the table and worse when designing an entire space.

Table 8.6: *Validation questions and results (interviewee P3)*

Validation (Interviewee) findings						
Does this framework look potentially useful to you? Give reasons please	**Under what circumstance would you use this framework?**	**Who is the best person to take ownership of this framework?**	**How would you compare this framework to current approaches towards embedding flexibility?**	**Is there anything missing in the content of refurbishment, flexibility, standardisation or BIM process? If yes, please state.**	**In what ways can this framework be improved**	**Points to consider**
Yes, It looks at the flexibility criteria required.	It can be used to introduce less experience professionals joining the design process, this may include: Engineers; builders; MEP; and other sub-contractors.	Design manager on site.	We don't have a specific flexibility process.	Flexibility: Sketching the flexibility approach at the Conceptual Stage. Building Information Modelling (BIM): I would not make 3 or 4 different models at RIBA Stage C. A BIM model can be developed in RIBA Stage D, when an option is chosen at Stage C. The Government BIM requirements should be included. Standardisation ADB is just a recommendation, when it gives too much or too little space; customisation can take place.	RIBA Stage C consists of sketches analysed by different stakeholders. There should be collaboration at all stages; there is no collaboration in Stage B and Stage C.	Other stakeholders need to understand that there is a project brief and it needs to be developed. The framework can help show stakeholders the process to achieve the design goals. Flexibility is expensive. We understand 4D as time and 5D as cost. The 4D modelling should come out of the model designed.

Table 8.7: *Validation questions and results (interviewee P4)*

Validation (Interviewee) findings						
Does this framework look potentially useful to you? Give reasons please	**Under what circumstance would you use this framework?**	**Who is the best person to take ownership of this framework?**	**How would you compare this framework to current approaches towards embedding flexibility?**	**Is there anything missing in the content of refurbishment, flexibility, standardisation or BIM process? If yes, please state.**	**In what ways can this framework be improved**	**Points to consider**
Yes, In so much as it promotes consideration of change-of-use/flexibility of buildings at the outset of both new build and refurbishment projects. This, however, should be good practice for any major project, so apart from promoting this aspect I'm not sure it takes good practice further.	I would consider it as one of a range of Frameworks – so providing it to be Official Journal of the European Union (OJEU) tender compliant then it would offer a convenient route to delivery avoiding the OJEU hurdle (very valuable in its own right).	Probably a significant Procurement Hub within the NHS or maybe Central Government.	As earlier stated, it is not the frameworks, but the forward thinking of estates staffs that decide to build flexibility into projects; most design work enables this, so it is just about building this into one's specification.	I would expect this advice to come from the design experts.	I suppose that the most important thing for me is to demonstrate how the framework can retro-build flexibility into existing buildings, which makes up the body of our estates for the next 30 years. New builds should design flexibility as a standard unless the change horizon (for that building) is static; unlikely.	This type of approach has been around a long time, building the thinking into a framework is a very good step, ensuring that flexibility and change are considered at the right design stage. Unfortunately, the current game is focussed on short-term savings, selling solutions, and building cost into projects today, to potentially save money in the future is very difficult to sell to hard pressed budget holders. Tenders from public sector above certain budget threshold need to publish documents (OJEU).

Table 8.8: *Validation questions and results (interviewee P5)*

Validation (Interviewee) findings						
Does this framework look potentially useful to you? Give reasons please	**Under what circumstance would you use this framework?**	**Who is the best person to take ownership of this framework?**	**How would you compare this framework to current approaches towards embedding flexibility?**	**Is there anything missing in the content of refurbishment, flexibility, standardisation or BIM process? If yes, please state.**	**In what ways can this framework be improved**	**Points to consider**
Yes. It could be used as a guide.	Within a team.	The client can request the procurement team to use the framework.	In some cases you could get a 50% refurbishment and a 10% new built. This could be confusing.	I'm not sure there is anything missing; it looks quite clear and straight forward.	What are you looking to achieve? What life cycle are you trying to manage weekly, monthly or yearly? Project Goal and Strategic Business should be linked The architect has a senior role but should not lead the framework application. More detail for space utilisation is required. Project objectives should be clearly identified and criteria for measurement should be set.	What happens when a project is partly refurbished and partly new built? How does the framework respond to this? With junior staffs there might struggle with this. You're still requiring flexibility and standardisation requirement in stage A and B. Collaboration should be put up at the early stages. You would not know if you want to do a new built or refurbished at stage B. How can the framework inform an NHS estate manager that they are some underutilised spaces.

Table 8.9: *Validation questions and results (interviewee P6)*

Validation (Interviewee) findings						
Does this framework look potentially useful to you? Give reasons please	**Under what circumstance would you use this framework?**	**Who is the best person to take ownership of this framework?**	**How would you compare this framework to current approaches towards embedding flexibility?**	**Is there anything missing in the content of refurbishment, flexibility, standardisation or BIM process? If yes, please state.**	**In what ways can this framework be improved**	**Points to consider**
Yes. It looks very useful. It in-cooperates all the RIBA design stages with an overlay.	The framework can work in line with the RIBA Plan of Work (2013).	More collaborative BIM processes inspire stakeholder to work together to make more informed decisions. It would be best for the entire design team to own the framework.	The flexibility approaches will depend on the different working schemes of architectural practices.	-	It has to work with the new RIBA Plan of Work (2013). There should be collaboration at all stages for a more collaborative BIM.	There is a development between the 2007 and the new 2013 version that is supported by the construction industry council who are working with the cabinet office on the various BIM task groups. These include: The creation of new stage 0 (strategic definition) underlines the need to strategically appraise and define a project prior to developing an initial project brief. The Developed Design Stage is aligned with cost information. It may not increase the amount of design work required but will necessitate additional time for reviewing and co-ordinating information. The design work ends at Stage 4, although designers at this stage may have to respond to design queries that arise from work undertaken on site during Stage 5. In-use Stage is introduced into Stage 7.

8.5.1.2 Concerns raised by interviewees

The validation interviewees had some concerns regarding the framework design. The key questions addressed by the validation interviewees regarding methods of improving the framework were identified. These include: collaboration at all levels; provision of schematic sketches; the need to utilise existing spaces. Kagioglou and Tzortzopoulos (2010, p. 163) are of the view that "*managing space as a resource rather than as territory will improve space utilisation rates and will almost certainly require changes in working practices to become fully adopted*". There is a need to utilise healthcare spaces, EC Harris (2013) described that a lot of money is spent on underutilised spaces, autonomously increasing the costs of managing healthcare spaces. Other issues raised by the interviewees are presented below

Why is the framework not applicable to all buildings?

The framework can be applied to other buildings, but the findings relating to the applications of flexibility and standardisation were centred on healthcare buildings; all other findings are applicable to all building types. For example, the effective application of flexibility in healthcare buildings is suggested to be applied on a long-term basis (questionnaire survey findings); the effective application of standardisation in healthcare buildings is advised to be applied to rooms (questionnaire survey findings). Due to the 24 hour round the clock services provided by healthcare buildings, a total of 65 percent of healthcare project work is centred on MEP services (validation interviewees: P1). Therefore, the framework suggests clash detections and other analysis before a virtual plan is selected for construction. It is vital that stakeholders collaborate during the analysis and evaluation process at the early project stages. However, the framework can be applied to other buildings with minor alterations.

How is flexibility infused into existing facilities?

To input flexibility into an existing facility, it was suggested by Slaughter (2001) to identify the features of the existing facility. These include: capacity, operational flow pattern and functions. The proposed changes should also be identified and organised. Hence, the existing and proposed findings can be carefully integrated while focusing on circulation, way-finding, clashes of functional flow and systems support (interviews). To input flexibility in refurbished or new buildings, Brand (1994) identified six S`s which are centred around building elements. The type of building element to consider will depend on the type of flexibility in focus. For example, short-term flexibility will require building elements such as *stuff* within a building *space*. While long-term flexibility focuses on the building *structure* or *site*. When embedding flexibility in refurbished or new buildings all relevant stakeholders should collaborate and participate in the decision making process to make informed decisions (interviews).

What is in-use/in-house flexibility and what is expert built flexibility?

Experts can handle both in-use (short-term) and structural flexibility (long-term). A time the facility managers are responsible for conducting the in-house facility flexibility. With many years of managing facilities, the facility managers are capable of re-arranging or re-configuring the facility space more closely. Design experts are mostly required to develop structural and long-term flexibility. However, experts are required at all levels as they provide designs that are coupled with flexible strategies. In-house flexibility is a time an *aftermath approaches* (interviews). Therefore, it is advisable to design for flexibility at early design stages rather than building flexibility while a facility is occupied and operational. Validation interviewee P4 stated that "*it's not the framework, but the forward thinking of estate staff that decides to build flexibility into projects*". It seems facility mangers have a lot to offer when dealing with in-house flexibility. However, there might be a need for a different delivery system. Facility managers should collaborate at the early design stages with healthcare designers and planners to embed short-term, mid-term or long-term flexibility strategies in order to achieve an effective change-ready healthcare facility.

Who is the framework meant for?

The framework is important to different stakeholders in the AEC industry; it is designed to inform all stakeholders involved in the process of embedding flexibility. The framework is generally meant to be managed by the design manager or design team. The framework can be used in institutions to inform students the use of BIM and flexibility within the RIBA Plan of Work (2013) that is accepted throughout the UK. Validation interviewee: P3 stated that "*the framework would also be important to newly or in-experienced designers by stating the needs and requirements essential for designing a change-ready healthcare facility*".

What is the contractual arrangement of the framework within the building delivery process?

The framework explicitly needs more collaboration at all stages; all the validation interviewees were of the view that collaboration is eminent. The use of BIM could change the building delivery process from traditional to a more collaborative contractual arrangement where all the stakeholders involved, participate and collaborate at the early stages of the building delivery process (Eastman *et al.*, 2011). Therefore, the RIBA is continuously refining the delivery process to meet the needs and requirements of BIM implementation within the AEC industry. There are five defined procurement methods described by the RIBA Plan of Work (2013). These are: the Traditional contract; one Stage Design and Build contract – contractor`s proposals at stage 3; two Stage Design and Build Contract – contractor`s proposals during Stage 4; management contract; and contractor-led contract. However, interview findings in chapter 7 showed that traditional delivery method is the most common approach. But whatever the procurement method adopted, this framework supports a more collaborative approach towards designing and decision making.

What are the specific BIM considerations for the framework designed?

Bew and Underwood (2010) stated that despite the advantages and disadvantages of applying BIM in the AEC industry, it is vital that the basis of BIM in the industry is understood to make informed decisions on its application. Therefore, it is vital to understand that the application of BIM has many barriers; these challenges could affect the general use of the framework developed for the design of a change-ready healthcare facility. Some of the validation respondents stated their key concerns with regards to the application of BIM in the developed framework. The concerns of the interviewees are described below:

- **Who manages the model?**

The BIM model is attached with information from various stakeholders. These include architects, structural engineers, MEP contractors, quantity surveyors etc. The BIM model proposed within this framework is similar to any other model designed in a BIM environment. It is clear that most professionals do not want to be responsible for managing the BIM model due to cost implications (interviews); there are factors that create barriers towards the management of the model. These are budget, time and the responsibility of coordinating information from all stakeholders. The individual or organisation responsible for managing the model has to be equipped with management skills, BIM skills, design, construction and facility management awareness. As a result, a BIM manager/information manager should be hired and appointed to manage the model information.

- **Who owns the model?**

The client is the best person to own the model, after the analysis and evaluation of the different *design options* with BIM, an appropriate design is constructed virtually with the exploration of its schedule of completion (time), entire budget (cost) and building performance before the design is eventually constructed in the real world. There is a need to use precise information and real live information within the BIM model to manage the facility efficiently and effectively after it is fully occupied. For example, repairing building elements through warranties or refurbishment requires existing information that the BIM model can store and provide when required. As a result, the client needs the BIM model to provide existing information for future works that include facility management/refurbishment.

- **Who pays for the model?**

The individual or party that should pay for the BIM model has not been verified by this study. However, for the purposes of this research, the client/owner could get many benefits. For example, the benefits of the BIM model include: storing existing information, providing information for refurbishment, warranties and repairs. The existing stored project information can be used in other projects in a different site with similar site properties, functions, flow, and capacity; saving part of the cost associated with architectural redesigning.

- **How are the problems of interoperability tackled? (information exchange)**

The problem of interoperability can affect the entire application of BIM in the AEC industry. However, there are many on-going researches that are dedicated towards the development of information exchange processes as the panacea to problems associated with information compatibility. These include organisations such as BuildingSmart. BIM project protocols are used to define the software use in order to promote effective information exchange. BIM goals, needs and requirements set for the purpose of a given project should be identified at the early design stages to enable good information exchange capabilities. There is also a BIM library developed by the National Building Specification (NBS) which is a commercial body of the RIBA. It provides BIM objects that are compatible. Isikdag *et al*. (2007) stated three processes of data exchange and sharing mechanism. These are: file exchange formats (data exchange), working form (data sharing) and shared database (data sharing). To inform collaborative project working within the AEC industry; a Collaborative Construction project Web Site (CCWS) is used for information sharing. Underwood and Watson (2003, p. 130) stated that the CCWS is "*a collaborative environment for the management and exchange of documents between organisations and is therefore neutral of any individual organisation*" they also stated that it provides the ability to:

- managed document workflow;
- fast publishing and downloading;
- audit trails/logs;
- automated revision control;
- automatic generation of notification;
- e-mails;
- multi-format storage; and
- standardised document issuing procedures

- **How is BIM implemented?**

BIM has to be implemented within an organisation, across an office or in a given project before the framework can be fully explored. There are different implementation plans available to guide the adoption of BIM at different level. Ahmad *et al.* (2012a) presents the analysis of different implementation plans, key issues when implementing BIM are identified. The key issues can be considered when BIM is scheduled to be implemented. However, the barriers towards implementing BIM were also outlined.

8.6 THE FRAMEWORK REVISED BY VALIDATION INTERVIEWS

The framework for designing a change-ready healthcare facility was developed from the literature review, questionnaire survey and interviews. The three research methods were used to generate one final framework. The framework was revised based on the following key issues addressed by the validation interview respondents. These include:

- the framework should take up in-house flexibility approaches from facility managers at the early design stages;
- the should be collaboration at all levels;

- the framework should be merged with the RIBA Plan of Work 2013
- all stakeholders involved should sign off at each stage;
- cost targets should be clearly addressed;
- there are no approaches towards space utilisation
- sketches should be developed at the Conceptual Stages; and
- creating a BIM model is not sustainable (cost) at the Conceptual Stages for some practices. This has also been considered in the revised framework.

The validation changes made to the framework revised from interview findings

The RIBA Plan of Work 2013 has been in cooperated into the framework previously revised from interviews. Inconsistency with the RIBA Plan of Work (2013) and the revised framework were not identified by any of the participant. However, the interview participants stated this for information purpose. Collaboration with all relevant stakeholders was introduced to all stages of the RIBA Plan of Work (2013). Furthermore, while collaborating with relevant stakeholders an input was made to allow them to all sign off. In order for the framework to take up in-house flexibility from facility managers, collaboration at RIBA Stages 1 and 2 allows the exchange of information from different stakeholders at the early design stages. Cost involved in any specified project is identified at the early stages. Budget is a key driver to the scale of projects. Therefore, cost was identified at RIBA Stages 0, 1 and 3 of the revised framework; in Stage 2, the conceptualised design is based on the cost target suggested at Stage 1. An input was made at RIBA Stage 1 to identify underutilised space at early design stages for any given project to progress with. This study has suggested further research to identify possible strategies of specifying utilised and underutilised spaces within existing facilities. The framework suggested the introduction of sketches before a design that a project can progress with is identified and modelled at Stage 2; as some of the interviewees suggested that it is expensive to develop a BIM model at the early stages while a sketch could satisfy.

8.7 FRAMEWORK IMPLEMENTATION STRATEGY

The framework is designed mainly for projects requiring flexible and standardised healthcare spaces that are adaptable to known/expected future changes. The strategy of applying the revised framework is to input refurbishment, flexibility, standardisation and BIM contributions at appropriate stages of the framework as it works in line with the RIBA Plan of Work (2013); its application is accepted, acknowledged, recognised and conventional in the design, construction and facility management of buildings in the UK construction industry. Therefore, while following the RIBA Plan of Work, the framework can be implemented. There is a UK Government BIM mandate by 2016. Therefore, the framework has to address the need for BIM. It proposes an overlay or approach that enables the application of flexibility to be applied within healthcare facilities. The implementation enables projects to be executed within short-term, mid-term and long-term basis. Sequences of steps are provided for BIM implementation. PAS 1192 and this framework both support and facilitates project delivery with collaborative working between stakeholders through information (graphical, non-graphical and documents) management. There is a need to focus on refurbishment projects; the validation interviewee P4 stated that "*there is a need to build flexibility into existing buildings; new buildings should design for flexibility as a standard*". The revised framework presented in Figure 8.3 is equipped to progress and manage both existing and new buildings at the early project stages; the framework is focused on refurbishment projects but can be easily used in new projects. The previous framework (interviews) consists of 13 steps, while the revised framework consists of sixteen steps after considering the (validation interviews) findings.

8.8 BARRIERS TO IMPLEMENTATION OF THE FRAMEWORK

There is a need for clients to change their mind set and appreciate lifecycle thinking. The framework is suitable for flexible healthcare facility projects. Flexibility cost money, but the operational cost reduces when a building is adapting to changes. The framework has a challenge to appeal to the different building procurement approaches within the AEC industry (Validation interviews). The framework supports and promotes a more collaborative approach towards projects. A traditional building procurement approach would unsettle the framework implementation sequence. In a survey conducted by the RIBA in 2012, findings showed that most architectural practices within the UK frequently use the Traditional Procurement route (86%) followed by the One Stage Design and Build approach (41%) (RIBA, 2013). There are currently no specific standardised approaches towards embedding flexibility into buildings within the different architectural practices that participated in the validation interviews. Therefore, it would be difficult to change the norm practice of architects to use a defined standardised framework that can provide guides, check and balances when embedding flexibility in healthcare facilities. The notion of *change* in current practice will always have its advantages and disadvantages. Despite this, most architectural practices use experience gained over the years of practice in order to embed flexibility into facility projects (validation interviews). The validation interviewees P1; P2; P3; and P6 were of the opinion that there is no one way of applying flexibility to buildings. The framework welcomes the different flexibility approaches as long as they have backing from literature or current practice. Another problem is the early creation of BIM models; most of the architects interviewed in the validation process were of the view that it will cost more money to created BIM models before a design that the project team will progress with is identified (agreed upon). The validation interviewee P3 stated that "*I will not make three or four different models at Stage C, but at Stage D when an option is chosen to further develop*". As a result, it would be better to produce sketches at the early design stages to save cost. Stages C and D of the RIBA Plan of Work (2007) are equivalent to Stages 2 and 3 of the RIBA Plan of Work (2013). The framework can easily be applied by following the 16 steps of the revised framework (validation interviews) sequentially. The revised framework is presented below.

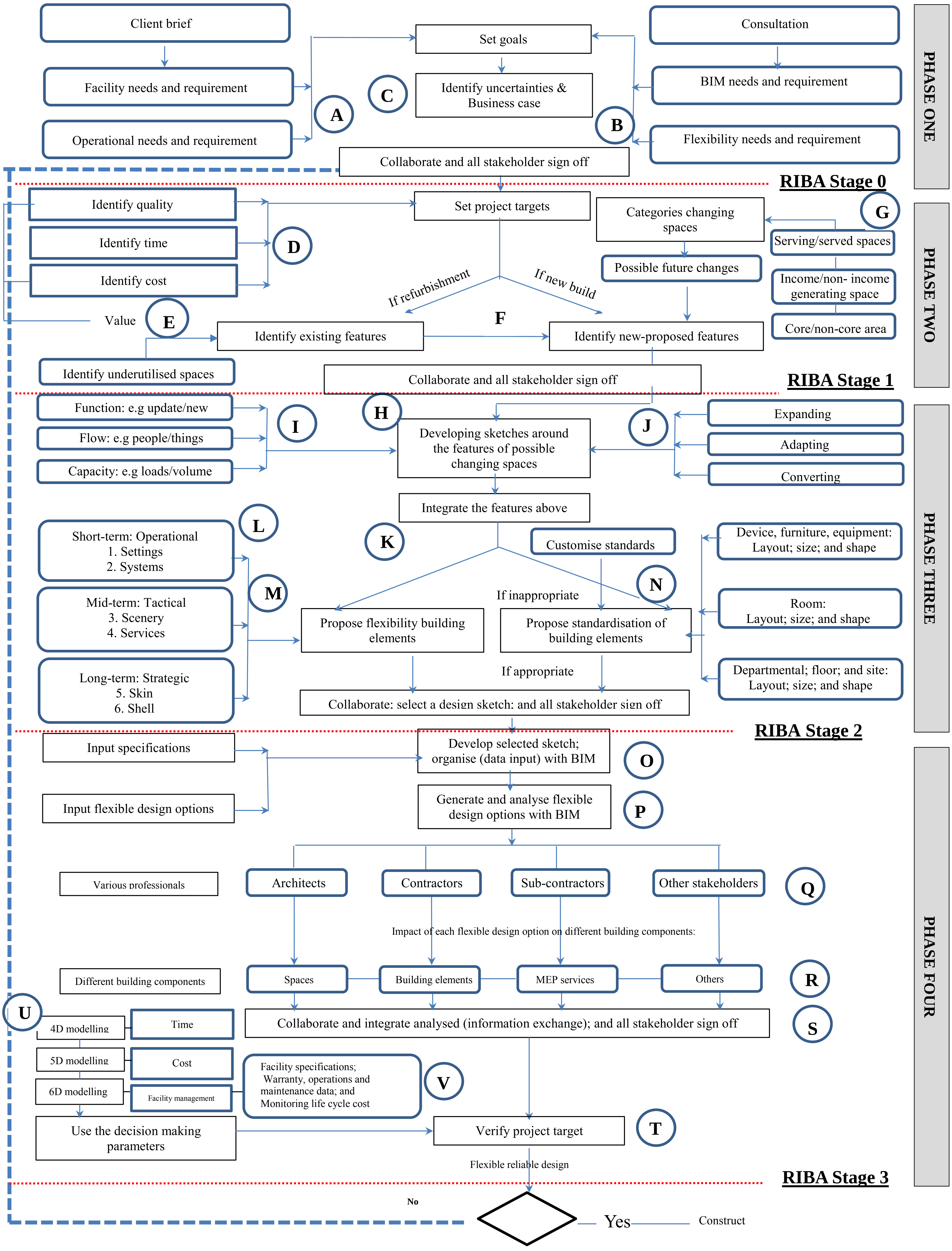


Figure 8.2: A *framework to design a change-ready healthcare facility generated from literature review, questionnaire and interview findings*

8.9 CHAPTER SUMMARY

This chapter focuses on the development of the framework for designing a change-ready healthcare facility. The framework was developed from literature review, questionnaire survey and interviews, and was further validated through an interview process. The framework presents a sequential process that can facilitate the adaptation of future changes in healthcare facilities. The findings of the validation were presented in detail. The benefits and challenges of implementing the framework in a healthcare facility were identified. The challenges include dealing with uncertainties; the adaptability of the different contractual project delivery method, the framework can work with traditional delivery method, but will not be very effective and efficient. Other challenges include: choosing a BIM implementation plan; cost of implementation BIM; managing the BIM model; information exchange within the BIM environment; paying for the BIM model; and identifying the owner of the BIM model. It is not proven how much time and cost this framework can save, or the quality standard that can be achieve through its implementation. However, BIM can facilitate transformational changes within a project or an organisation. The use of BIM can undoubtedly cut cost and save time through automation, MEP clash detection, virtual performance analysis and collaborative analysis of data from various stakeholders at early project stages. All the validation respondents were of the view that the framework is useful. They identified some points to consider while revising the framework. These include: collaboration at all stages; all stakeholders signing off at each stage; creating sketches at Stage 2 to save cost; and identifying underutilised spaces. The next chapter summarises the entire research and proposes areas for further research.

9 CHAPTER 9: CONCLUSION, RECOMMENDATIONS AND AREA OF FURTHER RESEARCH.

9.1 CONCLUSION

This chapter presents conclusion, recommendations and contributions of this research. The contribution of this research has both theoretical and practical implications. Advantages and limitation of the research are also discussed. The boundaries of this research are clearly defined, while areas of further research are described explicitly. The aim of the research centres on the development of the framework for designing a change-ready healthcare facility. The framework has been developed and validated with different stakeholders in the healthcare sector through the analysis of literature review, questionnaire survey and interviews. Another set of interviews were conducted to verify and validate the framework. In addition, parameters that can facilitate decision making on the different design options generated using the framework were identified. After the generation of these options there is a need to decide which option is most appropriate for a given Design Brief. BIM can be used to record and present the key decisions made at specific stages of the framework for each design option to facilitate decision making.

Future healthcare facilities need to respond to the rapidly changing nature of healthcare facilities during its life cycle process. These could be due to: an ageing and growing population; advance technology in equipment and medical care; Government policies; and the needs of different facility users. These changes can cause facilities to be unsuitable for modern healthcare delivery and result to frequent refurbishments. As a result, healthcare facilities need to change and adapt to future requirements. It is difficult to predict these changes, but it is possible to forecast some changes from precedent studies or evidence based research. The main objective of this research is to develop a framework that can guide the design of a change-ready healthcare facility, to achieve a flexible facility that can adapt to future changes. Findings show that the framework developed is useful, but it is not very compatible with the traditional procurement method which is the most frequent building procurement method in the UK (RIBA Plan of Work, 2013). The uses of the four applications (refurbishment, flexibility, standardisation and BIM) were combined into the framework developed to improve project quality. These applications have to be strategically and effectively applied within healthcare projects to achieve cost effectiveness and project value.

9.2 FINDINGS FROM RESEARCH OBJECTIVES

This research presents a framework developed to guide healthcare designers and planners to design healthcare facilities that can adapt to future changes. The aim of designing a change-ready healthcare facility is to cut costs, save time and improve the quality of healthcare delivery on a short-term, mid-term or long-term basis. The application of *BIM* can facilitate the combined application of *flexibility* and *standardisation* within a healthcare *refurbishment* project. Findings from the six research objectives are presented.

9.2.1 OBJECTIVE 1

To understand refurbishment, flexibility, standardisation and the application of BIM within a healthcare environment

This objective was set to explore and understand available literature around the context of the four applications used in this research. These includes: the application of refurbishment and reconfigurations; flexibility concepts and approaches; the need for refurbishment, flexibility, standardisation and BIM in healthcare facilities; and the description of a refurbished space, flexible space and standardised space in healthcare.

Refurbishment is understood as a process of extending the useful life of an existing building through upgrading, developing, improving or expanding a facility. Findings showed that healthcare buildings need to be refurbished at some point to achieve sustainability in regards to cost, quality and performance. The BBC (2010) stated that one fifth of the NHS Estates were designed and constructed before the NHS was created in 1948. This shows that 20% of the NHS estates are likely to be unsuitable for modern healthcare delivery. Flexibility is the ability to change or adapt to future needs when required. But Neufville *et al*. (2008) stated that it is impossible to predict future patient activity with reasonable degree of accuracy. Despite this, there are known future changes that can be predicted in healthcare, such as the number of beds required in a given population. Lam (2008) noted that there is a ratio of one bed to 1000 people. This can be applied to an approximate population figures provided by appropriate Government bodies.

There is a need to explore and understand the application of BIM in healthcare. It supports the design of virtual models and the analysis and evaluation of different flexible design options. The specifications attached to the models include space dimensions, windows and door sizes, materials and equipment information; these can all be organised and managed efficiently within a BIM environment. There is a relationship between refurbishment, flexibility and standardisation with BIM as a tool. There is also a relationship between refurbishment, flexibility and standardisation with BIM as a process. The application of BIM as a process was considered more appropriate as it supports more collaborative working. It can be used to analyse and evaluate different design options within a virtual environment with the provision of information from different stakeholders involved in a given project. Each design option is attached with specific information, such as cost, time-frame of construction, performance analysis and possible clash detection within the MEP services. Chellappa (2009) and Eastman *et al*. (2011) described that BIM models can be used to store existing building information (specifications) such as building size, shape, layout, function, warranty information and so on. When refurbishing a building, existing information is very important; it can easily be used to propose schemes that can improve the existing conditions of healthcare facilities such as space utility and operational effectiveness. PAS 1192 can be used to facilitate the application of BIM in the framework by providing guides for information (3D; 2D; and documents) management.

9.2.2 OBJECTIVE 2

To explore the challenges of BIM in the design of a flexible and standardised healthcare facility;

A flexible and standardise healthcare facility is designed with the combination of flexible approaches and standard/customised specifications that are agreed by *Management* such as the NHS trust/estates through HTN/ADB. BIM has to be implemented before its benefits can be industrious and profitable. As there are different understandings of BIM in the AEC industry, there are different definitions and BIM implementation plans. A very good question is how do you choose a good BIM implementation plan? Ahmad *et al*. (2012a) (appendix 2) presents different BIM implementation plans from three different categories. These are: academicians; software vendors; and AEC industry and other organisations. 16 key issues were identified to be considered when implementing BIM. These include:

- defining BIM goals;
- plan BIM uses;
- start with a team;
- leadership;
- managerial support;
- specify level of BIM implementation
- continuous training and development;
- information exchanges execution;
- appropriate hardware and software;
- conformity to standardisation;
- educational BIM awareness;
- spreading implementation from one team to the others; and
- reviewing performance.

There is a lack of agreement in some of the features identified, such as starting with a team and spreading the implementation across an organisation. The advantage of starting with a team is that the implementation procedure can easily be managed within a team compared to an entire organisation; changes that can improve BIM implementation can easily be accomplished when the need arises. The top three implementations plans were identified as the plans from Autodesk, Penn State University and Indiana State University. There have provided most of the 16 key issues identified above. Despite this, they have guides that can easily facilitate information collection from users to ensure that appropriate information for BIM implementation is available.

There are arguments in literature and social media regarding the impact of BIM tools on design creativity. Design creativity is required when designing flexible spaces. Some literature sources have shown that BIM tools can affect design creativity, while other sources showed that BIM tools empower designers to achieve their imaginative creativity, in some situations BIM tools supports infinite creativity. Creativity is important when designing a facility; the early design stages (Concept Design) are crucial to achieving creativity. Ahmad *et al*. (2012b) (appendix 3) presents findings from literature and questionnaire survey to illustrate the view of respondents on the impact of BIM tools on design creativity. Questionnaire survey respondents were the top 100 UK architectural firms presented in chapter 6. It was noted that there is a higher mean of questionnaire survey respondents of the view that BIM tools could improve design creativity compared to BIM tools affecting design creativity. A strategic approach was suggested to respond to the questionnaire survey respondents of the view that BIM tools affect design creativity *negatively*. Meneely and Danko (2007) stated that one should not just question the tools but the designer as well. To create awareness, three key issues were modified. These are: *motive* as what a designer expects to do with BIM tools; *mind* as how the designer expects to use BIM tools; and *media* to understand how BIM tools can empower designers.

The other challenges of applying BIM in the design of a flexible and standardised healthcare facility include the problem of information exchange, choosing the information manager, paying for the model, owning the model, the contractual arrangement for applying BIM and so on. The specification of a standardised healthcare facility can be stored in a BIM environment, but there is a challenge of effectively sharing the information within a BIM environment.

9.2.3 OBJECTIVE 3

To examine an effective and strategic process of applying refurbishment, flexibility, standardisation and BIM in healthcare

The four applications have an important role in the development of the framework for designing a change-ready healthcare facility. Table 3.1 in chapter 3 claims a possible relationship between the four applications. Within the ten different factors identified, the four applications seem to have five similar factors recorded from different literature review sources. These include:

- saving time and cost;
- ease to use/ reuse facility;
- increase operational management;
- increase patient and staff safety; and
- increase whole life cycle cost effectiveness.

The four applications are strategically designed to be applied in a healthcare facility in chapter 5. The application of flexibility, standardisation and BIM were considered to be applied during a refurbishment or new project. The application of refurbishment was categorised into three scales. These are minor, average and major works. The applications of flexibility, standardisation and BIM can be situated around the three scales of refurbishment identified. Findings from chapter 5 showed that the application of BIM is more effective when stakeholders are collaborating (major works). The application of flexibility is more effective when applied on long-term basis (major works). The application of standardisation is more effective when applied to healthcare rooms (average works). Each one of the four applications contributes toward the development of the framework. Refurbishment is mainly considered as an opportunity to improve the existing situation of a building, it allows the use of flexibility, standardisation and BIM to take place. BIM is understood to be used as a tool, process and information manager. The planning approaches and concepts used for designing flexible spaces in healthcare were found to be (expanding, converting or adapting). It was also found that the use of modular design facilitates the design of multi-purpose spaces. Figure 3.16 in chapter 3 shows the process of using modular spaces in different similar unit sizes. The multi-use of the similar size spaces for different functional purposes can ease the process of designing a universal space. The six key building elements used for achieving flexibility were identified as Brand`s six “S”. These are: site; shell; skin; services; scenery; systems; and settings. Literature review findings were used to sequentially organise and assemble the four applications within the framework through the RIBA Plan of Work (2013).

9.2.4 OBJECTIVE 4

To identify how healthcare planners in-corporate flexibility in healthcare facilities;

Battisto and Allison (2002) stated that to achieve a flexible healthcare facility; the functional spaces can be divided into three different zones. These are: highly flexible; semi flexible; and least flexible zones; with each zone having a different level of standardisation. A questionnaire survey was used to identify key issues when building flexibility into healthcare facilities. There are two groups of findings: Sample One findings are from the top 100 UK architectural firms, while Sample Two findings are from the CNBR Yahoo Group (web based sample). The *top three flexibility design principles* identified by Sample One were identified as use of modular design, universal/generic space design and open building planning. While the use of structural grid design, shell space planning and scenario planning were identified by Sample Two. Samples One and Two had an agreement in the use of structural grid and modular design applications for achieving flexibility. The *top three important considerations for designing flexible spaces* were identified by Sample One as: cost; standardisation; and centralised support services and systems. While possible expanding/changing spaces, standardisation and services were identified by Sample Two., there is an agreement by both Samples One and Two on the use of standards and consideration for MEP services when designing flexible healthcare facilities. It was stated that 65% of hospital designs are centred on MEP services (Validation Interviews). This closely coincides with Sullivan (2007, p. 194) who quoted Boryslawski that "*in the health industry most of the problems occur in MEP construction coordination and about 45 percent to 55 percent of the total cost of hospitals projects are in the MEP system*". Another important finding is to *identify possible changing spaces* at the early design stages. The top six rapid changing spaces identified sequentially by Sample One as: surgery theatres; wards; clinical laboratories; consultant treatment areas; imaging unit; and entrance areas. While laboratory, wards, surgery theatre, emergency unit, nurse station and public support spaces were identified by Sample Two. To analyse both samples, clinical and patients areas can be categorised as the most frequent changing spaces. When incorporating flexibility into a healthcare facility it is important to identify key factors that can drive the flexibility process. For example, the cost involved and possible changing spaces need to be identified at the early design stages. When these spaces change, other mutual spaces may also be affected in order to achieve optimum performance. For example, when a multi-purpose space is equipped to handle scanning procedures and treatment for elderly patients when required, support facilities for the elderly have to be available in toilets or access routes leading to the multi-purpose space. It was stated by one of the validation interviewee P2 that "*it might be cheaper to design two different spaces than to design a multi-purpose space*". This indicates that lots of organisation, designing and planning goes into the design of a multi-purpose space and it is expensive to build. A cost analysis would always be required before any flexible design option is considered. The concepts and approaches towards applying flexibility have to be understood. For example, it is essential to have an idea of what concepts and approaches are best situated for short-term, mid-term or long-term flexibility to make informed decisions.

9.2.5 OBJECTIVE 5

To develop a framework for designers to produce digital flexible and standardised healthcare refurbishment realities using BIM

Future healthcare facilities are expected to respond to changes. The spaces that accommodate these changes should be flexible and designed in accordance to the NHS specification standards. BIM can be used to analyse, evaluate and visualise the different flexible and standardised options generated using the framework. To develop the framework, there was a need to improve the framework generated from existing literature to progress with a structure that is theoretically grounded. The framework that this research presents is new; the introduction of BIM into the framework poses a new challenge for this research. Therefore, there was a need to elicit the opinion of practitioners in the AEC industry on proposing new connections and applications within a flexible healthcare framework. More detailed information was required; a questionnaire survey and interview was conducted with architectural practices to further progress with a framework that is practically grounded. Digital flexible design options were explored using BIM tools; different similar designs can be developed from an original design within a BIM environment (interviews). However, the flexible planning schemes and approaches have to be organised by the designers and planners, BIM applications can only facilitate the process of designing, construction and facility management, but does not provide solutions. BIM is described as an effective tool and process that can be used to analyse and evaluate different flexible design options in chapters 6 and 7. For example, a function in Revit called *Design Options* can be used to show optional design intents to clients (interviews). An original design has to be developed first; other design options can then be created from the original design. There is a number of BIM software that can be used to analyse and evaluate the virtual design options generated. The analysed findings from the various stakeholders involved such as architects, quantity surveyors, MEP sub-contractors are put together; an informed decision is made on the most appropriate design option that's works within the set project target. This notion is incorporated into the framework to design virtual flexible and standardised healthcare design options in a BIM environment.

9.2.6 OBJECTIVE 6

To validate the framework

There was a need to validate the framework for designing a change-ready healthcare facility before it is implemented. The validation process targeted architects, the NHS estates, facility managers and the RIBA BIM working group. The validation interviewees raised many concerns with the framework designed. These include: the need for collaboration at all stages with relevant stakeholders; the need for sketches in the Design Stages; all relevant stakeholders should sign off at all stages; and informed decision is required when different design options are generated. Findings also showed that the RIBA Plan of Work was updated in 2013; and it supports five different procurement plans. These include the: Traditional Contract; One Stage Design and Build Contract; Two Stage Design and Build Contract; Management Contract; and Contractor-led Contract. This framework could be more effective with the One Stage or two Stage Design and Build Contract; it allows more collaborative work at early design stages. To practically implement the framework, the first problem identified from the architects that participated in the validation interviews was the non-use of frameworks/guidelines by architectural designers when embedding flexibility. All the designers that participated in the validation interviews were of the opinion that experience is mostly used to implement flexibility in projects when required. For this reason, applying a framework for designing a change-ready healthcare facility can be a management change issue. After the framework validation, findings were used to further improve the framework. Before the validation, the framework had 13 steps; after the validation, the framework had 16 steps.

9.3 RESPONSES TO THE RESEARCH QUESTIONS

The general achievement of the research objectives is that a framework for designing a change-ready healthcare facility was developed through the sequential steps of the research objects. Different research methods were explored and the explorations of the applications of refurbishment, flexibility, standardisation and BIM within healthcare facilities were key to achieving the framework. Before the framework was developed many research questions relating to the four applications had to be answered.

9.3.1 RESPONSE TO RESEARCH QUESTION CATEGORY 1

How can refurbishment increase the value of a facility?

Refurbishment is a process that allows a facility to improve its existing condition through maintenance, repairs, renovation or developments. Refurbishment is sometime more favourable compared to building a new facility. When the operational cost of a facility is increasing, it could be more sustainable to refurbish the facility compared to operating the facility in its current state. Any refurbishment scheme that is not capable of increasing the life span of the facility should be abandoned. This can be explored during the refurbishment appraisal process (pre-design process). The value of a facility increases when spaces are suitable for use and the operational cost of a facility is within reasonable project targets.
How can refurbishment allow flexible opportunities in a facility? Flexibility can easily be embedded into new buildings during the design process while it can be embedded into existing facilities during the refurbishment process. When building flexibility into existing facilities all existing and proposed design features are identified. These include spaces,

functions, systems, flow, way-finding, facility performance etc. the flexibility schemes should correlate with the proposed and existing features to achieve a balance in the design process structure. Flexibility can be achieved in a facility without conducting a refurbishment; in this case, adaptable short-term flexibility is embedded into a facility. In existing healthcare facilities, long-term flexibility requires structural alteration or adjustments that can only take place during refurbishments.

How can healthcare designers and planners combine the application of flexibility and standardisation within a refurbishment process? Flexibility and standardisation can be applied in different healthcare facilities such as Acute, Mental and Community hospitals. It was found in this study that both flexibility and standardisation can improve the quality of healthcare delivery (questionnaire survey). Price and Lu (2012) stated that there is no ratio of their combined application. The application of standardisation is expected to be implemented first before flexibility. The application of standardisation allows the use of flexibility to take place. For example, windows are mostly manufactured in a multiple of 300 millimetres (mm) standards; this creates some sort of flexibility as windows can be considered in different flexible formats such as 600 mm x 900 mm, 1200 mm x 900 mm and so on. Another example, similar room sizes can be used for different range of space purposes depending on their requirements. Flexibility can be applied in places where standardisation is less effective and vice versa. Battisto and Allison (2002) were of the view that a fully flexible healthcare facility can be divided into three categories. The level of standardisation applied in the highly flexible zone could be higher compared to the least flexible zone. This works in line with the design theory noted by Gibb (2001, p. 312) that within the four different design categories described by Fox and Cockerham (2000) as bespoke, hybrid, custom and standardised designs; different levels of standardisations can be applied within the different design categories. Bespoke designs have no standards. Hybrid designs have the least amount of standards; they are a combination of bespoke designs and designs with standard sub-assemblies. Custom designs are integrated with standards up to the assembly level. While standard designs are fully specified with standard components and standardised connections. It can be argued that there is no specific ratio of applying flexibility and standardisation, but there is a level of applying standards in the design process. Standardisation and flexibility can be combined within a design process.

How can BIM facilitate cost effective and cost efficient healthcare refurbishment processes? BIM is understood differently by different individuals and different organisations; but for the purpose of this research, it is understood as tool, process and information manager. Automation through the use of BIM applications enables time saving within the different construction tasks such as architectural design, structural design, quantification and performance analysis. Time saving increases cost efficiency. A refurbishment is expected to be an improvement on the existing structure; BIM visualisation can be used to share the details of a refurbishment project with clients and other stakeholders to allow the scope of work to be understood diagrammatically instead of using figures and words. The performance of a proposed refurbishment can be optimised virtually before its construction takes off. A BIM model can store warranty and repair information for facility management utilisation, reducing the costs associated with the maintenance process.

What is the refurbishment process? An appraisal analysis is conducted before any design is produced for refurbishment. The appraisal process is stated by Palgrave (2011) as an expensive analysis; it costs more that the preliminary design analysis conducted in new building schemes. There are conducted in order to decide whether to refurbish or demolish an existing building. The next step is the design process. Sheth (2011) described refurbishment process to include pre-refurbishment, refurbishment and post refurbishment stages.

What is the most effective refurbishment method that can deliver desirable project outcomes? It is vital that an appraisal is conducted before any refurbishment takes places. The findings discussed in chapter 7 described that the constraints of refurbishment should be identified by the stakeholders involved in the entire process. These include organisational and technical constraints, such as lack of skilled workers and appropriate information, site and space restrictions, communication, adequate planning schemes etc. Some interviewees in chapter 7 described that best practices for cost effectiveness and cost efficiency in refurbishment include: managing the refurbishment process properly; analysing existing information; planning to re-use and re-cycle; the operational records of existing facilities should be analysed and evaluated for performance and cost reduction; focus on budgets; decision making; and identifying and improvising solutions to manage possible constraints, disruptions, existing structures or construction waste.

9.3.2 RESPONSE TO RESEARCH QUESTION CATEGORY 2

How can flexibility improve the quality of a facility?

Once a facility is able to adapt to future changes when the need arises, it is assumed to be flexible and the quality of a healthcare facility can be enhanced. Quality within any given project can be set by the clients or facility user. For example, The NHS as a client can set quality standards for their projects. Flexibility could improve the quality of services provided by healthcare staff to patients; autonomously increasing the quality of care within a healthcare facility through the use of multi-functional/universal spaces to reduce travelling distances for both staff and patients.

How do designers in-corporate flexibility into a facility? Flexibility can be embedded into a facility using the flexibility planning and approach schemes identified in chapter 3. There are schemes for a facility expanding, adapting or converting to respond to changes. Flexibility can also be embedded into a facility using standards. For example, use of modular and standardised design layouts.

What are the most important considerations when embedding flexibility within a facility? Three important considerations were deducted from chapter 6. These are: identifying possible rapidly changing spaces; cost and services. Identifying the spaces that are expected to change by expanding, adapting, relocating or converting is important at the early design stages. Flexible designs are situated around a possible changing space.

Who manages the flexibility process during the designing and implementing process? Findings from the questionnaire survey presented in chapter 6 described that flexibility is designed collaboratively by all the relevant stakeholders involved in the project delivery. Facility managers in the validation interviews claimed that in-house flexible schemes are mostly managed by the estate managers such as the NHS estates. However, it is important that all relevant professionals collaborate to build flexibility into healthcare facilities at the early design stages.

What are the impacts of standardisation on the ability to design flexible spaces? It is very important to consider the application of standards in the design of healthcare spaces. Flexibility without standards can be customised for a small group of people, rather than for the average users.

What is the most effective type of flexibility when designing a facility? It has been identified in chapter 5 that long-term flexibility is more cost effective in a healthcare facility. This finding coincides with Neufville *et al.* (2008) that strategic flexibility is suitable on a long-term basis.

What are the impact of flexibility on cost efficiency and the value of a facility? With regards to cost, flexibility can mitigate the cost of early refurbishments when it adapts to future changes. Value can be achieved through the use of universal spaces or flexible equipment that are designed to reduce staff and patient travelling distance, autonomously reducing the hurdles of moving fragile patients. Flexibility can make healthcare spaces suitable for healthcare delivery.

9.3.3 RESPONSE TO RESEARCH QUESTION CATEGORY 3

How does standardisation impact the healthcare facility design?

Standardisation enables healthcare facilities to be designed effectively and efficiently. Price and Lu (2012) described features of a standardised space as: ergonomics specifications; modular units; standardising room sizes; creating similar room patterns; and modular detailing. Standardisation is a major driver towards achieving an effective healthcare facility. Staff can work effectively in an appropriate and suitable healthcare facility to deliver state of the art services to patients. The National Patients Safety Agency (2010, p. 16) stated that standardisation "*reduces costs, reduces mental workload, reduce errors and deviations from normal working easier to detect*".

What are the drivers and barriers to standardisation in healthcare? The top drivers and barriers towards achieving standardisation are presented in Ahmad *et al.* (2011), see appendix 1. The analysed secondary data showed the top five drivers for standardisation as: clinical functionality; clinical usability; staff efficiency; patient safety; and staff safety. While the barriers include: conflict with flexibility; unclear design guidelines/standards; lack of information; technical constraints; and budgets.

How can standardisation improve the quality of healthcare delivery? Quality of healthcare can be achieved through the use of standardised guidelines that have been tested to improve healthcare delivery through EBD/precedent studies. It has been stated by the NHS estates (2004) that the use of standards improves the quality of healthcare.

How is standardisation related to cost reduction in healthcare facilities? When standards are tested and approved in healthcare facility design, they design details can be re-used in other facilities with similar functions, saving the cost of redesigning. For example, the design layout of a patient room can be used in a different facility. There are also costs saving in standard designs; they suggest use of standardised building elements. Customised building elements are more expensive compared to standardised building elements. Hence, modular designs are more cost effective. Standardisation can also reduce maintenance costs due to routine pattern of use. For example, using standardised procedures or equipment manuals can result to less maintenance complexity; reducing cost.

How is standardisation applied within a BIM environment? To develop a standardised prototype model that can easily be re-used. Chellappa (2009, p. 57) described four processes of prototyping a project using BIM. These include: *setting parameters* for a desired area. For example, describing the allowable or minimum clear floor area; *obtaining components* (objects), such as wash hand basins, documentation area and storing area; *setting parameters for clearances*, such as the allowable working area required around a component; and *setting schedule parameter*. For example, the process of identifying the physical space details using recommended guidelines. The availability of different BIM tools allows designs to be stored, shared and re-use.

What is the most effective standardisation approach when designing a facility? Price and Lu (2012), Egan (1998) and Yorkon (2010) concord with the findings from the analysed secondary data used in this research stating that standardised rooms are most effective when standardising healthcare facilities.

How do designers and planners deal with the constraints of existing spaces when dealing with refurbishment? Findings from the interviews conducted with architectural firms in chapter 7 showed that some of the interviewees were of the view that the approach will depend on the nature of the existing spaces, and that the constraints of existing spaces are treated as any other constraints such as the constraint of budgets or project site. Nevertheless, the interviewees' findings were categorised into three groups. These are dealing with existing and proposed connections and integrations; way-finding and circulation; and overlapping functions to achieve an effective flow of healthcare delivery processes.

9.3.4 RESPONSE TO RESEARCH QUESTION CATEGORY 4

How can BIM aid in designing healthcare facilities?

BIM can be applied as a tool, process or information manager in the design of healthcare facilities. BIM as a tool can be used for automation, visualisation, analysis and presentation purposes. As a process, it can be used to facilitate information management and promote more collaborative analysis and evaluation between different stakeholders to make informed decisions. As an information manager, BIM can be used to store and share information with different stakeholders to facilitate the collaborative process.

How can BIM support the process of embedding flexibility within a healthcare facility? Interview findings with architects presented in chapter 7 identified four key factors that were effective in designing flexible healthcare facilities. These are: designing *what if scenarios*/different design options with BIM; visualisation; early collaboration and collaborative decision making; and information management.

How can BIM support the use of standardisation within a flexible space? Modular design supports the use of flexible designs (Yorkon, 2010). Modular designs enable the use of universal spaces, and BIM can be used to store, share and re-use the specifications of the spaces in a given design. The universal spaces can be optimised in a BIM environment through the use of "*design options*" in Revit Architecture.

What are the benefits and challenges of applying BIM in healthcare? Azhar *et al.* (2008) identified the benefits of BIM to include: faster and more effective processes through information sharing and re-use; better designs through optimisation of operational performance; controlled whole-life costs and environment data are better understood; automated assembly during manufacturing; better production quality; better customer service through presentation; life-cycle data for facility management. The challenges of BIM include: BIM myth; interoperability; legal issues; managing the model; controlling data entry (Eastman *et al.*, 2011). Bernstein and Pittman (2005) stated that there are two main challenges of BIM in the AEC industry. These are technical and managerial issues. Nevertheless, interoperability and people are major problem to the use of BIM. Other benefits and challenges of BIM are explicitly described in chapter 2.

How can BIM cut down the cost of designing a facility? BIM can save time through automation in design adjustments, autonomously saving cost. For example, objects are constructed within CAD software, but using BIM tools, objects can be used from *libraries* within BIM tools with the touch of a button. BIM is used in clash detection analysis, when a clash is prevented through MEP services analysis, cost is reduced. Costs savings are also expected within the entire life cycle of a building. Two important factors are key in cost saving. These are *information exchange* and *collaboration.* Life-cycle costs are better understood through the application of BIM (Azhar *et al*., 2008). Eastman *et al*. (2011) described that the optimisation of the operational performance of a facility can lead to cost reduction.

When and how do BIM tools impact design creativity? Park and Lee (2010) conducted a survey and found out that BIM tools have a higher usage in construction compared to design; and also Conceptual Design have a higher BIM usage compared to Schematic Design and Documentation. BIM tools could allow users to express his imaginative ideas in a virtual environment. It will be difficult to express some design ideas in the physical world without exploring their limitations in a virtual environment. However, some designers may disagree with BIM tools facilitating imaginative ideas due to the need of accurate data at early stages.

What is the most effective BIM approach when designing a facility? The most effective application of BIM in the AEC industry is to achieve a collaborative working relationship with appropriate stakeholders within a given project. Eastman *et al*. (2011) Hardin (2009); and Weygant (2011) are all of the view that BIM is effective when explored in a collaborative system.

Are there any special healthcare features in BIM? There are no special features in BIM specifically associated to the healthcare sector.

9.4 CONTRIBUTION TO KNOWLEDGE

This research has contributed to the design management of flexible and standardised healthcare facilities; autonomously developing a change-ready healthcare facility. The framework makes key contributions to knowledge as the first framework supported by the application of BIM. The contributions of this research are present below:

- the strategic applications of refurbishment, flexibility, standardisation and BIM can be merged within a single project;
- the combined application of flexibility and standardisation can be supported by BIM;
- a framework was developed for designing a change-ready healthcare facility. See Figure 8.2 for the detailed framework in chapter 8;
- 15 design parameters that can facilitate decision making when dealing with different flexible design options were identified. See Table 7.18 in chapter 7 for details;
- the framework creates basis for BIM to record and present the sequential guides used in designing each of the different flexible *design options* in order to improve the decision making process;
- 16 key considerations were identified when choosing a BIM implementation plan. See appendix 2: Ahmad *et al*. (2012a); and
- A refurbishment scope of work map showing were the applications of flexibility, standardisation and BIM are more effective within a refurbishment project is presented in Figure 5.6 of chapter 5.

The main contribution of this research can be attributed to the aptitude of consultants convincing clients to opt for an improvisation that can respond to known future changes when required; this improvisation takes place when proposing for a future healthcare facility design.

9.5 IMPLICATIONS OF THE RESEARCH

The outcome of this research helps to learn about how healthcare facilities can be designed to adapt to future challenges of modern healthcare delivery. As a result, this study has practical and theoretical implications; and provides benefits to healthcare facility users on short-term, mid-term and long-term basis. One of the academic implications of this research can be the sequential steps collected from primary data and added to the framework. The key findings from questionnaire survey and interviews can be added to existing literature.

9.5.1 PRACTICAL IMPLICATION OF THE RESEARCH

The framework developed in this research facilitates early collaboration between designers, planners and facility managers to build facility flexibility that can adapt to future changes. A change-ready healthcare flexibility can increase the life span of a facility. It was also reported by EC Harris (2013, p. 9) that there is a Hyde Park size opportunity of un-used spaces within the NHS estates which is currently underutilised and managed; causing a £2.3 billion gap, the cause of underutilised spaces are attributed to lack of full standardisation in healthcare facilities. They suggested new operating models, improving operational efficiency and delivery, collaboration and communication, and embracing standardisation. Perhaps this framework can be used in improving NHS estates as it promotes standardisation, collaboration through BIM and builds flexibility to improve operational efficiency. When designing a flexible healthcare facility, it is important to understand that flexibility is effective on the long-term basis, while standardisation is effective when applied to patient rooms. BIM is effective when collaborating with appropriate stakeholders involved in a given project. Many practices encouraged by this framework are currently applied in the AEC industry. The design features of each design option can be compared during the selection process. Hence, a change-ready healthcare facility can be designed with confidence.

9.5.2 THEORETICAL IMPLICATION OF THE RESEARCH

The framework emerged from data collection. There are existing frameworks related to flexibility and standardisation, but there are no flexibility frameworks that are reinforced with the application of BIM. The framework developed is supported through the use of BIM as a tool, process and information manager. The framework can be a guide for designers and planners to embed flexibility effectively and efficiently within a healthcare environment. The framework was developed using mixed methods. The process of developing the framework also involved a deductive approach; the process started from more generation to more specific. The framework is grounded in theory. The ratio of combining flexibility and standardisation is inconclusive. Frameworks are not used by professionals in the AEC industry to design for flexibility. This research suggests the use of framework to provide checks and guides for building flexibility. The use of BIM in post refurbishment or facility management is still yet to be fully explored.

9.5.3 IMPLICATION OF RESEARCH TO FACILITY USERS

The benefits of both theoretical and practical implications of this research have an impact on facility users, such as medical staff, patients and visitors. A change-ready healthcare facility will enable users to use various spaces resourcefully and competently. The findings of this research saves patient and staff travelling distance, error reduction, improving staff efficiency, cutting the costs of operating healthcare facilities and improving the existing situation of healthcare spaces. A successfully designed healthcare facility enables healthcare staff to provide organised, efficient, structured and commendable delivery to patients. Effective healthcare delivery to patients enables effective patient care.

9.6 RESEARCH LIMITATION

This research has identified some limitation that need to be identified for future research to further develop this study. The limitation of this research can be categorised into three. These are: limitation of the framework, time and resources constraints and the limitation of the sample size.

9.6.1 LIMITATION OF THE FRAMEWORK

The framework is designed to guide healthcare designers and planners to design healthcare facilities that are adaptable and can respond to known or expected future changes. The framework provides a detail sequence that requires precise information. Neufville *et al.* (2008) stated that future changes cannot be predicted with a high degree of accuracy. Gressel and Hilands (2008) stated that "*the only certainty in healthcare is change*". It was argued by Simpson (2004) that "*Evidence-based nursing offers certainty in the uncertain world of healthcare*". Nevertheless, the framework requires detailed information to guide the design of a change-ready healthcare. The framework does not support traditional design methods, more collaborative work is promoted. The framework requires a BIM model to be managed; it faces the challenge of appointing a BIM manager. The framework has not been practically implemented in any organisation, but has been validated by different stakeholders in the AEC industry.

9.6.2 TIME AND RESOURCES CONSTRAINTS

Due to the limitation of time and resources, the primary data respondents for this research were situated in the UK. Countries such as the US and Finland have developed immensely in the field of BIM. Despite the fact that the UK is left behind in the application of BIM in the AEC industry, respondents had to be contacted within the UK due to limitation of time and resources. The research department of Autodesk and Graphisoft were contacted, no response was recorded. Questionnaire survey and interviews response rate was at the discretion of the organisations and companies contacted. Some respondents have made some commitment to respond to the research invitation for the purpose of data collection, while lots of companies failed to participate. The research analysis schedule programme could not be delayed any longer; the analysis and evaluation process was conducted with the available responses.

9.6.3 LIMITATION OF SAMPLE SIZE

Some of the respondents from the top 100 UK architectural firms have opted for the option to participate in a further data collection. It was found that the number of the respondents that participated for the further data collection was decreasing. Some respondents stated that there are very busy with very tight deadlines. Out of a total of 100, a 10% response rate was recorded after the questionnaire survey collection. After the interviews, a total of 8% response rate was registered. During the validation interviews a 3% response rate was documented from the top 100 UK architectural firms. Other healthcare groups such as Architects for health were invited to take part in the questionnaire survey and interview data collection. The administration department suggested putting up the questionnaire survey and interview invitation on their websites. No response was recorded. The BuildingSmart UK chapter was contacted for the questionnaire survey. The buildingSmart`s administrative department was also responsible for forwarding the questionnaires to their members to avoid disclosing contact details. A low response rate was also recorded. Facility users and medical professionals were not approached (supply side), only healthcare industry professionals were contacted (delivery side) rather than both delivery and supply side.

9.7 RECOMMENDATION

This research focuses closely on refurbished buildings compared to new buildings. Existing facilities are more difficult to design due to the existences of constraining structures, spaces, functions, flows and systems etc. New buildings have constraints such as budgets and site constraints, but they do not deal with existing features. Therefore, most of the recommendations focused on the features of an existing facility. This section presents recommendations for: healthcare designers and planners; the NHS; and future research.

9.7.1 RECOMMENDATION FOR HEALTHCARE DESIGNERS AND PLANNERS

Existing healthcare facilities need to be designed with BIM to have detailed information in a single BIM model that can be used for further development of refurbishment projects. Sometimes certain projects do not have detailed existing information for refurbishment purposes. Collecting this information can increase the project cost through the use of 3D scanners. Healthcare designers and planners should have frameworks or guidelines that suit their desired project goals. It was found from the validation interviews that all of the healthcare designers do not use a flexibility scheme/framework/guideline, but rather use experience to embed flexibility into a facility. The framework developed can be customised to suit different organisational working patterns. The framework can also be a guide for designers to achieve their goals while storing facility information. BIM can provide the ability to generate different design options in a BIM environment. Healthcare designers and planners should carefully make informed decisions when selecting an appropriate and suitable design option for the building contractor to progress with.

9.7.2 RECOMMENDATION FOR THE NHS

This research has found out that 20% of the NHS estates were built before 1948 when the NHS was established. To ensure that all the NHS estates designed before and after 1948 are improved to the required standard, refurbishment could be the most likely solution. When developing these estates, the NHS should ensure that they are designed with flexible solutions that could respond to changes in order to adapt to future challenges. A change-ready healthcare facility can increase the life span of a facility. Therefore, the framework can guide NHS refurbishment projects to be more flexible.

9.7.3 RECOMMENDATION FOR FUTURE RESEARCH

This research developed a framework for designing a change-ready healthcare facility based on the research findings; the recommendations for future research were centred on the framework designed. These include:

- There is a need to record the key decision made at strategic stages to inform stakeholders when choosing an appropriate design from the different *design options* generated. The application of BIM can be used as an information manager as described in chapter 3 to provide detail of each design option generated to ease the process of decision making. This way, the features that make up each *design option* can be explored in detail. This research proposes the organisation of the features of each *design option* using BIM by presenting the features of the different options side-side. See section 8.9 in chapter 8 for an example;
- The framework provides an opportunity to use the generated model for future redevelopment. In cases where a BIM model is not available, a laser 3D scanner can be used to retrieve existing information of a facility. Further research can look into the application of 3D scanning and BIM in order to manage existing buildings effectively;
- Further research should also focus on the effective ratio of combining the applications of flexibility and standardisation to improve the efficiency and effectiveness of healthcare facilities;
- To explore and develop Key Performance Indicators (KPI) for measuring the level of quality standards, flexibility and successful refurbishment;
- To investigate mathematical methods of identifying underutilised spaces in existing healthcare facilities and explore strategies of utilising the identified spaces; and
- To explore the advantages and disadvantages of the framework upon its application on real live projects.

9.8 CLOSING REMARKS

Modern healthcare facilities need to adapt to the rapid changing nature of healthcare facilities. Therefore, this study presents a framework used to design flexible and standardised healthcare facilities that can respond to known or expected future changes in order to improve the value of existing or new facilities. The NHS could be potentially, the most beneficial to the successful application of the framework in existing healthcare facilities. The process of designing healthcare facilities with flexibility capabilities in the future could change the way buildings are designed. The issue of change is a management aspect that needs to be addressed when designing healthcare facilities. A framework was developed from literature analysis; it was further revised from questionnaire survey, interview and validation interview findings to present state of the art framework that can guide the process of adapting to future changes. This research is focused on existing buildings; new buildings do not face the staggering challenge associated with existing features such as spaces, functions, flow, capacity and structures. However, the framework can easily be used in new buildings. As a result, new build was included into the framework design. Some of the interviewees in chapter 7 stated that there is no specific solution when dealing with the challenges of existing healthcare facility features such as spaces. Existing features are treated as any other constraint associated to the AEC industry. The main outcome of this research is that clients can be convinced to initiate flexibility strategies in their projects based on historical evidence of change taken place over time. However, flexibility is argued to be used as an *insurance policy* that would be effective when the need arises. The UK Government has proposed a BIM mandated by 2016. As a result, this research promotes the use of BIM through the RIBA Plan of Work (2013).

REFERENCE

1. Adam, A. (2008). *Medicine by Design: The Architect and the Modern Hospital, 1893-1943*. Minneapolis: University of Minnesota Press.
2. AGC of America, (2010). BIM Educational Program: An AGC Construction Learning Tool, Your Resource for Successful BIM Implementation. Available from: http://www.agc.org/galleries/career/AGC%20BIM%20Education%20Program%20Brochure.pdf. [Accessed on: 15th of July, 2012]
3. Association General Contractors of America (AGC), (2006). *The Contractors Guides to BIM*, 1st ed., Las Vegas, United States: AGC Research Foundation. Available from: http://www.agcnebuilders.com/documents/BIMGuide.pdf. [Accessed on: 15th of July, 2012].
4. Ahmad, M. A., Price, A. D. F., Demian, P. and Lu, J. (2011). Space Standardisation and Flexibility on Healthcare Refurbishment. Architecture in the Fourth Dimension, *Open Building Conference*. Boston, MA, USA, pp. 250-257.
5. Ahmad, M. A., Demian, P. and Price, A. D. F. (2012a). BIM Implementation Plans: A Comparative Analysis. *ARCOM International Conference*. Edinburgh, UK, pp. 23-32.
6. Ahmad, M. A., Demian, P. and Price, A. D. F. (2012b). Creativity with Building Information Modelling (BIM) Tools. *First UK Academic Conference on BIM*. Newcastle, UK, pp. 152-163.
7. Ajah, A.N., Herder, P. M., Grievink, J. and Weijnen, M.P.C. (2005). Framework for Proper Integration of Flexibility in Conceptual Designs of Energy and Industrial Infrastructure. *European Symposium on Computer Aided Process Engineering,* 15 (38), pp. 781-786.
8. Allahaim, F., Alfaris, A and Leifer, D. (2010). Towards Changeability: Adaptable Building Design (ABD) Framework. The 5th *International Conference of Arab Society for Computer Aided Architectural Design* (ASCAAD). Morocco 19-21 October, 2010, pp. 189-200.
9. Ali, S.A. (2010). Design Information in Managing Refurbishment Projects in Malaysia. *International Journal of the Physical Science*, 5 (6), pp. 768-773.
10. Aldridge, A and Levine, K. (2001). *Surveying the Social World: Principles and Practice in Survey Research*. Buckingham: Open University Press.
11. American Institutes for Research (AIR), (2010). *Comparability Analysis*. [Online]. Available from: http://www.air.org/topics/topic_comparability_analysis.aspx. [Accessed on: 1st March, 2010].
12. Aranda, M. G., Succar, B., Chevez, A., and John, C. (2008). BIM National Guidelines and Case Studies." Cooperative Research Centres (CRC) for *Construction Innovation*, Melbourne, Australia, pp. 1-122.
13. Aranda M.G., Crawford, J., Chevez, A. and Froese, T. (2009). Building Information Modelling Demystified: Does It Make Business Sense to Adopt BIM? *International Journal of Managing Projects in Business*, 2 (3), pp. 419-434.
14. Aranda, M, G. et al. (2007). Final Report, *Business Drivers for BIM*. Cooperative Research Centres (CRC) for Construction Innovation. Brisbane.

15. Arora, V. and Johnson, J. (2006). A Model for Building a Standardised Hand-off Protocol. *The Joint Commission Journal on Quality and Patient Safety*, 32 (11).
16. Ashcraft, H.W. (2006). Building Information Modelling: Electronic Collaboration in Conflict with Traditional Project Delivery. *Construction Litigation Reporter*, 27 (7-8), pp. 335-348.
17. Ashcroft, H and Shelden, D. R. (2008). *BIM Implementation Strategies*. [Online] Available from: projects.buildingsmartalliance.org/files/?artifact_id=1399Similar. [Accessed on: 12th July, 2011].
18. Autodesk, (2003). *Building Information Modelling in Practice: Autodesk Building solutions*. (White Paper). Available from: http://images.autodesk.com/emea_s_main/files/bim_in_practice.pdf. [Accessed on: 12th July, 2010].
19. Azhar, S., Hein, M. and Sketo, Blake. (2008). Building Information Modelling (BIM): Benefits, Risks and Challenges. Proceedings of the 44th ASC Annual Conference, Auburn, Alabama, April 2-5, 2008.
20. Baker, M., J and Foy, A. (2008). *Business and Management Research: How to Complete Your Research Project Successfully*. Argyll: Westburn Publishers Ltd. ISBN-13: 978-0946433049.
21. Barista, D. (2007). Early BIM Adopters are Receiving a Windfall of Healthcare Work. *Building Design and Construction*. February, 2007. Available from: http://www.bdcnetwork.com/article/CA6417000.html. [Accessed on: 12th July, 2011].
22. Battisto, D. and Allison, D. (2002). *Nature and Rate of Change in Clinical Laboratories*. (Final Report). San Francisco, California, USA: The Coalition for Health Environment Research (CHER).
23. BBC, (2006). *NHS` Not Giving Value for Money*. [Online]. Available from: http://news.bbc.co.uk/1/hi/health/4846492.stm. [Accessed on: 2nd July, 2010].
24. BBC, (2010). *Many Buildings Unsuitable NHS Figures Shows*. [Online]. Available from: http://www.bbc.co.uk/news/health-11769182. [Accessed on: 2nd July, 2010].
25. BBC, (2012). *Surveys Finds A and E Waiting Times Longer*. [Online]. Accessed on: 20th January, 2013. Available from http://www.bbc.co.uk/news/health-20623825. [Accessed on: 13th January, 2013].
26. BBC, (2013). '*NHS Heading for £30bn Funding Gap'* [Online]. Available from: http://www.bbc.co.uk/news/health-23258962. [Accessed on: 22nd June, 2013].
27. Blaikie, N. (2010). *Designing Social Research*. 2nd (ed). USA: Polity Press.
28. Blaxter, L., Hughes, C. and Tight, M. (2006). *How to Research*. 4th (ed). UK: Open University Press, Mc-Graw-Hill Education.
29. Bentley, (2011). *About BIM*. [Online]. Available from: http://www.bentley.com/en-GB/Solutions/Buildings/About+BIM.htm. [Accessed on: 13th July, 2011].
30. Bernstein, P.G. and Pittman, J.H. (2005). *Barriers to the Adoption of Building Information Modelling in the Building Industry*. Autodesk Building Solutions Whitepaper. CA: Autodesk Inc.
31. Bisgaard, S. (2009). *Solutions to the Healthcare Quality Crisis: Cases and Examples of Lean Six Sigma in Healthcare*. USA: America Society for Quality, Quality Press.
32. BIM Journal, (2011). *Improving the Construction Process*. Available from: http://www.bimjournal.com/what-is-bim/. [Accessed on: 21st May, 2013].

33. BIM Road Map, (2011). *BIM Implementation Plan for Military Construction Projects*, Bentley Platform. US Army of Corps Engineers. Available from: acwc.sdp.sirsi.net/client/search/asset/1002733. [Accessed on: 21st May, 2013].
34. Blaxter, L., Hughes, C. and Tight, M. (2006). *How to Research.* 3rd (ed). England: Open University Press.
35. Boland, P. (1996). Redesigning Healthcare Delivery: A Practical Guide to Reengineering, Restructuring, and Renewal. California: Seventeenth Street Studios.
36. Boucher, A., Eberle, T.M. and Yeo, S. (2007). The Importance of Standards and its use in Healthcare. Chapter Five. Available from: www.itsc.org.sg/pdf/5_Healthcare.pdf. [Accessed on: 21st May, 2013].
37. Bowling, A. (2002). *Research Methods in Health: Investigating Health and Health Services.* 2nd (ed). Buckingham: Open University Press.
38. Brand, S. (1994). *How Buildings Learn*. New York: Penguin Books.
39. Bew, M. and Underwood, J. (2010). Delivering BIM to the UK Market in: Underwood, J and Isikdag (eds). Handbook of Research on Building Information Modelling and Construction Informatics: Concepts and Technologies. IGI Global.
40. Brewer, R.C. (2007). *Your submitted PhD Thesis.* London.
41. Britain`s Best Architects, (2013) [Online]. Available from: http://www.bestarchitects.co.uk/sector-healthcare.asp. [Accessed on: 21st May, 2013].
42. Brinkman, S. and Kvale, S. (2009). *Interviews: An Introduction to Qualitative Research Interviewing*. Los Angeles: Sage.
43. Bryman, A. and Bell, E. (2007). *Business and Research Methods. 2nd* (ed). Oxford: Oxford University Press. ISBN-0-1992-8498-9.
44. Bryman, A. (1998). *Quantity and Quality in Social Research*. London: Routledge.
45. Bryman, A. and Bell, E. (2011). *Business Research Methods.* 3rd (ed). London: Oxford University Press.
46. Bryman, A. (2004). *Social Research Methods.* Oxford: Oxford University Press.
47. Burney A. (2008). Deductive and Inductive Research. [Online]. Available from: http://www.drburney.net/INDUCTIVE%20&%20DEDUCTIVE%20RESEARCH%20APPROACH%2006032008.pdf. [Accessed on 20th February 2012].
48. Burton, S. and Kesidou, S. (2005). Refurbishment of Old Buildings for Sustainable Use. *Passive and Low Energy Cooling for the Built Environment*. Santorini, Greece.
49. BuildingSMARTalliance, (2008*). Charter for the National Building Information Model (BIM) Standard Project: A project for the BuildingSMARTalliance*. [Online] Available from: http://www.buildingsmartalliance.org/client/assets/files/bsa/NBIMS_Charter.pdf [Accessed on: 1st September, 2011].
50. BuildingSmart, (2010). [Online]. Available from: http://www.buildingsmart.co.uk/. [Accessed on: 3rd February, 2010].
51. Building, (2013) [Online]. Available from: http://www.building.co.uk/. [Accessed on: 2nd March, 2013]
52. CABE, (2006). "*Who we are? What we do? Why it matters*?" Available from: www.cabe.org.uk. [Accessed on: 3rd February, 2010].
53. Carthey, J., Chow, V., Jung, Y. M. and Mills, S. (2010). Achieving Flexible and Adaptable Healthcare Facilities – Findings from a Systematic Literature Review. *HaCIRIC International Conference*. UK, pp. 109-118.

54. Carthey, J., Chow, V., Jung, Y. M. and Mills, S. (2009). *Flexibility and Adaptability Report: An International Review for the NSV Context*. Sydney: Centre for Health Assets Austrasia (CHAA), Built Environment, University of New South Wales.
55. Chartered Institute of Building, (2010). *Code of Practice for Project Management for Construction and Development*. UK: John Wiley and sons.
56. Chellappa, J.R. (2009). *BIM + Healthcare: Utilization of BIM in the Design of a Primary Healthcare Project*. Your D. Arch submitted Thesis. School of Architecture. University of Hawai`i.
57. Chaudhury, H., Mahmood, A. and Valante, M. (2004). *The Use of Single Patient Rooms versus Multiple Occupancy Rooms in Acute Care Environments*. USA: Coalition for Health Environments Research (CHER). ISBN NO.0-9743763-2-9.
58. Chefurka, T., Nesdoly, F. and Christie, J. (2006). Concepts in Flexibility in Healthcare Facility Planning, Design, and Construction. CIFE Technical Reports. *The Academy Journal,* pp. 34-43. Available from: http://www.aia.org/aah/journal, or http://cife.stanford.edu/Publications/index.html .
59. CIC Research Team, (2010). *Penn State University: BIM Execution Planning Process.* [Online] Available from: http://www.advsolinc.com/pdf/events/PennStateBIMExecutionLinksTemp.pdf. [Accessed on: 12th July, 2011].
60. Cleveland Clinic, (2010) [Online]. https://docs.google.com/viewer?a=v&q=cache:ySLS0rJZ6WcJ:portals.clevelandclinic.org/LinkClick.aspx?fileticket%3DpjMn%252BM3HWJw%253D%26tabid%3D2631+cleveland+clinic+flexible+facility+planning&hl=en&gl=uk&pid=bl&srcid=ADGEESifJCSvSVAdGN3Z-6hGsA0OfLTwZnu1QFu-6CH88Luz-5_QwCBfLpiR4l9aq2qY6tiBaPXPD-nKoc4HmDYzwCwbtt5GbNKR46B5aGQzKJzUorL-LJyOUiTOR6FpvcP9754tcZXj&sig=AHIEtbRImuPB42WfhNT1DObbGjIkOw1HrA&pli=1
61. Conradi, D. (2009). A Guide to Ecological Design: Building Information Modelling (BIM). Green Building Handbook South Africa, 1, pp. 225-231.
62. CRC Construction Innovation, (2007). *Adopting BIM for Facilities Management: Solutions for Managing the Sydney Opera House*. Brisbane, Australia: Cooperative Research Centre for Construction Innovation.
63. Creswell, J.W. (2003). *Research Design: Quantitative, Qualitative and Mixed Method Approaches*. 2nd (ed). California: Sage Publication.
64. CURT, (2004). *Collaboration, Integrated Information and the Project Lifecycle in Building Design, Construction and Operation*. In Committee, A.E.P (ed). WP-1202. Construction Users Roundtable (CURT).
65. Dainty, A.R. J. (1998). *A Grounded Theory of the Determinants of Woman`s Under-achievement in Large Construction Companies*. Loughborough: Loughborough University.
66. Davis, M. (2005). *Scientific Papers and Presentations*. United Kingdom: Elsevier Ltd.
67. Department of Health, (2010-2015). *From Good to Great: Preventative, People Centred, Productive*. The Stationery Office (TSO).
68. Dawood, N. and Sikka, S. (2008). Measuring the Effectiveness of 4D Planning as a Valuable Communication Tool. *ITCon*, 13.

69. Dawson, C. (2002). *Practical Research Methods: A User-friendly Guide to Mastering Research Techniques and Projects*. Oxford: How to Books Limited.
70. Dean, R. (2007). *Building Information Modelling (BIM): Should Auburn University Teach BIM to Building Science Student?* Graduate Capstone, Department of Building Science. Auburn: Auburn University.
71. Demkin, J.A. (2008). *The Architect`s Handbook of Professional Practice*. American Institute of Architects. 14th (ed). New Jersey: John Wiley and Sons.
72. Denholm, C. and Evans, T. (2007). *Supervising Doctorates Down Under: Keys to Effective Supervision*. Australia: Acer Press.
73. Denscombe, M. (2007). *The Good Research Guide: For Small Scale Social Research Projects*. 3rd (ed). England: Open University Press, Mc Graw-Hill Education.
74. Denzin, N. and Lincoln, Y. (1998). *Collecting and Interpreting Qualitative Materials.* CA: Sage, Thousand Oaks.
75. Deutsch, R. (2011). *BIM and Integrated Design: Strategies for Architectural Practices.* USA: American Institute of Architects.
76. DH, (2010). *The Design Development Protocol for PFI schemes - Revision 1.* [Online] Available from: http://www.dh.gov.uk/en/Managingyourorganisation/NHSprocurement/Publicprivatepartnership/Privatefinanceinitiative/DesigndevelopmentprotocolforPFIschemes/DH_4016496. [Accessed on: 10th June, 2011].
77. DH (2010A). ProCure 21+ Guide. Available from: www.procure21plus.nhs.uk/resources/downloas/proCure21plus%Guide.pdf.
78. DH, (2009-2010). *Hospital Estates and Facilities Finding 2009-2010.* [Online] Available from: http://www.dh.gov.uk/prod_consum_dh/groups/dh_digitalassets/documents/digitalasset/dh_120811.pdf. [Accessed on: 10th June, 2011].
79. Drenth, P.J.D., Thierry, H. and Wolff, C.J.D. (1998). *A Handbook of Work and Organisational Psychology*. 2nd (ed). UK: Psychology Press Ltd.
80. Dykstra, A. (2011). *Construction Project Management: A Complete Introduction.* US: Kirshner Publishing Company Inc. ISBN: 978-0-9827034-9-6.
81. Eastman, C.M. et al. (2008). *BIM Handbook: A Guide to Building Information Modelling for Owners, Managers, Designers, Engineers and Contractors*. New Jersey: John Wiley and Sons.
82. Eastman, C.M. et al. (2011). *BIM Handbook: A Guide to Building Information Modelling for Owners, Managers, Designers, Engineers and Contractors*. Canada: John Wiley and Sons.
83. Easterby-Smith, M., Thorpe, R. and Lowe, A. (1991). *Management Research: An Introduction.* 1st (ed). London: Sage Publications. ISBN 0-8039-8392-1.
84. EC Harris, (2013). Delivering Better Healthcare Outcomes More Efficiently: A £2.3 Billion and Hide Park Sized Opportunity. The EC Harris NHS Estate Efficiency Annual Review.
85. Ehlers, U.D. and Pawlowski, J.M. (2006). *Handbook on Quality and Standardisation in E-Learning*. Germany: Springer.
86. Fellows, R. and Liu, A. (2005). *Research Methods for Construction*. 2nd (ed). UK: Blackwell science.
87. Fien, J. et al. (2007). Flexible Guidelines for the Design of Remote Indigenous Community Housing. *Australian Housing and Urban Research Institute* (AHURI). Positioning Paper NO.98.

88. Fisher, J. (2011). *BIM Technology Briefing Steering Committee*: *BIM Execution Plans*. [Online]. Available from: http://www.advsolinc.com/pdf/events/StLouis_BIMExecutionPlan.pdf. [Accessed on: 12th July, 2011].
89. Finch, E. (2009). Flexibility as a Design Aspiration: The Facilities Management Perspective. Ambiente ConstruA-do. 9 (2).
90. Fischer, M. and Kunz, J. (2006). The Scope and Role of Information Technology in Construction. Available from: http://cife.stanford.edu/online.publications/TR156.pdf. [Accessed on: 15th August, 2011].
91. Fitzgerald, B. and Howcroft, D. (1998). Towards Dissolution of the IS Research Debate: from Polarisation to Polarity. *Journal of Information Technology,* 13, pp. 313-326.
92. Fitzpatrick, J.J. and Wallace, M. (2006). *Encyclopaedia of Nursing Research*. 2nd (ed). USA: Springer Publishing Company, Inc.
93. Flick, U. (2009). *An Introduction to Qualitative Research*. 4th (ed). Sage Publishers.
94. Gallant, D. and Lanning, K. (2001). Streamlining Patient Care Processes through Flexible Room and Equipment Design. *Critical Care Nursing Quarterly*, 24 (3), pp. 59-76.
95. Gao, J. and Fischer, M. (2008). Frame work and Case Studies Comparing Implementations and Impacts of 3D/4D Modelling across Projects. Technical Report #TR172. *Centre for Integrated Facility Engineering* (CIFE). Stanford.
96. GBXML, (2011). *Open Green Building XML Schema*. [Online]. Available from: http://www.gbxml.org/ . [Accessed on: 15th August, 2011].
97. Gesler, W., Bell, M., Hubbard, P. and Francis, S. (2004). Therapy by Design: Evaluating the UK Hospital Building Program. *Health and Place,* 10, pp. 117-128.
98. Gill, J. and Johnson, P. (2010). *Research Methods for Managers*. 4th (ed). London: Sage Publications Ltd. ISBN-10: 1847870945.
99. Glaser, B.G. and Strauss, A.L. (1967). *The Discovery of Grounded Theory: Strategies for Qualitative Research*. New Jersey: Transaction.
100. Goddard, W. and Melville, S. (2004). *Research Methodology: An Introduction*. 2nd (ed). Canada: Juta and Co. Ltd
101. Graphisoft, (2003). *Building Information Modelling: A look at Graphisoft`s Virtual Building Concept*. (White Paper). USA: Cyon Research Corporation.
102. Graphisoft, (2012). *Renovation and Refurbishment Support*. Available from: WWW.graphisoft.com/products/archicad/ac15/renovation.html. [Accessed on: 15th August, 2011].
103. Gray, C and Hughes, W. (2001). Building Design Management. Oxford: Butterworth-Heinemann. ISBN 0 750650702.
104. Grinnell Jr, R.M. and Unarau, Y.A. (2011). *Social Work Research and Evaluation: Foundation of Evidence-Based Practice*. 9th (ed). New York: Oxford Press University.
105. Groat, L and Wang, D. (2002). *Architectural Research Methods*. Canada: John Wiley and Sons.
106. Gressel, S., and Hilands, S. (September, 2008). New Hospital Designs Focus on Reducing Cost, Improving Health and Flexibility. Available from: file:///Volumes/LT/articles/New%20Hospital%20Designs%20Focus%20on%20Reducing%20Cost,%20Improving%20Health%20and%20Flexibility.webarchive.

107. Guan, J. (2008). Measurement of Manufacturing System Flexibility with Fuzzy Set Theory. *International Conference on Management Science and Engineering*. USA, 15, pp. 713-718.
108. Gibb, A.G.F. (2001). Standardisation and Pre-assembly: Distinguishing Myth from Reality using Case Study Research, Construction Management and Economics, 19:3, pp. 307-315.
109. Guba, E.G. and Lincoln, Y.S. (1994). Competing Paradigms in Qualitative Research. Chapter 6 in: Denzin and Lincoln (1994) Handbook of Qualitative Research. USA: Sage Publishers.
110. Gu, N., Singh V., Taylor C., London K. and Brankovic, L. (2008). Adopting Building Information Modelling (BIM) as Collaboration Platform in the Design Industry. *Proceedings of CAADRIA Conference*, CAADRIA. Australia.
111. Gu, N., Singh, V., London, K., Brankovic, L. and Taylor, C. (2008a). Building Information Modelling: What is there for Architects? *Annual Conference of the Australian and New Zealand Architectural Science Association* (ANZAScA). University of Newcastle, Newcastle City Hall, Newcastle, Australia, pp. 33-40.
112. Gupta, S.K., Kant, S., Chandrashekhar, R. and Satpathy, S. (2007). *Modern Trends in Planning and Designing of Hospitals: Principles and Practice*. India: Jaypee Brothers Medical Publishers (p) Ltd.
113. Haldenby, A. (2009). *The NHS is Bleeding to Death and the Time to Operate is Now.* Telegraph. [Online]. Available from: http://www.telegraph.co.uk/comment/personal-view/5498395/The-NHS-is-bleeding-to-death-and-the-time-to-operate-is-now.html. [Accessed on: 6th of July, 2009].
114. Hall, D.J. and Giglio, N.M. (2010). *Architectural Graphic Standards for Residential Construction*. 2nd (ed). The American Institute of Architects. New Jersey: John Wiley
115. Hannon, J.J. (2007). Estimators` Functional Role Change with BIM. Association for the Advancement of Cost Engineering (AACE). International 51st Annual Meeting, Nashville, TN. *International Transactions, IT*, 03, pp. 1-8.
116. Hardin, B. (2009). *BIM and Construction Management Proven Tools, Methods, and Workflows*. Indiana: Wiley Publishing.
117. HefmA, (2013). NHS Holds £2.3bn in ‘Wasted’ Property. [Online]. Available from: www.hefma.co.uk/news/item/nhs-holds-23bn-in-wasted-property. [Accessed on: 26th June, 2013].
118. Herzlinger, R.E. (2006). *Why Innovation in Health Care is So Hard*. Harvard Business Review. OnPoint.
119. Hignett S. and Lu, J. 2009. An Investigation of the Use of Health Building Notes by UK Healthcare Building Designers, *Applied Ergonomics,* 40 (4), July 2009, pp. 608-6.
120. Hignett, S. and Lu, J. 2008. Need for New Design Guidance Identified, *Health Estate Journal* (January) (2008), pp. 35–37.
121. Holstein, J. A. and Gubrium, J. F. (2006). The Active Interview. In: Silverman, D, (ed). *Qualitative Research: Theory, Method and Practice*. 2nd (ed). New Delhi: Sage Publication.
122. Holt, L.E., Pelham, T.W., and Holt, J., (2008*) Flexibility: A Concise Guide: To Conditioning, Performance, Enhancement, Injury Prevention and Rehabilitation*. New Jersey: Humana Press.

123. Howard, R., and Bjork, B.C. (2008). Building Information Modelling: Expert`s Views on Standardisation and Industry Deployment. Advanced Engineering Informatics 22 (2008) 271-280. Elsevier.

124. Huberman, M, A. and Miles, M.B. (2002). *The Qualitative Researcher`s Companion*. London: Sage Publications.

125. Indiana University, (2010). *BIM Execution Plan*. University Architect`s Office. USA: Indiana University.

126. Isikdag, U., Underwood, J., Aouad, G. and Trodd, N. (2007). Investigating the Role of Building Information Models as a Part of an Integrated Data Layer: A Fire Response Management Case, Architecture Engineering and Design Management, 3(2), pp. 124-142.

127. Isikdag, U. and Zlatanova, S. (2009). Chapter 6: Towards Defining a Framework for Automatic Generation of Buildings in CityGML using Building Information Models. In Lee, J and Zlatanova, S. (eds), *3D Geo-Information Science*, pp. 379-395.Berlin Heidelberg: Springer-Verlag.

128. Iskidag, U., Aouad, G. and Underwood, J. (2007). Building Information Models: A Review on Storage and Exchange Mechanism, 24th CIB-W78 Conference, Maribor.

129. Issa, R.R.A. and Liu, R. (2012). Automatically Updating Maintenance Information from A BIM Database. Proceeding of the *2012 ASCE International Conference on Computing in Civil Engineering*, pp. 373-380.

130. Jakobs, K. (2000). *Standardisation Process in IT: Impact, Process and Benefits of User Participation.* 1st (ed): Germany: Vieweg and Sohn.

131. Jackson, L.S. (2012). *Research Methods and Statistics: A Critical Thinking Approach.* 4th (ED) USA: Cengage Learning.

132. Jason, U, J. and Isikdag, U. (2010). A Synopsis of the Handbook of Research on Building Information Modelling. In*: CIB World Congress*, University of Salford, Salford University, UK.

133. Jeng, T. (2009). Towards a Ubiquitous Smart Space Design Framework. *Journal of Information Science and Engineering* 25, pp. 675-686.

134. John, G.A., Clements-Croome, D.J., Fairey, V. and Loy, H.M. (2005). Contextual Prerequisites for the Application of ILS Principles to the Building Services Industry. Engineering. *Construction and Architecture Management*, 14(4), pp. 307-328.

135. Jonker, J. and Pennink, B. (2010). *The Essence of Research Methodology: A Concise Guide for Master and PhD Students in Management Science*. New York: Springer.

136. Joint Commission Resources, (2004). *Environment of Care: Essentials for Health Care.* 5th (ed). USA: Joint Commission on Accreditation of Healthcare Organisations.

137. Joint Commission Resources. (2004a). *Joint Commission Guide to Priority Focus Areas Improving Healthcare Quality*. USA: The Joint Commission on Accreditation of Healthcare Organisations.

138. Joint Commission Resources. (2006). Planning Designing and Construction of Health Care Facilities. USA: The Joint Commission on the Accreditation of Healthcare Organisations.

139. Joint Commission Resources, (2009). Planning, Design and Construction of Healthcare Facilities. 2nd (ed). USA: Joint Commission on Accreditation of

Healthcare Organisations. Available from: store.jointcommissioninternational.org/assets/1/14/PDC09_Pages.pdf. [Accessed on: 15th July, 2013].

140. Jung, Y. A. and Joo, M. (2011). Building Information Modelling (BIM) Framework for Practical Implementation. *Automation in Construction*, 20 (2), pp. 126-133.

141. Kagioglou, M. and Tzortzopoulos, P. (2010). *Improving Healthcare through Built Environment Infrastructure*. USA: Wiley-Blackwell Publishing Ltd.

142. Kala, k., and Thursby, M. (1994). Flexibility: A Partial Ordering. National Bureau of Economic Research.

143. Kelleher Jr T. J., Aberbathy IV, T. E., Bell Jr Hubert J. and Reed Steven L. (2010). Federal Government Construction Contracts: A Practical Guide for the Industry Professional. New Jersey: John Wiley and Sons.

144. Kendall, S. (2005). Open Building: An Architectural Management Paradigm for Hospital Architecture. In: Emmit, S. and Prins, M. (eds), Proceedings *CIB W096 Architectural Management Symposium, CIB Proceedings on designing value: New Directions in Architectural Management. Publications 307, November, Lyngby, pp. 273-284.*

145. Kensek, K.M. (2009). *The Power of Diversity: Practice in a Complex World.* San Francisco: (AIA Convention 2009).

146. Kent, D and Becerik-Gerber, B. (2010) "Understanding Construction Industry Experience and Attitudes toward Integrated Project Delivery. Journal of Construction Engineering Management 136 (8), pp. 815-825.

147. Key Statistics on the NHS, (2010). [Online] Available from: http://www.nhsconfed.org/OurWork/political-engagement/Pages/NHS-statistics.aspx, [Accessed on: 20th September 2010].

148. Kerzner, H. (2009). *Project Management: A System Approach to Planning, Scheduling, and Controlling*. New Jersey: John Wiley.

149. Khemlani, L. (November 22, 2007). *Top Criteria for BIM Solutions.* AECbytes, October issue, Available from: http:// www.aecbytes.com. [Accessed on: 20th September, 2010].

150. Knight, A and Ruddock, L. (2008). *Advanced Research Methods in the Built Environment*. United Kingdom: Wiley-Blackwell.

151. Kotabe, M., and Helsen, K. (2009). *Handbook of International Marketing. London: Sage.*

152. Koh, E.T. and Owen, W.L. (2000). *Introduction to Nutrition and Health Research*. USA: Kluwer Academic Publishers.

153. Kraus, W.E., Watt, S. and Larson, P.D. (2007). Challenges in Estimating Costs using Building Information Modelling. AACE, *International Transactions, IT.* 01, pp. 1-3.

154. Kumar, R. C. (2008). *Research Methodology*. India: APH Publishing Corporation.

155. Kunders, G.D. (2004). *Hospital Facility Planning and Management*. New Delhi: McGraw – Hill.

156. Lam, K.C. (2008). *Planning the Inherent Growth or Change of a Hospital,* Hong Kong. Hospital Engineering and Facility Management, Design and Construction Report. Touch Briefings 2008.

157. Lee, Y.C. and Gilleard, J.D. (2002). Collaborative Design: A Process Model for Refurbishment. *Automation in Construction*, 11 (5), pp. 535-544.
158. Levy, S. M. (2009). *Construction Process Planning and Management: An Owner`s Guide to Successful Projects*. United Kingdom: Elsevier Inc.
159. Malkawi, A.M. and Augenbroe, G. (eds), (2004). *Advanced Building Simulation.* New York: Taylor and Francis Group.
160. Manning R., and Messner, J. I. (2008). Case Studies in BIM Implementation for Programming of the Healthcare Facilities. ITcon Vol.13 pp. 446-456.
161. Marshall, C. and Rossman, G. B. (2011). *Designing Qualitative Research*, 5th (ed). UK: Sage Publication Inc.
162. Manor College, (2006). *What is Empirical Research*? [Online] Available from: http://library.manor.edu/what isempiricalresearch.mht. [Accessed on: 10th January, 2010].
163. Manning R., and Messner, J.I. (2008). Case Studies in BIM Implementation for Programming of the Healthcare Facilities. *ITcon*. 13, pp. 446-456
164. McLoughin, V. and Leatherman, S. (2003). Quality or Financing: What Drives Design of the Health Care System? International Journal of Health Improvement. 12, pp. 136-142.
165. Medical Construction and Design, (2010). [Online] Available from: http://www.mcdmag.com/component/content/article/117-news/114-turners-utilization-of-bim-and-lean-construction-on-middle-tennessee-medical-center-in-murfreesboro-tenn-to-save-project-millions-of-dollars.html. [Accessed on: 22nd November, 2010].
166. Messner, J., Hunter, S. and Anumba, C. (2010). *Project Execution Planning for Building Information Modelling (BIM).* A BuildingSMART Alliance Project. Penn State University.
167. Miller, K. M. (2006). Design and Construction of Health Care Facilities. United States: Joint Commission on Accreditation of Healthcare Organisations
168. Miles, M. B. and Huberman, A. M. (1994). *Qualitative Data Analysis: An Expanded Sourcebook*. 2nd (ed). Thousand Oak, Calif: Sage Publications.
169. Milburn, A. (2004). *Building a Better Patient Environment in CABE* (ed). Good Design is a Commitment to a Better Quality of Life for All. Leeds: Centre for Healthcare Design.
170. Messner, J., Hunter, S. and Anumba, C. (2010*). Project Execution Planning for Building Information Modelling (BIM).* A BuildingSMART Alliance Project. USA: Penn State University.
171. Monsen, E.R. and Horn, L.V. (2008). *Research: Successful Approaches*. 3rd (ed). USA: Diana Faulaber Publisher.
172. McNabb, D.E. (2008). *Research Methods in Public Administration and Non-profit Management: Quantitative and Qualitative Approaches*. 2nd (ed). USA: M.E. Sharpe. Inc.
173. Fottler, M.D., Ford, R.C., Roberts, V. and Ford, E.W. (2000). Creating a Healing Environment: The Importance of the Service Setting in the New Consumer-Oriented Healthcare System. Journal of Healthcare Management. 45(2).
174. National Patient Safety Agency. 2010. New Hospital at Pembury: Learning from the Experiences during the Design Stage for the New Hospital at Pembury. Summary Report. Available from:

www.nrls.npsa.nhs.uk/EasySiteWeb/getresource.axd?AssetID. [Accessed on: 15th August, 2011].

175. National Institute of Building Science (NIBS), (2010). *Tackling the Big Picture Issues of BIM*. [Online]. Available from: http://www.nibs.org/index.php/nibs/newsevents/news/Entry/tetralogyofbim [Accessed on: 15th July, 2011].

176. National Institute for Health and Clinical Excellence (NICE, 2012). *Healthcare Quality Standards Process Guide*. Draft for Consultation. UK.

177. Naoum, S.G. (2007). *Dissertation Research and Writing for Construction Students*. Oxford, UK: Elsevier Butterworth Heinemann,

178. Neufville, R. D., Lee, Y. S. and Scholtes, S. (2008). Flexibility in Hospital Infrastructure Design. *Paper presented at the IEEE Conference on Infrastructure Systems*. Rotterdam, 10-12 November, 2008.

179. Neufville, R. D., Lee, Y. S. and Scholtes, S. (2008a). Using Flexibility to Improve Value-for –Money in Hospital Infrastructure Investments. Infrastructure Systems and Services: Building Networks for a Brighter Future (INFRA), International Conference, pp. 1-6, Rotterdam.

180. Neuferts, F., Neufert, P. and Kister, Johannes. (2012). *Architect`s Data*. 4th (ed). UK: Blackwell Publishing.

181. NHS, (2011). *The ProCure21+ Guide – Achieving Excellence in NHS Construction*. Leeds: Department of Health.

182. NHS Choices (2012a), NHS Principles. Available from: http://www.nhs.uk/NHSEngland/thenhs/about/Pages/nhscoreprinciples.aspx . [Accessed on: 15th January, 2013].

183. NHS Choices (2012b), NHS Structure. http://www.nhs.uk/NHSEngland/thenhs/about/Pages/nhsstructure.aspx. [Accessed on: 15th January, 2013].

184. NBS, National BIM Survey. (2012). [Online]. Available from: http://www.thenbs.com/pdfs/NBS-NationalBIMReport12.pdf. [Accessed on: 2nd February, 2012].

185. Newell, R. and Burnard, P. (2011). Research for Evidence-Based Practice in Healthcare. 2nd (ed). USA: Wiley-Blackwell.

186. Nemetschek`s Vectorworks, (2010). BIM Brochure: Better Designs with Better BIM. USA.

187. Neufville, R.D. and Scholtes, S. (2011). *Flexibility in Engineering Design*. USA: Massachusetts Institute of Technology (MIT).

188. Olatunji, O. A. (2011). A Preliminary Review on the Legal Implications of BIM and Model Ownership. *Journal of Information Technology in Construction* (ITcon), 16, pp. 687-696.

189. Olofsson, T., Lee G. and Eastman C. (2008) Editorial – Case Studies of BIM in Use. *ITcon*. 13, pp. 244-245.

190. Oxford Dictionary, (2013). [Online]. UK: Oxford University Press. Available from: http://oxforddictionaries.com/definition/flexibility. [Accessed on: 13th January, 2013].

191. Page, P., Carr, J., Chadwick, D. and Porter, K. (2012). *An Introduction to Clinical Research*. UK: Oxford University Press.

192. Palgrave, (2011). Background of the Refurbishment and Maintenance of Buildings, Part One. Available from: www.palgrave.com/PDFs/9780230290143.Pdf. [Accessed on: 13th January, 2013].

193. Panter, D. (2011). New Royal Adelaide Hospital Project. Schedule 18 – Design Specifications: Functional Brief. South Australian Department of Health.

194. Park, H. J., & Lee, J. H. (2010). Exploring Integrated Design Strategies for the Optimal Use of BIM. Architectural Research, 12(2), 9-14.

195. Park, C. (2005). New Variant PhD: The Changing Nature of the Doctorate in the UK, *Journal of Higher Education Policy and Management*. 27:2, pp. 189-207.

196. Pati, D. and Harvey, T.E. (2011). Inpatient Unit Flexibility: Design characteristics of a successful flexible unit. World Health Design.

197. Patton, M. Q. (1990). *Qualitative Evaluation and Research Methods*. 2nd (ed). Newbury Park, Calif: Sage Publications.

198. Payne, H. and May, D. (2009). Evaluation of a Refurbishment Scheme Incorporating the King`s Fund: Enhancing the Healing Environment Design Principles. *Journal of Facility Management* .7, pp. 74-89.

199. Pommer, E.E., Horman, M.J., Messner, J.I. and Riley, D. (2010). A Unified Process Approach to Healthcare Project Delivery: Synergies between Greening Strategies, Lean Principles and BIM. In Ruwanpura, J., Mohamed, Y. and Lee, S. (eds). Innovation for Reshaping Construction Practice. *Proceedings of the 2010 Construction Research Congress,* Volume 1. Canada May, 2010. Virginia: Construction Institute.

200. Pope, C. and Mays, N. (2006). *Qualitative Research in Health Care*. 3rd (ed). USA: Blackwell Publishing Ltd.

201. Porter, A. (2009). *Labour Admits it Cannot Increase NHS Funding*. Telegraph. [Online]. Available from: http://www.telegraph.co.uk/news/newstopics/politics/labour/5506996/Labour-admits-it-cannot-increase-NHS-funding.html. [Accessed on: 6th May, 2010].

202. Pressler, G. R. (2006). Born to Flex: Flexible Design as a Function of a Cost and Time. *Health Facility Management.* 19(6), pp. 53-54.

203. Purves, G. (2002). Healthy Living Centres: *A Guide to Primary Health Care Design*. United Kingdom: Architectural Press.

204. Purves, G. (2009). Primary Care Centres: A Guide to Health Care Design. United Kingdom: Elsevier Ltd.

205. Purves, G. (2012). *Primary Care Centres: A guide to Health Care Design*. 2nd (ed). USA: Elsevier

206. Price, A.D.F. and Lu, J. (2012). Impact of Hospital Space Standardisation on Patient Health and Safety. *Architectural Engineering and Design Management*. 99, pp. 1-13.

207. RIBA Plan of Work, (2013). Overview. Available from: www.riba.co.uk . [Accessed on: 23th January, 2013].

208. RIBA, (2013) Find a UK Chartered Practice. Available from: Http://members.architecture.com/directory/default/. [Accessed on: 23th July, 2013].

209. Rajan, P.P.K. et al., (2003). Design for Flexibility: Measures and Guidelines. *International Conference on Engineering Design, ICED* 03. Stockholm August, 19-21. University of Texas: US.

210. Renner, M. (2003). *Analysing Qualitative Data. Program Development Evaluation*. USA: University of Wisconsin-Extension, Madison Wisconsin.

211. Reiling, J. (2007). *Safe by Design: Designing Safety in Health Care Facilities, Processes, and Culture*. USA: The Joint Commission on the Accreditation of Healthcare Organisations.
212. Ridley, D. (2008). *The Literature Review: A Step-by-Step Guide for Students*. United Kingdom: Sage
213. Reiling, J., Hughes, R.G. and Murphy, M.R. (2008). Impact of Facility Design on Patient Safety. In Hughes, R.G. (ed). *Patient Safety and Quality: An Evidence - Based Handbook for Nurses*. Rockville (MD): Agency for Healthcare Research and Quality (US).
214. Reddy, K.P. (2011). *BIM for Building Owners and Developers: Making a Business Case for Using BIM on Projects*. New Jersey: John Wiley and Sons.
215. Ruikar, K.D. (2004). *Business Process Implications of E-commerce in Construction Organisation*. Loughborough: Loughborough University.
216. Robbins, P.T. and Huzzair, F. (2011). *Exploring Central and Eastern Europe`s Biotechnology Landscape*. UK: Springer.
217. Royal Institute of British Architects (RIBA), (2011). *Building Information Modelling Report*. UK: RIBA Enterprises Ltd. Available from: http://www.thenbs.com/pdfs/bimResearchReport_2011-03.pdf.
218. Rozich, J.D et al. (2004). Standardisation as a Mechanism to Improve Safety in Health Care. Joint Commission Journal on Quality and Patient Safety. 30 (1), pp. 5-14 (10).
219. Slaughter, E.S. (2001). Design Strategies to Increase Building Flexibility. Building Research and Information. 29 (3), pp. 208-217.
220. Shah, S. (2012). *Sustainable Refurbishment*. USA: Wiley Blackwell.
221. Smith, D. k. and Tardif M. (2009). *Building Information Modelling: A Strategic Implementation Guide for Architects, Engineers, Constructors, and Real Estate Asset Managers*. Canada: John Wiley and Sons.
222. State of Ohio, (2010). *Building Information Modelling (BIM) Protocol: State Architects Office, General Services Division*. USA.
223. Shekedi, A. (2005). *Multiple Cases Narrative: A Qualitative Approach to Studying Multiple Populations*. North America, USA: John Benjamins.
224. Shuchi, S. and Drogemuller, R. (2012). Process Based Synthesis to Evaluate Design Flexibility in Airport Terminal Layout. In Skates, Henry (ed) 46th Annual Conference of the Architectural Science Association, ANZAScA Conference Proceedings, Griffith University, Gold Coast, QLD.
225. Stebbins, J. (2009). Successful BIM Implementation: Transition from 2D to 3D BIM. *Digital Vision Automation*. Available from: http://www.digitalvis.com/pdfs/Successful_BIM_Implementation.pdf.
226. Saunders, M., Lewis, P. and Thornhill, A. (2007). *Research methods for Business Students*. 4th (ed). Essex: Pearson Education. ISBN 0-273-70148-7, 9780273701484.
227. Sheely, B. (2008). *The Future is Now*: US. *2005 Planning Design and Construction Conference AIA*.
228. Schevers, H., et al. (2007). Towards Digital Facility Modelling for Sydney Opera House using IFC and Schematic Web Technology. *ITcon*, 12, pp. 347-362.
229. Simpson, R.L., (2004). Evidence-based Nursing Offers Certainty in the Uncertain World of Healthcare. Nursing Management, the Journal of Excellence in Nursing Leadership, 35 (10), pp. 10-12.

230. Silver, D. (2004). *Qualitative Research: Theory, Method, and Practice*. 2nd (ed). UK: Sage Publication Ltd.
231. Singh, A. (ed). (2000). *Creating Systems in Structural and Construction Engineering*. Rotterdam, Netherlands: A.A Balkema Publishing.
232. Smith, D. k. and Tardif M. (2009). *Building Information Modelling: A Strategic Implementation Guide for Architects, Engineers, Constructors, and Real Estate Asset Managers*. Canada: John Wiley and Sons.
233. Smith, B.S., Chiozza, E. and Edin, M. (eds), (2002). *Challenges and Achievements in E-Business and E-: Work*. USA: IOS Press.
234. Smith A.T. and Pollock, A. M. (2006). *The New NHS: A Guide*. New York: Routledge.
235. Smith. R. (2007). NHS is 'F*ailing Patients' Despite Record Funding*. Telegraph. [Online]. Available from: http://www.telegraph.co.uk/news/newstopics/politics/scotland/1562869/NHS-is-failing-patients-despite-record-funding.html. [Accessed on: 3rd July, 2010].
236. Smyth, H. and Pryke, S. (2008). Collaborative Relationships in Construction: Developing Framework and Network. USA: Blackwell Publishing Ltd.
237. Strohm, P. (2009). *Funding Crisis Threatens NHS Building Schemes*. [Online] Available from: http://www.guardianpublic.co.uk/nhs-procure21-funding. [Accessed on: 25th September, 2010].
238. Sheth, A, Z., Price, A.D.F. and Glass, J. (2010a). BIM and Refurbishment of Existing Healthcare Facilities. *26th Annual ARCOM Conference*. Leeds 6-8 September, 2010.
239. Sheth, A, Z., Price, A.D.F. and Glass, J. (2010b). Existing Healthcare Facilities, Refurbishment and Energy Simulation. *The Constructed Environment*. Venice, Italy 17-19 November, 2010.
240. Sheth, A, Z., Price, A.D.F. and Glass, J. (2010c). A Framework for Refurbishment of Healthcare Facilities, *HaCIRIC 2010 International Conference*, Better Healthcare through Better Infrastructure. Edinburgh 23-24 September, 2010.
241. Sheth, Z. (2011). *A Refurbishment Framework with an Emphasis on Energy Consumption of Existing Healthcare Facilities*. Your Submitted PhD Thesis, Loughborough University UK.
242. Spivak, S.M. and Brenner, F.C. (2001). *Standardisation Essentials: Principles and Practice*. New York: Marcel Dekker, Inc.
243. Sullivan C. C. (2007). Integrated BIM and Design Review for Safer, Better Building: How Project Teams using Collaborative Design Reduce Risk, Creating Better Health and Safety in Projects. *AIA / Architectural Records*, Continuing Educational series, pp. 191-199.
244. Succar. B. (2006). *A Believer`s Guide to BIM Adoption: Technology Implementation*. White Paper. ChangeAgents AEC.
245. Succar, B., Sher, W. and Aranda-Mena, G. (2007). A Proposed Framework to Investigate Building Information Modelling Through Knowledge Elicitation and Visual Models. *Conference Proceedings of the Australasian Universities Building Education Association*. Melbourne, Australia 4th -5th July, 2007.
246. Succar, B. (2009). Building Information Modelling Framework: A Research and Delivery Foundation for Industry Stakeholders', *Automation in Construction*, 18 (3), pp. 357-375.

247. Swetnam, D. and Swetnam, R. (2007). *Writing your Dissertation*. Oxford: Spring Hill House.

248. Sweet, J. and Schneier, M. M. (2009). *Legal Aspects of Architecture, Engineering and the Construction Process*. 8th (ed). USA: Cengage Learning.

249. Tatarinov, I., et al. (2002). *Storing and Querying Ordered XML Using a Relational Database System*. Proceedings of the ACM SIGMOD International Conference on Management of Data. New York, USA, pp. 204-215.

250. Taylor, J.E. and Bernstein, P.G. (2008). Paradigm Trajectories of Building Information Modelling Practice in Project Network. *ASCE Journal of Management in Engineering.*

251. Taylor, E., Joseph A., Keller, A. and Quan, X. (2011). *Designing Safety Net Clinics for Flexibility*. US: California Healthcare Foundation, the Centre for Health Design.

252. The National Audit Office, (2007). Building for the Future: Sustainable Construction and Refurbishment on the Government Estate. London: The National Audit Press Office.

253. Thomas J. K., Thomas E. A. IV., Hubert J. B Jr., and Steven L. R. (2010) *Smith, Currie and Hancock Federal Government Construction Contracts: A Practical Guide for the Industry Professional*: United States: AGC of America.

254. Thomas, D.R. (2006). A General Inductive Approach for Analysing Qualitative Evaluation Data. *American Journal of Evaluation*, 27, pp. 237-246.

255. Tompkins, J. A, White, J., Bozer, Y. and Tanchoco, J.M.A. (2010). *Facility Planning*. 4th (ed). USA. John Wiley and Sons.

256. Triggle, N. (2010). *Analysis: An Out-of-Date Estate*? [Online]. BBC News. Available from: www.bbc.co.uk/news/health-11828485. Accessed on: 10th January, 2011.

257. Underwood, J. and Watson, A. (2003). An XML Metadata Approach to Seamless Project Information Exchange between Heterogeneous Platforms. *Engineering, Construction and Architectural Management* (ECAM), 10 (2), pp. 128-145.

258. UK Construction Strategy Report, (2011*). A Report for the Government Construction Client Group: Building Information Modelling (BIM).* Working Party Strategy Paper.

259. US General Services Administration (GSA), (2011). [Online] Available from: http://www.gsa.gov/portal/content/105075. [Accessed on:15th July 2011]

260. Verderber, S. and Fine, D J. (2000). *Healthcare Architecture in an Era of Radical Transformation*. New Haven: Yale University.

261. Vorel, R. (2009). *Increase the Potential Profit in Healthcare Facilities using Collaboration and Unique Business Modelling Healthcare Developments Reports.* US.

262. Von Hippel, E. (1990). Task Partitioning: An Innovation Process Variable. Research Policy. 19 (6), pp. 407-418.

263. VVT, (2006). *Building Information Models: Inter-Organisational Use in Finland*. VBE2 (1) Research and Development Project, Work Package 1.4, Public Report.

264. Hei, L.W. (2008). Wong and Ouyang: *Blueprints for Hong Kong (the Master Architect Series).* Australia: Images Publishing.

265. Wang, X. and Schnabel A. M. (2008). *Mixed Reality in Architecture Design and Construction*. Australia: Springer.

266. Webster, C. (2002). *The National Health Service: A Political History*. Oxford: Oxford University Press.

267. Webster, R. M. and Simon, P. (2007). *Starting Out in Project Management: A Study guide for the APM Introductory Certificate in Project Management*. 2nd (ed). United Kingdom: CPI Anthony Rowe.

268. Weygant, R. S. (2011). *BIM Content Development: Standards, Strategies and Best Practices*. New Jersey: John Wiley and Sons.

269. Wilkinson, S.J. and Reed, R.G. (2006). Office Building Characteristics and the Links with Carbon Emissions. *Emerald*. 24, pp. 240-251.

270. Wolper, L.F. (2011). *Health Care Administration: Managing Organised Delivery Systems*. 5th (ed). Canada: Jones and Bartlett Publishers.

271. World Population Ageing, (2009). Department of Economics and Social Affairs (DESA). Population Division United Nation. New York. ESA/P/WP/212. Available from: http://www.un.org/esa/population/publications/WPA2009/WPA2009_WorkingPaper.pdf. [Accessed on: 3rd March, 2013].

272. Yan, H. and Demain, P. (2008). Benefits and Barriers of Building Information Modelling. *12th International Conference on Computing in Civil and Building Engineering*. Beijing 2008. Available from: http://www.staff.lboro.ac.uk/~cvpd2/PDFs/294_Benefits%20and%20Barriers%20of%20Building%20Information%20Modelling.pdf.

273. Yin, R.K. (1994). Case Study Research: Design and Methods. Applied Social Research Methods Series. 3rd (ed). California: Sage Publications.

274. Yin, R.K. (2008). Case Study Research: Design and Methods. Volume 5 of Applied Social Research Methods Series. 4th (ed). Los Angeles: SAGE Publications. Fourth Edition.

275. Yorkon, (2010). *Primary and Community Care-A guide to Health Building Note 11-01: How to Plan and Design Flexible and Adaptable Facilities for Primary Community Care*. Technical Report. Available from: www.yorkon.co.uk/pdf/health_building.pdf. Or http://estatesknowledge.dh.gov.uk/. [15th July, 2012].

276. Zammoria, F., Bragliaa, M. and Frosolinia, M. (2011). Engineering Computations: A Measurement method of Routing Flexibility in Manufacturing System. Italia. *International Journal of Industry*.

277. Zhao, T and Tseng, C.L. (2007). Flexibility Facility Interior Layout: A Real Options Approach. *The Journal of the Operational Research Society*, 58 (6), pp. 729-739.

APPENDIX 1: PAPER 1

Space Standardisation and Flexibility on Healthcare Refurbishment

Ahmad, M.A.[1], Price, A.D.F.[2] Demian, P.[3] and Lu, J.[4]

[1] Research Student, Department of Civil and Building Engineering,
Loughborough University, UK.
[2] Professor, Department of Civil and Building Engineering, Loughborough University, UK.
[3] Senior Lecturer in Construction and Project Management, Department of Civil and Building Engineering,
Loughborough University, UK.
[4] Research Associate, Department of Civil and Building Engineering,
Loughborough University, UK.

Abstract

One of the most common features and aims of a flexible solution is to help all stakeholders throughout the lifecycle of a healthcare facility, own or take (full or part) responsibility of reducing, mitigating or abating the redundancy impacts throughout a building's lifecycle with the integration of flexibility and standardisation into healthcare refurbishment, this can be achieved effectively with task partitioning. This paper has acknowledged that there are barriers to task partitioning. Flexibility and standardisation strategies have been implemented globally across different sectors and industries. Refurbishment is usually undertaken to improve the current state or functionality of a building in order to extend its valuable life span. Flexible designs are intended to provide future proof solutions. This requires providing the ability to adapt to unforeseen future changes at a specific place and time. Standardisation can and should be used to improve efficiency and reduce errors, it has been implemented in many manufacturing processes such as the automobile industry, but the question is how will it impact buildings especially existing healthcare spaces?

This paper is aimed at identifying the impact of space standardisation and flexibility on healthcare refurbishment, with the view to identifying best practice and prescribing possible processes for integrating and optimising space standardisation and flexibility during the refurbishment of healthcare facilities.

Keywords: flexibility; space; refurbishment; standardisation; healthcare facility.

*Corresponding author

Email address: A.M.Ahmad@lboro.ac.uk

1. Healthcare buildings and refurbishment (Introduction)

Refurbishment can include redevelopment, renovation, reorganisation, extension, expanding, contracting or modification to suit current or future functions. This paper discusses refurbishment in the context of spaces within healthcare facilities as they house critical activities and are usually subjected to constantly and rapidly changing needs, for example the introduction of new technologies and the challenges created by an ageing and growing population. It is important to appreciate that refurbishment is different from a larger scale maintenance. Refurbishment often involves providing an ability to support new activities whereas maintenance is more about maintaining the status quo. The Joint Commission Resources Inc. (2006) stated that air quality, infection control, utility requirement or interruptions, noise, vibration and emergency procedures needs to be included with any risk assessment associated with the construction or refurbishment of healthcare facilities.

PROBLEM IDENTIFICATION

There is increased recognition that new and refurbished hospitals need to be flexible and adaptable, however, there is a large number of old hospitals in the UK which fail to meet current guidelines and standards. The state of many of the older properties can make it extremely difficult for staff to perform their tasks efficiently and effectively, thus affecting the quality of treatment and patient recovery. The Department of Health (DoH) figures shows that:

- In total, 17% of the NHS estate being used is deemed to be “not up to scratch”.
- 33 hospitals have at least half of their estate below standard.
- There are more than 100 other sites - mainly community hospitals and mental health units - that have 50% or more of their estate not up to scratch.
- Part of the problem is that a large chunk of the NHS estate - nearly a fifth - dates back to before the NHS started in 1948.
- NHS estates classed as not suitable, mostly had design functionality problems.
- There are unpleasant spaces with poor space layout design, (lack of toilet, storage and suitable office spaces). “Mark Masters, the hospital's director of estates and facilities, said it means staffs are left to do their best in these circumstances” (BBC, 2010).

Although such reports need to be treated with caution due to the language being used such as “not up to scratch”. What does “below standard” really mean? Were there justifiable and contextual reasons for deviation from the standards? Many standards and guidance documents are written mainly to support the design of new and refurbished facilities rather than as a tool to assess current facilities.

The need for healthcare refurbishment

The aim of refurbishment is to improve the current conditions of healthcare buildings. This can be based on the need to adapt to a rapidly changing environment, treatment, equipment, etc. With increasing concerns regarding the sustainability of existing facilities and facility whole life costs, researchers and healthcare planners are being encouraged to provide innovative means of improving these facilities. The refurbishment of healthcare buildings varies depending on the nature of the problem and the culture of responsible organisations such as NHS Trusts. Refurbishment is vital especially from a sustainability perspective; it frequently involves reconfiguring (recycling, modifying, extending, contracting and re-planning) existing spaces, meeting energy targets (carbon reduction), meeting users' needs to achieve desirable goals of healthcare facilities. Refurbishment can also be undertaken to save time and money, for example: higher fuel costs can mean that it is cheaper to refurbish a building (with double glazed windows and revolving doors) than to continue operating and maintaining it in its current state. Refurbishment is required to improve both internal and exterior elements and functions such as, indoor air quality and natural lighting. Sheth (2010a) has categorised the types of healthcare refurbishment into 3 drivers; user drivers, construction drivers and future drivers. This research has modified it as summarised in Table 1 to include space design, building structure, and facility management drivers.

Table 1: Categorisation of healthcare facility refurbishment key drivers

Users	Space design	Building structure	Facility management	Future challenges
Infection control	Redundant spaces	Poor natural lighting	Operational cost	New treatment procedures
Improving patient privacy/dignity	Inadequate circulation	Ageing structure	Maintenance cost	New equipment
Improving quality to staff and patient	Lack of proper ventilation	Upgrading building facades	Energy consumption	Survey response
Increase in staff	Increasing communication between functional spaces	Damage to structures	Facility causing accidents	Demographic growth
User feedback	Creating natural distractions with green spaces	Structures with asbestos content	near miss (possible hazards in facility)	Competition
Introducing nursing stations closer to patients units	Improving distributed care, reduce walking	Upgrading windows (double glazing)	Change in leadership	Standardisation compliance
Patients using facility differently from how it is designed	Improving design to suit staff and elderly patients	Introducing more wash hand basins	Change in facility focus	Flexibility compliance

Why Flexibility in Healthcare Projects?

Flexibility is an alternative option, it supports buildings adapt to changes in healthcare, such as growing and ageing population, technological innovation in medical treatment and equipment. A building is able to perform effectively over the years, if it adapt to changes mentioned above. Experts' views on flexibility are listed below.

- Ruwanpura et al, (2010) stated that "Hospitals are constantly under construction with on-going renovation and expansion to accommodate new modalities, new protocol, and new technologies".

- Gupta et al, (2007) stated that flexibility should be the cornerstone of the design as flexibility allows the facility to grow and expand in case of up gradation and also changes in internal functions.
- Improving quality, safety and flexibility of healthcare facilities are one of the 5 Evidence Based Design (EBD) principles defined by Eileen Malone, 2007 (McCullough, 2009).
- Miller, (2006) quotes Mortland stating that clinical laboratories are changing frequently; that most labs accommodate new equipment or technology frequently.
- Pressler, (2006) states that a good hospital design should have an adequate amount of flexible.
- McCullough, (2009) noted that future flexibility is important and essential for long term viability of healthcare institutions.
- Pati and Harvey, (2010) stated that healthcare facilities more than occasionally need to be adjustable to adapt changes in operation, equipment and management.
- Sheth et al, (2010) suggested that storage space, flexibility and adaptability help to make healthcare facility future proof. This could help save cost and improve quality.

Lam, (2008) was of the view that healthcare facilities have life span of 30-60 years, without design flexibility, they could be functional superseded. Flexibility has a place in healthcare centres as an influencing factor that allow hospitals to function properly over years, flexibility can be a functional declining inhibitor, that helps centres achieve their whole life cycle targets without compromising its efficiency.

2. Literature review

Space flexibility and (changes and growth)

Lam, (2008) stated that flexibility is required due to changes or growth, which is inevitable, as hospitals are designed for a span 30-60 years and have a residual value at the end of their design life that makes refurbishment a viable and sustainable option. Also at some point in a building's life, standards and functions will change. Lam, (2008) listed flexibility drivers; this research categorised them into changes and advancement, and presented in Table 2.

Table 2: Flexibility drivers in healthcare

Flexibility drivers	
Changes	**Advancements**
High density	Provision of better building performance
Special cases (epidemics)	Obsolescence and decline
Social and political issues	Advancement in medicine/equipment
Change in statutory requirements	Structural appearance

Over the years many healthcare facilities are becoming obsolescent while the life span has not reached its peak level. Due to variable demographics, cost and availability of technological hospital demands, operational and functional load requiring attention over the life span of facility, repudiating these factors in a given healthcare facility tends to reduce its life span, increase operational cost, causing early reconstruction, redevelopment and refurbishment. Adams, (2008:121) imagined that a flexible hospital could be designed today but used for an alternate operational and functional use in the future.

Space for growth is one of the factors that initiates flexibility to take place in the future, Both growth and flexibility require space, but growth is considered as one of the major drivers for flexibility, it requires more space, while flexibility requires space to be organised and designed to adapt to different activities without compromising productivity or alternative to expand.

Space flexibility and forecast for uncertainties

To deal with uncertainty, the major problem is how do we forecast how healthcare facilities will operate and function in the next 10 years, 20 years or 30 years? And at what point in time will change or growth be necessary and to what extent? Another difficulty is for the healthcare facility to serve its exact purpose when the building is supposed to change in use or adapt to some specific changes. Predicting spaces that do not need to be used immediately but will be needed in the near future is another problem. When making flexible design decisions stakeholders involved should participate to achieve optimal results, as exact forecasts cannot be achieved. It is difficult to predict the future, but from past reference a clear projection can be drawn, at times healthcare facilities might need to be downsizing by offering these spaces to third parties for sub-letting. Neufville et al, (2008) reported that “it is impossible to predict future patient activity with a reasonable degree of accuracy”. but Lam, (2008:43) suggested that the size of a big hospital depends on the number of beds, he also stated that in Hong Kong there is a standard of 5-6 beds per 1000 people population in a given area, this shows that the larger the population the higher number of bed required, with an estimated projection in population growth, an approximate amount of hospital beds in the near future can be specified.

Space standardisation and patient care

Designs attributed to Patient health and safety consider factors such as quality of working environment, healing environments (quality air flow, natural and artificial distractions, closeness to green environments, closeness of visitors) privacy, infection free healthcare environment. McCullough, (2009) noted that according to Eileen Malone, (2007) research was used to create healing environment using 5 Evidence Based Design (EBD) principles which included “design for maximum standardisation, future flexibility and growth”. Apart from providing quality spaces that will give desirable comfort to patients, staff performance has an impact on patient care. Standardisation can help improve healthcare space to adapt to patient needs, by providing standardised procedures and guides. Standardisation can also reduce patient incidents such as falling down in the bath room, by providing handrails. A standardised space is designed so that patient can use healthcare facility with ease, it should take patient`s need and safety into consideration to improve patient care.

Space standardisation and staff performance

According to Reiling, (2007) Standardisation routine is important; it improve safety of both staff and patient. standardisation reduce the possibility of errors occurring during healthcare delivery, he also described the human brain to create patterns, which works subconsciously, standardisation helps these patterns work perfectly over time. Non standardisation leads to thinking consciously which “can lead to fatigue and human error in routine functions” also standardisation does not allow the ease to focus on imaginative problem solving. Standardisation routine or process can easily be analysed and evaluated for enhancement, hence simplification and standardisation helps ease human error. When human error is reduced in healthcare delivery, performance has been achieved. Joint Commission

Resources, (2004a) states that "in the manufacturing industry, companies reduces error rates and increase productivity by standardising and simplifying" and also that "standardisation allows for the automation and predictability of many tasks so that they are unaffected by fatigue and interruptions, enabling staff to focus on clinical issues. Standardisation can help staff adapt to healthcare delivery by providing work flow delivery processes.

Impact of growth, uncertainties, patient care and staff performance on healthcare refurbishment

Literature shows that space flexibility can facilitate healthcare facility in adapting to growth and uncertainties, while space standardisation encourage and guides the ability to achieve patient care and staff performance. All these factors listed above make up the key drivers for refurbishment. Table 3 shows the relationship between space functions stated above and healthcare refurbishment. To achieve benefits of space standardisation and space flexibility they have to be implemented first. Swayne et al., (2006:413) stated that to carry out standardisation or flexibility it is vital to take into consideration the following.

- Financial resources available
- Skills
- Policies
- Human resources
- Management talent
- Facility and equipment
- Required information

Table.3: relationship between impacts of space functions and healthcare refurbishment drivers

Space functions	Impact	Category of refurbishment driver
Space flexibility	Growth	Future challenges
Space flexibility	Uncertainties	Future challenges
Space standardisation	Staff performance	Users
Space standardisation	Patient care	Users

3. Research Methodology

Literature review

Literature searched involved the use of both online and offline publications to gather information on flexibility and standardisation in healthcare facilities. More than 25 papers relating to space, flexibility, standardisation and healthcare were reviewed and analysed. Keywords such as *healthcare staff, patient, flexible spaces, refurbishment, standardisation in healthcare* were used to find relevant publication. Literature review helped in identifying healthcare drivers for space flexibility, space standardisation and refurbishment that were used to develop a framework relating all the three functions together, categorising them into three different phases, this can be found in figure 3 below.

Primary data collection

Questionnaire was distributed to a group of professionals that included architects, healthcare planners and project managers. Respondents came from different parts of the world comprising UK, Europe, North America, Africa, the Far East and the Middle East, Figures 1 and 2 shows demographics of the questionnaire respondents. Respondents were asked to indicate whether they agree or not with certain issues regarding space standardisation and space flexibility. Ranging from "strongly agreed", "agreed", "not sure", "disagree" and "strongly disagree", these were rated from 1-5 (strongly disagree-strongly agree) respectively. Questions were distributed via e-mail

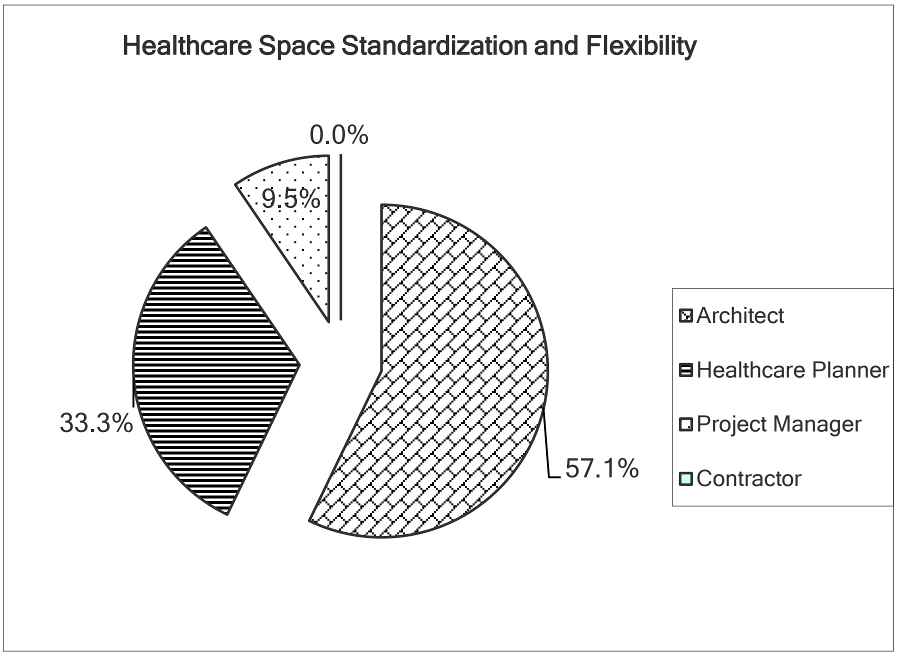


Figure.1: Professionals involved in questionnaire survey.

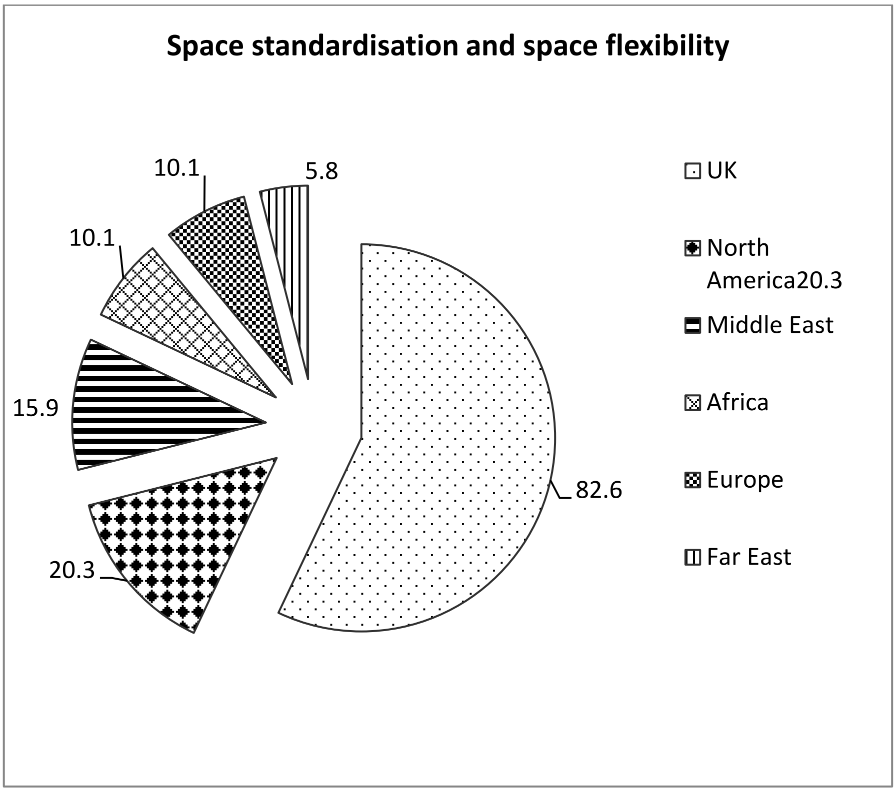


Figure 2: Location of professionals involved in questionnaire survey.

4. Discussion on findings

Due to the importance of both space flexibility and space standardisation on healthcare staff and patient, it is crucial they are applied during refurbishments. Sheth, (2010) categorised refurbishment into 4 levels which includes; 1) "Do nothing", 2) Interior works, 3) Exterior works, 4) Demolish. Flexibility and standardisation can take place at different phases of refurbishment, which includes minor, average and major refurbishment, putting limitation of refurbishment into consideration, such as budgets, constraints of existing structures and functions, certain flexibility concept can be applied at specific time and places to achieve specific type of flexibilities. Figure.3 proposes a possible relationship between refurbishment and both space functions identified in this research. Effective implementation of this strategic innovation can be facilitated by the concept of task partitioning. Von Hippel (1990) stated that "An innovation project of any magnitude is divided up ("partitioned") into a number of tasks and subtasks that may then be distributed among a number of individuals, and perhaps among a number of firms". He also stated that most problems can be resolved by decomposing them to tasks and reducing the cost involved with cross boundary problem solving. Tasks for both space functions at different refurbishment phases can be assigned to different individuals or firms. Task partitioning simplifies the whole process of integration in this paper by dividing and breaking down goals into targets that are easily achievable.

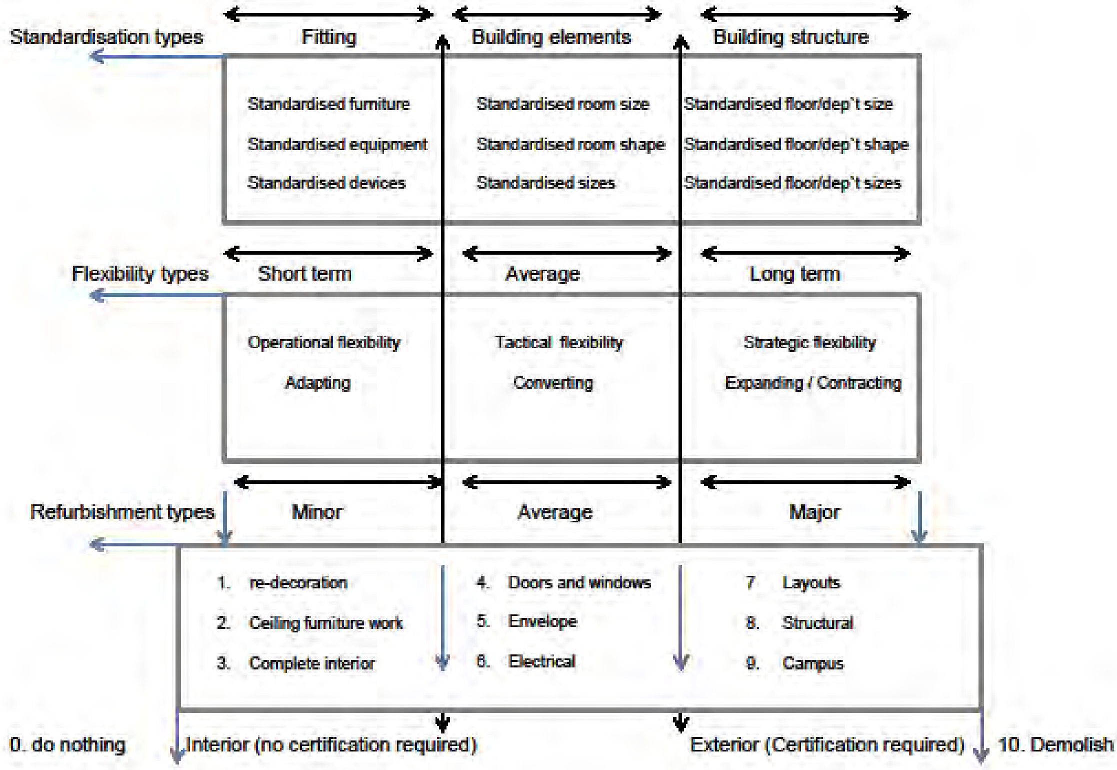


Figure 3: Proposed relationship between refurbishment and both space functions.

During the standardisation process, existing structures does affects the design brief, for instance a brief with a 100 percent single room target, might achieve 75 percent or 50 percent, this varies depending on the context, nature of existing structures and laid down standards involved in the type, location and need of projects, hence standards may vary, depending on their respective nature. Diversity in flexibility is expensive a time, as the more the space, the more the cost associated to flexible spaces. An innovative trend is to use spaces that expand and contracts back to their original size and shape after providing required services. Another major issue is how much flexibility is needed in a healthcare facility?

Findings

Points to consider for space standardisation, space flexibility and refurbishment in healthcare facilities

It is vital to consider user participation in developing space standards for patient, visitors and other healthcare users. Facility users such as patients tend to use a facility different from how it is been designed to functions, there is a patient motive to always use a facility in a way they find ease and simplicity. Hence space standardisations should be simple, precise, concise and user friendly. Most respondents identified that clinical areas are more suited for space standardisation, it is still unclear if healthcare designers and planners can consider standardisation in an entire building, due to its rigidity, and the nature of existing structures.

The questionnaire used in this research showed Design brief to be the most important tool for achieving space flexibility, as other tools such as Health Building Notes, Activity DataBase gives information to choose from, while a Design Brief tells you exactly what is needed, but on the other hand it does not tell you how to achieve the brief aims, which is a major problem of depending entirely on the design brief. Questionnaire respondents also suggested healthcare designers to consider furniture flexibility and equipment flexibility while dealing with space flexibility, as space could change by converting, expanding, contract or adapting to changes when flexible process are taken place, this could affect furniture and equipment positioning and ease of use. Flexibility is considered to be expensive due to failure to link first building cost with building lifecycle cost in the initial stage of building design, construction and facility management phase.

During refurbishment, lack of flexibility affects the building process, while hospitals are still operational, it has been noticed by the questionnaire respondent that there is always lack of alternatives spaces to move entire patient and staff while current used spaces are under construction, refurbishment in this scenario can affects healthcare delivery processes.

Questionnaire findings and decision making during refurbishment

The questionnaire findings can improve decision making during refurbishment, by specifying where best space standardisation and flexibility are more effective and efficient, Figure 3 shows relationship between types of (refurbishment and space functions used in this research), Figure 3 can also be used as a map, to decide where and when to introduce space standardisation and space flexibility best. These findings should be considered when refurbishment is taken place, as stated before, for a successful refurbishment, a facility has to be developed, improved, re-planned to solve major problems relating to sustainability, such as energy consumption, reducing facility management cost, improve users' needs, accommodating advancements in healthcare delivery and also natural ventilation and lighting.

Findings show that it is feasible to implement flexibility in the long term. Flexibility is linked with major refurbishments in Figure.1. Flexibility, in the opinion of the respondents should be introduced at long term basis in regards to room / ward / department / building / site levels, their responses showed that in three different cases, flexibility should be applied at long term basis. This gives an opportunity to in-cooperate it into building refurbishment. When making refurbishment decisions, it is effective to plan for long term flexibility during major refurbishments. Questionnaire results from three different questions was put together to compare and analyse the best time for flexibility impact in healthcare buildings, as this will help in decision making during refurbishments. Respondents were asked to indicate whether they agree or not that it is easy to implement cost effective space flexibility at three different places, identified as A-(building /site level), B-(specific area/room level) and C-(ward/department level) in healthcare design. At A, out of 70 respondents 48 answered and 22 skipped, at B, out of 70 respondents, 48 answered and 22 skipped. At C, out of 70 respondents, 48 answered and 22 skipped. Figure 4 shows the findings from A, B and C.

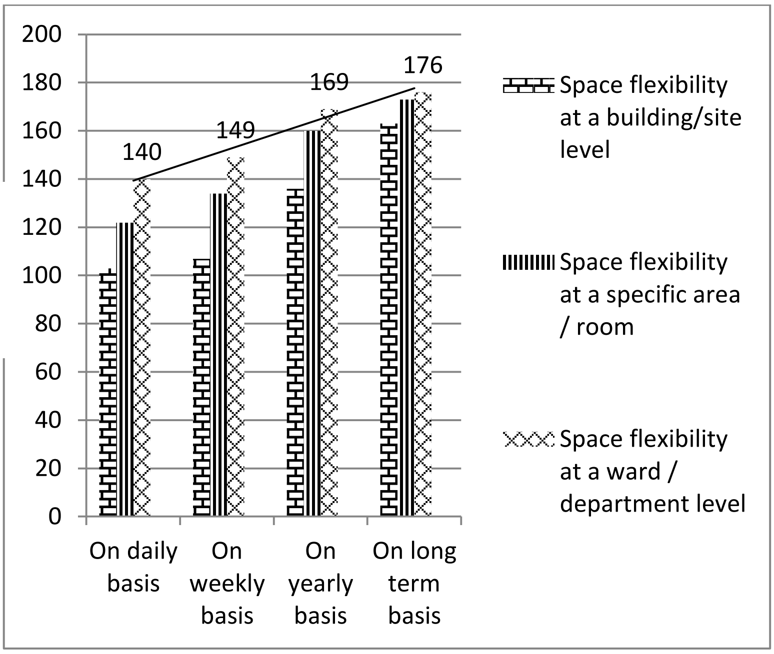


Figure 4: Questionnaire responses: Impact of space flexibility at three different places.

It is important to introduce space standardisation into refurbishment as staff efficiency and patient safety are one of the main key drivers initiating standardisation in healthcare. This was described and presented in Figure 5 below. Questionnaire respondents were asked to indicate whether they agree or not that the following are key drivers to achieving space standardisation. Out of 70 respondents, 56 answered this questions and 14 skipped. Space standardisation had a good impact on patient safety and staff efficiency according to the opinion of the respondents

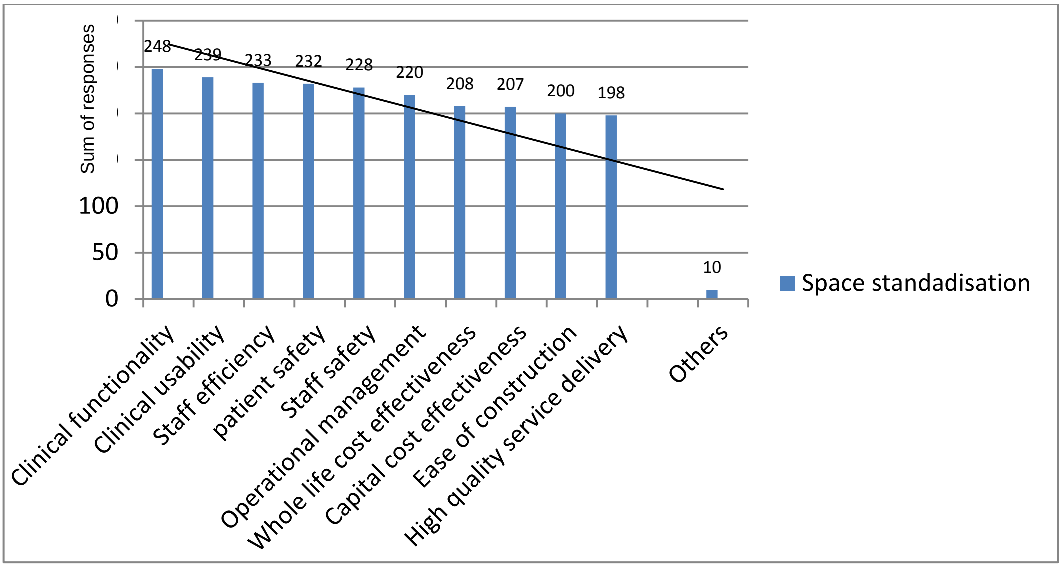


Figure.5: Questionnaire responses: Key drivers for space standardisation.

Figure 5 above and Figure 6 shows key drivers for both space flexibility and space standardisation in healthcare facilities. Respondents were asked to please indicate whether they agree or not that the following are key drivers to achieving space flexibility? Out of 70 respondents 49 answered and 21 skipped. Clinical functionality and usability with staff efficiency were essentials in the design of healthcare spaces in the opinion of the respondents.

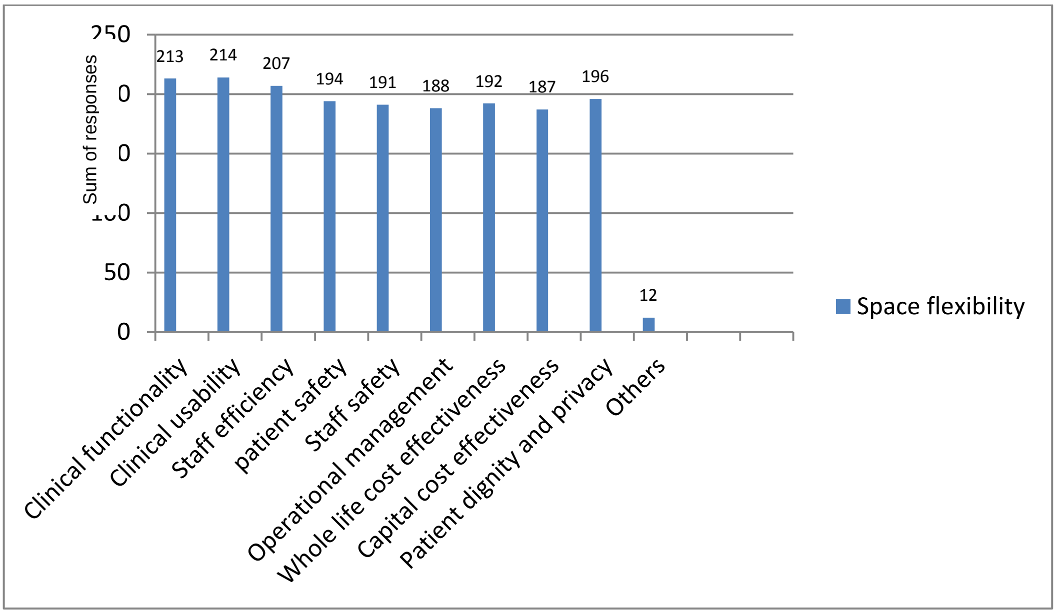


Figure 6: Questionnaire response: Key drivers for space flexibility.

Table 4: Relationship between key drivers for refurbishment and ones for (space flexibility and space standardisation).

Refurbishment drivers category	Space flexibility drivers	Space standardisation drivers
Users	Staff safety Patient safety	Staff safety Patient safety
Space design	Patient dignity and privacy	-
Building structure	Whole life cost effectiveness	Whole life cost effectiveness Ease of construction
Facility management	Clinical usability Clinical functionality Operational management Capital cost effectiveness	Clinical usability Clinical functionality Operational management Capital cost effectiveness
Future challenges	Consistency of: Staff efficiency	High quality service delivery Staff efficiency

Figure 7 shows questionnaire response. Respondents were asked to choose the best type of standardised function. Out of 70 respondents 57 answered and 13 skipped. It was identified by the respondents that standardisation is easier to implement at room level. When refurbishment is taking place, rooms can be standardised to achieve optimum healthcare outcomes. Joint Commission Resources (2004) Environment of Care, (2004) stated that "standardisation of treatment areas, room layout, and medical equipment supplies provide flexibility to accommodate changing patient care needs"

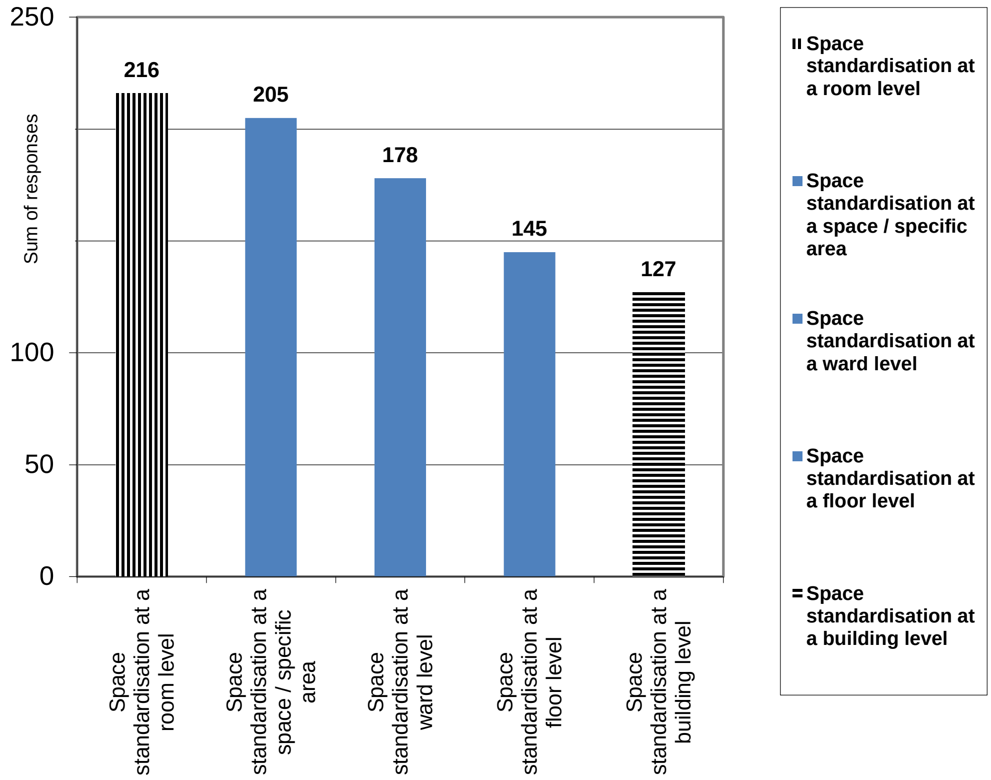


Figure 7: Questionnaire response: Best standard space/unit in healthcare buildings.

5. Conclusion

Table 3 and 6 shows the relationship between refurbishment and (space standardisation and space flexibility) having similar key drivers, if both space functions are achieved, quality of refurbishment will be enhanced. Refurbishment as already stated is carried out to improve current situation of a building structure, accommodating changes and advancement in technology and method of healthcare treatment and delivery. Introducing questionnaire findings into healthcare refurbishment can help to achieve optimum results worthwhile. Questionnaire key findings were; 1) With regards to space standardisation, standardised rooms were noted to be the most effective standardised unit in a healthcare facility in the opinion of the questionnaire respondents, in Figure 3, standardisation can be better achieved in healthcare refurbishment, if "standardised rooms" are used at the level (average) of refurbishment, which focuses on building elements such as doors and windows, with the ability to allow conversions to take place. 2) With regards to space flexibility, applying flexibility at long term was suggested to be the most effective opportunity to achieve it in healthcare space / rooms / ward / department or any other specific unit in the opinion of questionnaire respondents, in Figure 3, flexibility can be better achieved in healthcare refurbishment, if “long term flexibility” is applied at the level (major) of refurbishment, were structural expansion and contraction is involved.

The implementation of space standardisation and space flexibility in healthcare refurbishment can be simplified by tasks partitioning, stakeholders involved in the design, construction, and facility management of healthcare facility should collaborate and divide this goal into simpler and achievable targets to facilitate integration. This research has identified a gap that further research can improve on.

6. References

1. Adam, A. (2008). Medicine by design: The architect and the modern hospital, 1893-1943. Minneapolis: University of Minnesota Press.
2. BBC (2010). Many buildings unsuitable, NHS figures show [Online] Available from: http://www.bbc.co.uk/news/health-11769182. [Accessed on: 15th July, 2011]
3. Miller, K. M., (2006). Design and construction of healthcare facilities. United States: The Joint Commission on Accreditation of Healthcare Organisations.
4. Gupta, S.K., Kant, S and Satpathy, S. (2007). Modern trends in planning and designing of hospitals: Principle and practice. Jaypee Brothers Medical Publishers Ltd.
5. Carthey, J., Chow, V., Jung, Y. M and Mills, S. (2010). Achieving flexible and adaptable healthcare facilities – Findings from a systematic literature review, Proceedings, HaCIRIC International Conference 2010. pp. 109-118.
6. Joint Commission Resources. (2004) Environment of Care: Essentials for health care. 5 (ed). USA: Joint Commission on Accreditation of Healthcare Organisations.
7. Joint Commission Resources. (2004a). Joint commission guide to priority focus areas improving healthcare quality. USA: The Joint Commission on Accreditation of Healthcare Organisations.
8. Joint Commission Resources Inc. (2006). Planning, design and construction of health care facilities. USA: The Joint Commission on Accreditation of Healthcare Organisations
9. John Reilling, (2007). Safe by design: Designing safety in healthcare facilities processes. USA: The Joint Commission on Accreditation of Healthcare Organisations.
10. Lam, K.C. (2008). Planning the inherent growth or change of a hospital. Hong Kong: Design and Construction. Touching Briefings 2008.
11. Mc Cullough S.C. (2009). Evidence-based design for healthcare facilities. United States of America: Renee Wilmeth.
12. Neufville, R. D., Lee, Y. S. and Scholtes, S. (2008). Flexibility in hospital infrastructure design. IEEE Conference on Infrastructure System.
13. Pressler, G. R. (2006). Born to flex: Flexible design as a function of cost and time. Health Facility Management, 19(6), 53-54.
14. Ruwanpura. J., Mohamed, Y. and Lee. S. (2010). Innovation of reshaping construction practice. Proceedings of the 2010 construction research congress. Virginia: Construction Institute.
15. Sheth, A.Z., Price, A.D.F. and Glass, J. (2010a). BIM and refurbishment of existing healthcare facilities. In: Egbu, C (ed). Proceedings of the 26th annual ARCOM Conference, 6th-8th September, Leeds, United Kingdom, vol. 2, pp. 1497-1506.
16. Sheth, A.Z., Price, A.D.F. and Glass, J., (2010). Existing healthcare facilities, refurbishment, and energy simulation. International Conference of the Constructed Environment, 17th-18th November, Venice, Italy.
17. Swayne, L.E., Duncan.J. W. and Ginter. P.M. (2006). Strategic management of health care organizations. USA: Blackwell Publishing.
18. Von Hippel, E. (1990). Task partitioning: an innovation process variable. Research Policy, vol. 19, Issue 6, pp.407-418.

APPENDIX 2: PAPER 2

BIM IMPLEMENTATION PLANS:
A COMPARATIVE ANALYSIS

1. Ahmad, M. Ahmad[1], 1. Demian, Peter [2] and 1. Andrew, D.F Price[3]

1. School of Civil and Building Engineering, Loughborough University, UK.

To realise the benefits of BIM in construction management using (4D and 5D applications), it has to be implemented first. There are various BIM implementation plans to select from; with BIM features and guides, companies better understand BIM concepts and can easily choose a plan to apply in their operations. A literature review was conducted and 15 different definitions of BIM were encountered. 12 different BIM implementation plans were found in publications by academics, software vendors and Architecture/Engineering/Construction (AEC) industry professionals. Those implementation plans were compared using a matrix which covers the complete building lifecycle. This research concludes that out of the 12 implementations plans, three were equipped with additional guides attached to their plans, simplifying project data collection; namely those by Autodesk, Penn State University and Indiana University. One implementation plan that scored very highly (based on 16 key issues identified from the three categories of stakeholders specified in this project) was the implementation plan proposed by a major software vendor. BIM is poised to solve many of the shortcomings reported in the construction industry. However, before realising the full potential of BIM in construction management, it needs to be systematically implemented.

Keywords: BIM implementation plans, BIM use, BIM, construction management.

INTRODUCTION

Eastman et al (2011, 2008) and Hardin (2009) agreed that BIM use is growing in the AEC Industry. It is undoubtedly important in construction management, but needs to be implemented to reap its benefits. Currently there is no universal BIM implementation solution. Therefore, a question arises, how do you choose a good BIM implementation plan? It is important to first understand the nature and scope of BIM. It is characterised with many features; Isikdag and Zlatanova (2009) noted BIM as object oriented, equipped with spatial relationship between building elements, data rich with functional information about a building, and enabling automation of multi view generation. However, there is no standard universal implementation guide for BIM; standards are being produced by different organisations for different purposes. Eastman et al (2011) stated that the existence of various

---

[1] A.M.Ahmad@lboro.ac.uk

[2] P.Demian@lboro.ac.uk

[3] A.D.F.Price@lboro.ac.uk

BIM implementation approaches can change existing working pattern of organisations to allow the implementation of new technology. Howard and Bjork (2008) stated that "many standards relevant to BIM exist but it was suggested that there is a lack of frameworks into which they could fit". They were also of the view that BIM deployment standards are not compatible with all companies due to differences in organisational cultures, procedures, size, company goals and objectives. It is crucial before choosing any implementation plan, to have a good understanding of BIM; Aranda et al (2007, 2008); Succar (2009) agreed that BIM means different things to different people.

Table 1: BIM features described by three different categories.

A. BIM Definition by Academics

References	Information	Management	Modelling	Process	Technology	Analysis	Collaboration
1. Weygant (2011:vii)	x	x	x	x	x		x
2. Eastman et al (2011)	x	x	x	x	x	x	
4. Hardin (2009:4)	x			x			
6. Smith and Tardiff (2009:xi)	x			x			
7. Howard and Bjork (2008)				x			
9. Sweet and Scheier (2008:375)	x		x		x		

B. BIM Definitions by Software Vendors

12. Bentley (2011)	x	x	x	x	x	x	
13. Nemetschek`s Vectorworks (2010)	x		x	x	x	x	
14. Graphisoft (2002:5)	x		x	x	x	x	x
15. Autodesk (2002:1)	x	x	x	x	x	x	x

C. BIM Definitions by Architecture Engineering and Construction Industry and others

16. BIM Journal (2011)	x			x			x
17. BuildingSmart (2008)	x	x					x
19. VTT (2006:25)	x	x		x			
20. AGC (2006)	x						
21. State of Ohio (2010)	x	x	x	x			x

This research first identifies BIM features from the views of various stakeholders in the building industry. The methodology used in defining BIM and analysing BIM implementation plans is based on a literature review. The overarching aim of this paper is to compare BIM implementation plans; it is of great importance to understand BIM and plan for its implementation, due to the UK Government push to mandate the application of BIM in major public-sector building projects by 2016 and to realise its BIM benefits. Arguably some experts view BIM as either an IT tool or a procedural process, while others views BIM as the combination of both technological tool and a comprehensive building process used in improving building procurement and envisioned to promote collaboration between professionals in the building industry. Eastman et al (2011) agree with Hardin (2009) that

BIM is defined by various experts and organisations differently. This paper identifies BIM features within 15 definitions from three categories: A) academic sources; B) software and hardware vendors; and C) AEC organisations. Table 1 was tabulated by identifying seven keywords from the 15 different definitions of BIM. These keywords appeared at least three times in all the 15 different definitions of BIM. The following keywords: "Information"; "modelling"; and "process" had appeared more than any other feature of BIM from the keywords mentioned in Table 1. Therefore, BIM for the purpose of this research can be defined as the process of using information technology for sharing, modelling, evaluation, collaboration, and management of a virtually building model within a building life cycle. BIM was also classified into three groups: building model (simulation, automation and presentation); building process (thinking, scheduling and organisation) and information management (preservation, sharing and organisation) within a building life cycle.

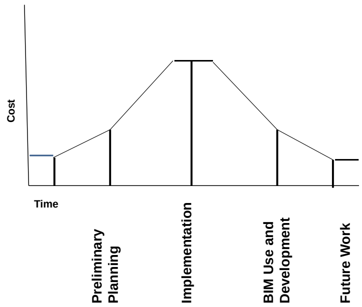
2. BIM Implementation Plans

2.1 Related Researches on BIM Implementation Plans

Stebbins (2009) considered BIM as a process rather than a piece of software. He clearly identified BIM as a business decision and the method of implementing BIM as a management decision. BIM implementation is strongly related to managerial aspects of professional practices; most industries have different working styles and cultures. AGC of America (2006) stated that “each project is unique, and the implementation of BIM should be tailored to the needs of the project”; therefore, standard implementation plans must be sensitive and can be tailored to the individual characteristics of each project. Fisher (2011) stated that a BIM plan: “defines scope of BIM implementation and information exchange; identifies the process flow for BIM tasks; and describes infrastructure needed for support”. He also noted that it provides a better understanding of goals, responsibilities attached to each personnel, teams, department, and management. BIM implementation plans also help to reduce unknown variables with competence to schedule and outline expected training and resources required for construction management.

2.2 Classification of BIM implementation Plans Levels

There are various methods of implementing BIM. The following methods were identified from literature: Top-down; bottom-up; slow and drawn out; using a selected team; using multiple teams; and implementing on a specific projects, all projects or the entire organisation. Jung and Joo (2010) described BIM implementation to be of three levels; industry, organisational and project levels. At the industry level, BIM standards are successfully developed, but the organisational and project level standards are different due to their formats, details and purpose, and are also related to managerial corporate strategy issues. Ashcraft and Sheldon (2008) noted that BIM adoption is divided into three groups of activities covering different scopes: Within an office: Selecting software; addressing IT issues; and training up and rolling out. Across the design team: Selecting software: addressing IT issues: and also legal and contractual issues. Across the project delivery team: Procedural scope (design, coordination, estimating, scheduling, submittal review, fabrication, agency review and facility management); and also legal and contractual issues. While the cost of BIM implementation is one of the major limitations of BIM adoption. There is no specific standardised amount designated to the cost of Implementation, nor a clear understanding of how to precisely estimate such cost. Hardin (2009) described that the cost of BIM implementation is higher when implementing; this involves the cost of training and software. In the life cycle cost of BIM implementation, the cost gradually reduces during the use and development phase. BIM users' experience lesser cost during the "future work" phase; perhaps training and (software and hardware purchasing) are the most expensive issues to think through when implementing BIM.



Figures 1: Cost of BIM implementation plans (Hardin, 2009).

2.3 Benefits of BIM in Construction Management

Weygant (2011); Autodesk (2002); Succar (2009); Hardin (2009); Aranda Mena et al (2008); Eastman et al (2008, 2011); AGC of America (2010) agreed that 4D and 5D modelling, helps clients and contractor to make inform decisions, by estimation, coordination and scheduling the construction process. The client can get a better scope and nature of the design and construction with BIM visualisation. Construction sequence can be visualised systematically, showing construction progress with time and cost implications attached. It also helps in synchronising the procurement of design and construction planning for early error detections. BIM is also used in managing existing facilities, by fully modelling and linking the structure to the virtual model. This way, energy consumption and operational faults can be detected from the model for management purposes. For example, the Sydney-Opera House is currently managed using a BIM model for facility management. It is also evident in literature that BIM is used more (higher percentage of use) on the construction phase compare to the design phase; perhaps BIM is effective in achieve quality and efficiency in construction management.

2.3 Barriers of BIM

Yan and Demian (2008) noted that people barrier seems to be the most challenging factor. Companies have to provide time; human resources; and to training, forming a business case for BIM. Howard and Björk (2008:23) described the need of education, sharing, standards and legal issues to implement BIM, weygant (2011) and Eastman et al (2008) agreed that legal issues are also barriers to implementation, Aranda Mena et al (2008:14) suggested that due to the nature, size, relationship of private and public sectors involved, it will be difficult to assign a standard implementation plan for each firm to observe. Eastman et al (2008) is on the view that there are both technological and sociological barriers to BIM implementation. Succar (2009:363); Aranda Mena et al (2008); Eastman et al (2008, 2011); AGC of America (2010); Howard and Bjork (2008) agreed that interoperability is a major issue of the use of BIM in the building industry. Succar (2009:363) defined interoperability as “the ability of two or more systems or components to exchange information and to use the information that has been exchanged.

3. Research Methodology

Literature review was used to define BIM: BIM implementations plans; levels of BIM implementation; identified best practices; barriers and benefits of BIM. About 20 high quality articles relating to BIM were selected for a comprehensive state of the art literature review. Research defined and compared BIM implementation plans from three stakeholder groups: academics; software vendors; and AEC industry and other organisations. The objective was to find the common key factors used to deploy BIM. Comparability is defined by Kotabe and Helsen (2009), as the similarity and difference features of one research results to another. It is important to compare studies to illustrate the significance of choosing an implementation plan by identifying its features. BIM can be understood from a building life cycle point of view. Therefore the BIM implementation plans (key factors) were categorised into pre-implementation, implementation and post-implementation. The comparison matrix was based on the criteria by Fisher (2011) who noted critical issues in adopting BIM execution Plan as: goals; participants; level of detail; infrastructures; software platforms and workflow. A total of 16 key factors were identified, from which 14 were mentioned in at least three different implementation plans amongst the 12 plans. Two other key factors were identified by (Arayici et al 2011; Messner et al 2010) and Eastman et al (2011) as vital issue of BIM implementation, there are: (specifying level of BIM implementation; and spreading BIM implementation from one team to others) respectively. Three of the 12 different implementation plans described from the three categories (stakeholders) in this paper, had additional data collection formatted documents, which are Indiana University, Penn State University and Autodesk.

3.1 Comparison synthesis

Table 2 shows categories of BIM implementation plans classified into three (A-C) and numbered (1-12): A. Software: Autodesk, (2010) [1]; and Dell, (2011) [2]. B. Academic: Eastman et al., (2011) [3]; Arayici et al., (2011) [4]; Hardin, (2009) [5]; Succar, (2009) [6]; (Penn State)-Messner et al., (2010) [7]; Indiana University (2009) [8]. C. AEC Industry and others: AGC of America, (2010) [9]; (BuildingSmart) - Lin et al., (2005) [10]; AIA, (2008) [11]; and BIM Road Map, (2011) [12]. Table 2 was tabulated based on the 16 key issues identified within the 12 implementation plans cited by this paper. Each implementation plan that had one of the listed 16 key issues was ticked with an “x”. Within the 16 key issues identified in this research, there was agreement with regards to 10 key issues, and some gaps in the remaining six key issues; this can be clearly seen in Table 2.

Table 2: Comparison of BIM implementation plans from three different categories.

	Analysis of BIM Implementation plans numbered (1-12)												
	Pre-BIM Implementation Phase	1	2	3	4	5	6	7	8	9	10	11	12
1	Define BIM goals	x	x	x	x	x	x	x	x	x	x	x	x
2	Plan BIM uses	x	x	x	x	x	x	x	x	x	x	x	x
3	Start with a team			x						x			x
4	Leadership	x	x	x	x	x	x	x	x	x	x	x	x
5	Managerial support	x	x	x	x	x	x	x	x	x	x	x	x
6	Specify level of BIM implementation	x	x	x	x	x	x	x	x	x	x	x	
7	All stakeholder involvement	x	x				x	x	x				x
8	Identify current skill and list required skills	x	x	x	x	x	x	x	x	x	x	x	x
	BIM Implementation Phase												
9	Continuous training and development	x	x	x	x	x	x	x	x	x	x	x	x
10	Collaboration	x	x	x	x	x	x	x	x	x	x	x	x
11	Information exchange execution	x	x	x	x	x	x	x	x	x	x	x	x
12	Appropriate hardware and software	x	x	x	x	x	x	x	x	x	x	x	x
13	Conformity to standardisation	x	x	x	x	x	x	x	x	x	x	x	x
	Post BIM Implementation Phase												
14	Educational BIM awareness	x			x		x	x		x			
15	Spreading implementation from one team to the others	x		x									
16	Review performance	x					x	x					x

4. Discussion of Findings

Table 1 was tabulated from 15 different definitions of BIM. There is an agreement in the features identified from the definitions that BIM is a technology, a process, and an information management tool that allows (data storing and sharing). Table 2 shows agreement across the selected BIM implementation plans within the pre-implementation and the implementation phases. There is lack of agreement in two of the 16 keywords listed as: starting with a team; and spreading the implementation to other parts of a given industry. The advantage of starting with a team is that, it can easily be managed rather than starting with the entire professionals with an organisation. Obstacles encountered by a small team could be avoided by an entire organisation; saving project time and cost.

Literature shows that BIM usage has a higher percentage in construction compared to the entire design process; its applications are many and varied. Impact of BIM in Construction management can be categorised into three: 1.) Pre-construction-. Hardin (2009) stated BIM in pre-construction fosters the capability of making designs constructible, providing clash detections analysis, estimations, and other detailing such as BIM prefabrication modelling and information management for manufacturers specifications. 2.) Construction - Autodesk (2002) described BIM in this phase to improve construction quality through 4D and 5D modelling. This involves time scheduling and information generation to make informed decisions. After analysing models in the pre-construction phase, the data can be used for organising and scheduling construction work progress with cost and time implications. This will eventually reduce errors and possible construction reworks. 3.) And management phase - the building life cycle includes inception, completion, and operational building management to demolition phases. Information for concurrent use of facility can be used to analyse the performance of a building for energy performance, utilisation analysis and their financial implications. The operational phase of a building is suggested by literature to always be linked to the first cost of a building, as the cost of running a building over some years could be more than the first time cost of a building. It is therefore important to analyse and compare the virtual analysis of a building performance to its real time performance. This can be used to improve the performance where it is deficient. The information on the performance of a building can also be used for managing the operation of a building.

BIM allows the architect and engineer time to collaborate within a project. Hardin (2009) stated that BIM "is mostly ineffective" in design-bid-build; this is one of the most traditional delivery methods that follow a linear sequence where the design precedes the construction, the ability of BIM to allow collaboration is hereby limited. Nevertheless, BIM can help with many other tasks such as quick financial quantification. BIM as a coordination tool for construction management works well with the design and build method; it is a combined service, with the full responsibility for design and construction, and could be architect or contractor lead. It allows BIM application to be fully explored and used to realise its benefits for construction management. However BIM has to be implemented before apprehending its benefits.

Olofsson et al (2008) described that when using BIM in a building life cycle, the client is understood to achieve more benefits. Some of the most common barriers mentioned among the 3 stakeholders were the cost of training, software and hardware, perhaps when Implementing BIM organisations should be clear on the reality of their capabilities (Jason and Isikdag (2010:88). Implementation plans forms the basis for the use of BIM in practice, Jung and Joo (2010) stated that “it is important that the proposed framework be used as an evaluation criterion for practical implementation”. Messner et al (2010) described key challenges of BIM implementation when developing an execution plan as defining appropriate purpose for the use of BIM, and information exchange. Indiana University (2009) and Autodesk (2010), have made recommendations to improve information exchange, they suggested one professional from each stakeholder group to form a team and agree a common naming and file format system, which makes each files easily identified to other professionals. Some parties tend not to share their process of achieving success with BIM

(Howard and Björk 2008:26). It is important to start with the best team before spreading BIM implementation to other teams and projects; this will require smaller budgets, with ease in controlling difficulties when they arise. Findings can easily be shared with the organisation at large and peer review for evidence based practice.

Fisher (2011) highlighted six key issues for BIM adoption; this research identified 16 key issues adopted and modified from Fisher (2011) and as seen from the 12 different BIM implementation plans. Perhaps BIM can be implemented efficient and effectively following these 16 key issues identified in Table 2 as a primary guide for a general BIM implementation before the benefits of BIM can be realised.

Limitation of research

Some of the keywords in Table 1were not directly quoted from the various definitions of BIM, but indirectly described. For example; "information" category was considered as: data; database; characteristics; features; and documentation. In Table 2, there are various key issues that appeared in at least three different BIM implementation plans, but the selected key issues were based on Fisher (2011) description of important factors considered for BIM adoption.

5. CONCLUSIONS

BIM implementation standards are being produced by different organisation for different purposes consequently, according to Howard and Bjork (2008:274) “many standards relevant to BIM exist but it was suggested that there is a lack of a framework into which they could fit” they are also on the view that BIM deployment standard are not compatible with all companies due to difference in culture, organisational traditions, size and company goals and objectives. This makes the standards variable. Table 7 shows agreement and gaps in key issues of BIM implementation plans highlighted. There was agreement in 10 key issues of BIM implementation, while six key issues had some disagreement. Most of the BIM implementation plans listed in Table 7 fail to acknowledge: identifying "specific levels" of BIM implementation plans in their framework or guides. It is important that users know the exact guide to pick which suits their specific needs, implementation at a project level, might not necessary need the same criteria for implementation as at an organisational level, office level, or team level. Nevertheless, provision of multiple options can encourage BIM implementation. The top three implementation plans in this paper starts with the Autodesk plan, it has identified most key issues of implementing BIM, followed by BIM execution plan by Penn State University, with a similar plan from Indiana University. Apart from prescribing key issues to BIM implementation, all three plans have guides that can easily facilitate information collection from users and help provide the appropriate guide to implementation. BIM has to be implemented before its benefits in construction management can be realised. Further research can be done with future emergence of more implementations plans. This research will further develop a framework for applying BIM in the design of flexible healthcare space.

REFERENCES

AIA (2008) Building Information Modelling Protocol Exhibit. Available from: http://www.revit3d.com/files/ipd/Revit3D%20E202 2008_eSample_Blank%20Property%20of%20AIA.pdf

AGC of America (2006) Contractor`s Guide to BIM. 1ed.

AGC of America, (2010) BIM Educational Program: An AGC Construction Learning Tool, Your Resource for Successful BIM Implementation.

American Institutes for Research (AIR) (2010) Comparability Analysis. [Online] Available at: http://www.air.org/topics/topic_comparability_analysis.aspx. [Accessed on: 1st March, 2010].

Aranda, M G, Chevez, A, Crawford, J R, Wakefield, R, Froese, T, Frazer, J H, Nielsen, D and Gard, S (2008) Business Drivers for Building Information Modelling. Cooperative Research Centre "Construction Innovation", Australia, Brisbane.

Aranda, M G, Crawford, J, Chevez, A and Froese, T (2009) Building Information Modelling Demystified: Does It Make Business Sense to Adopt BIM? International Journal of Managing Projects in Business, (2) 3, pp. 419-434.

Ashcroft, H and Shelden, D. R. (2008), BIM Implementation Strategies [Online] Available from: projects.buildingsmartalliance.org/files/?artifact_id=1399Similar. [Accessed on: 12th July, 2011].

Autodesk (2002) [Online]. Building Information Modelling: (white paper). Available from: http://images.autodesk.com/apac_sapac_main/files/4525081_BIM_WP_Rev5.pdf. [Accessed on: 12th July, 2010].

Bentley (2011) [Online] About BIM, Available from: http://www.bentley.com/en-GB/Solutions/Buildings/About+BIM.htm. [Accessed on: 13th July, 2011].

BIM Journal (2011) Improving the Construction Process. Available from: http://www.bimjournal.com/what-is-bim/. [Accessed on: 13th July, 2011].

BIM Road Map (2011) BIM Implementation Plan for Military Construction Projects, Bentley Platform. US Army of Corps Engineers.

BuildingSMARTalliance (2008) [Online] Charter for the National Building Information Model (BIM) Standard Project: A project for the BuildingSMARTalliance. Available from:http://www.buildingsmartalliance.org/client/assets/files/bsa/NBIMS_Charter.pdf [Accessed on: 1st September, 2011].

Dell (2011) White Paper: Future-Proofing BIM. [Online] available from: http://www.wbdg.org/pdfs/1103_dell_bdc_whitepaper.pdf. [Accessed on: 20th May, 2011].

Eastman, C M, Eastman, C, Teicholz, P, Sacks, R and Liston, K (2008) "BIM Handbook: A Guide to Building Information Modelling for Owners, Managers, Designers, Engineers and Contractors". New Jersey: John Wiley and Sons.

Eastman, C M, Eastman, C, Teicholz, P, Sacks, R and Liston, K (2011) "BIM Handbook: A Guide to Building Information Modelling for Owners, Managers, Designers, Engineers and Contractors". Canada: John Wiley and Sons.

Fisher, J (2011) [Online] BIM Technology Briefing Steering Committee. BIM Execution Plans. Available from: http://www.advsolinc.com/pdf/events/StLouis_BIMExecutionPlan.pdf. [Accessed on: 12th July, 2011].

Fischer, M and Kunz, J (2006) [Online] The Scope and Role of Information Technology in Construction. Available from: http://cife.stanford.edu/online.publications/TR156.pdf. [Accessed on: 15th August, 2011].

Graphisoft (2003) Building Information Modelling: A look at Graphisoft`s Virtual Building Concept. USA. Cyon Research Corporation.

Hardin, B (2009) "BIM and Construction Management Proven Tools, Methods, and Workflows". Indiana: Wiley Publishing.

Howard, R. and Bjork, B.C. (2008), Building Information Modelling: Expert`s Views on

Standardisation and Industry Deployment. "Advanced Engineering Informatics", 271-280. Elsevier.

Isikdag, U. and Zlatanova, S. (2009), Towards Defining a Framework for Automatic Generation of Buildings in CityGML using Building Information Models. "3D Geo Information Sciences Conference" Seoul, Korea. 79-96.

Jason, U J and Isikdag, U (2010) A Synopsis of the Handbook of Research on Building Information Modelling. "Information Technology n Construction", United Kingdom, 84-96.

Jung, Y and Joo, M (2011) Building information modelling (BIM) Framework for Practical Implementation. A College of Architecture, Myongji University, Yongin, South Korea. 20 (2), 126-133.

Kotabe, M and Helsen, K (2009) Handbook of International Marketing: London: Sage.

Lin, T. A and Fatt, C.T (2005) Building Smart- A Strategy for Implementing BIM Solution in Singapore. (CORENET) Initiative. "Systems", 5, 117-124.

Messner, J, Hunter, S and Anumba, C (2010) Project Execution Planning for Building Information Modelling (BIM) A BuildingSMART Alliance Project. Penn State University.

Nemetschek`s Vector works (2010) BIM Brochure: Better Designs with Better BIM. USA.

Olofsson, T, Lee, G and Eastman, C (2008) Editorial – Case Studies of BIM in Use. "ITcon" Vol. 13, 2008, 244-245.

Smith, D k and Tardif M (2009) "Building Information Modelling: A Strategic Implementation Guide for Architects, Engineers, Constructors, and Real Estate Asset Managers" Canada: John Wiley and Sons.

State of Ohio (2010) Building Information Modelling (BIM) Protocol: State Architects Office, General Services Division.

Stebbins. J (2009) Successful BIM Implementation: Transition from 2D to 3D BIM. "Digital Vision Automation".

Succar, B (2009) Building Information Modelling framework: A Research and Delivery Foundation for Industry Stakeholders. "Automation in Construction", 18 (3), 357-75.

Sweet, J and Schneier, M. M (2008) "Legal Aspects of Architecture, Engineering and the Construction Process". 8 ed. USA: Cengage Learning.

VVT (2006) Building Information Models: Inter-Organisational Use in Finland. VBE2 (1) Research and Development Project, Work Package 1.4, Public Report.

Weygant, R S (2011) "BIM Content Development: Standards, Strategies, and Best Practices". New Jersey: John Wiley and Sons.

Yan, H and Demain, P (2008) Benefits and Barriers of Building Information Modelling. http://www.staff.lboro.ac.uk/~cvpd2/PDFs/294_Benefits%20and%20Barriers%20of%20Building%20Information%20Modelling.pdf.

APPENDIX 3: PAPER 3

CREATIVITY WITH BUILDING INFORMATION MODELLING TOOLS

Ahmad, M.A.[1], Demian, P.[1] and Price, A.D.F.[1]

[1] School of Civil and Building Engineering, Loughborough University, UK.

Abstract

Whilst the application of BIM continues to be acknowledged and prevailing, design practitioners and academics find themselves in a paradox with an on-going discussion on the impact of BIM tools on design creativity and innovation. Literature suggests that BIM tools can hinder design creativity due to: parametric limitations; interoperability; and the demand for detailed information at preliminary design stages. However, other literature shows that BIM tools increase design creativity, and at some point provide limitless opportunities to be creative. The aim of this paper is to identify and verify the impact of BIM tools on design creativity. It is important for architectural students and practioners to be aware of the impact of BIM tools on the design. A literature review was used to identify the benefits and constraints of BIM tools on design creativity; a questionnaire survey was used to verify its impact. A questionnaire survey was conducted with the top 100 UK architectural firms (group one) and CNBR Yahoo Group (group two). It was found that BIM tools do not affect design creativity and innovation in the opinion of the respondents. This paper enlightens the status-quo of BIM tools on creativity and innovation, but will focus on the impact of BIM tools on architectural design creativity in the early design phase more closely. This research would be important to both academics and architectural designers using BIM in their various applications.

Keywords: BIM, BIM tools, creativity, design, innovation.

*Corresponding author

Email address: A.M.Ahmad@lboro.ac.uk

Introduction

Building Information Modelling (BIM) has the potential to significantly change the traditional design process, raising concerns within both academia and professional design studios. The impact of BIM technology on architectural design creativity has been previously debated in academic publications, such as Ibrahim and Rahimian, (2010); Meneely and Danko, (2007); Zarzycki, (2010); and Moreira, (2010). Other mediums used in conducting BIM and design creativity debates includes seminars, and professional`s online social networks. A questionnaire survey was conducted to collected primary data; the UK top 100 architectural firms based on the Building Magazine 2011 (group one), and CNBR Yahoo group (group two) were selected as questionnaire respondents. This paper focuses on the impact of BIM tools on architectural design creativity. However, architectural design is a process that usually starts with the following sequence: a client`s brief; design appraisal; and the conceptual idea (schematic design) that is later developed and realised as a design product. BIM tools play a major part in achieving productive design outcome and reducing total design hours through digital automation. Reddy, (2011) states that "*BIM also provides the ability to develop the wildest design concept within the constructability analysis of their design*". The BIM tools used to realise BIM`s benefits are arguably decreasing design creativity in the opinion of some BIM users, academics and professional architectural designers within the Architectural Engineering and Construction (AEC) Industry; whilst increasing creativity to others.. Creativity is important in the realm of design, it takes place in diversity, series of products, events and accomplishments; It can be found in various fields of disciplines. Attributes of creativity adopted from Pederson and Burton, (2009) describe creativity more closely as: Idea/analogy/knowledge; problem definition; original/originality; novel/new; imagination/artistic/aesthetic interests; risk taking /complicated/complex; and innovation/ freedom/ flexible. Creativity refers to the ability to invent new products, processes, solutions, and works of art that are useful and depicts originality; creativity can also be defined as a technique for creative thinking. The definitions of creativity in Table 1 were chosen to show in-depth and diversity in creativity. The applicability of creativity occurs in different realms of life. However from the various definitions of creativity in Table 1, creativity can be defined as new knowledge, product, development, or original idea that is useful, valuable, beneficial and important to our lives.

Table 1: What is creativity?

Reference	Definition
Martin, (2007)	States that scientific creativity is "moral creativity when it promotes human well-being, improves his environment, and enriches the meaning that we find in life".
Runco, (2006)	States that "creativity is defined so as to allow for both continues and discontinuities in development".
Stenberg, (2006)	Defines creativity as an innovation that is new, original and beneficial.
Nagel, (2000)	Defines creativity as more than finding new ways of doing things but refers to "finding alternatives that are capable of exceeding the best expectations of all sides and viewpoints to dispute or dilemmas".
Mumford, (2003)	States that "creativity involves the production of novel, useful products"
Boden, (1998)	Describes that "creativity is a puzzle, a paradox, some say a mystery" that is valuable.
Boden, (1994)	Describes that "creativity is a prized feature of the human mind" used to make a difference.
Feldman et al., (1994:1)	States that creativity is defined as "the achievement of something remarkable and new, something which transforms and changes a field of endeavour in a significant way".
Owen, (1992)	Describes that "creative thinking is not confined to the few, it can be systematically implemented and employed with great success to develop concepts for new products, systems and institutions".

BIM Tools

BIM has many advantages such as automation, modelling, visualisation, design (analysis and evaluation), information storing, and information sharing and so on. Aranda-Mena et al., (2008) suggest that the importance and benefits of BIM use are divided into three categories, which are: *Technical Capabilities* - this involves the ability to share information with other BIM users within and outside a given organisation; *Operational Capabilities* - this involves design collaboration, reducing errors and allows the ability to design within a 3D environment; and *Business Capabilities*- involves the completion of projects within specific time frames, by reducing errors, automation, early clash detection and so on; to realise these benefits, BIM has to be implemented first. BIM for the purpose of this research can be defined as a process and technology use to manage information within the life cycle of a building. There are different BIM tools used to achieve the benefits of BIM. However some BIM software solutions allow information exchange while others are incompatible, causing interoperability issues, which is one of the major problems to the application of BIM in industry. Nevertheless this research focuses on the applicability of BIM tools on design creativity in architectural design.

Design Creativity at Early Design Stages

The early building design phase (conceptualisation - design development - technical design) is described as an important stage for achieving architectural design creativity. Hu and Guo, (2011) states that *"the existing BIM software is so precise that architects` design capabilities is limited in the early stages of building design , which hampers the creativity of architects to a certain extent*". At the early design stages, the ability to achieve design creativity is much higher; this creates concerns within designers to prevent any loss of innovative ideas to achieve optimum productivity at this stage. BIM tools offer sketch capability to designers. Meneely and Danko, (2007) noted sketching as a process of idea generation, but also express their concern that creativity should not be lost when using digital tools. They stated that digital tools can improve design creativity if understood properly, and if the use of the digital tool is not affected by cultural, professional and personal values. Software such as Teddy: a sketching interface for 3D freeform design can be used to achieve freeform concept development; free hand sketches are developed into a constructed corresponding 3D model with freeform design features. Little information is required at preliminary conceptual phase; perhaps the application Teddy can be used to blend the gap between applying freehand and 3D for design creativity exploration only, as Teddy is not used for editing precise models. It is important to understand the competences and constraints of BIM tools, as they can have an impact on the final design product generated. BIM tools are encouraged to be used for architectural design creativity (Park, 2010; Reddy, 2011); a question arises, do BIM tools affect the ability of the designer to achieve artistic and imaginative desired creativity? Ching, (2003:184) states that "*despite rapid advances in digital imaging technology, drawing with a freehand holding a pen or pencil remains the most intuitive means we have for graphically recording observations, thoughts and experiences*", but the impact of technology on creativity has been previously debated in academic publications, seminars, online discussions and so on. An interesting intuition is that lots of the older generation designers are more comfortable with pen and paper for schematic designs while the younger generations have digital sketching interfaces to use at early career stages. Digital design tools are much more common and affordable with newer generation designers. Creative design depends on the knowledge and ability of the designer, but the inefficiency to use a tool for creative design purpose can limit the aptitude of the designer to achieve inventive ideas. This could be due to the inadequacy of the tool or the incapability of the designer to use the tool. Designers should not use BIM tools if they are incompetent of maximising their benefits; this could affect creativity in the schematic design stage and the entire design stage at large.

BIM Software Tools for Creative Design

This paper focuses on creativity in architectural design with the aid of BIM tools. There are various BIM tools available for use in the AEC Industry. A questionnaire survey was used to identify common design BIM tools. Findings from both (group one and two) questionnaire respondents showed that Revit Architecture followed by ArchiCAD are the most common BIM tools they used in their BIM applications. BIM tools have an impact on design creativity; this could be negative or positive. Creativity is not necessary (directly) affected by design tools, rather the ability of a designer to use the design tools for optimum creativity. Nevertheless, some design tools have more flexibility and unlimited freedom than others, for example; freehand sketching with a pencil creates design freedom with less information required at preliminary conceptual design stage, while digital sketching requires the designer to learn the software packages before using it. Meneely and Danko, (2007) states that *"digital sketching has the potential to bridge the widening gap between freehand conceptual drawing and computer aided design practices*", this gap creates concern within professional and educational architectural design studios. The applicability of these digital tools would also depend on the knowledge of the user. Wei, (2010) states that creativity in architecture comes with freeform designs, sometime students realise the constraints of BIM tools while developing freeform concepts, but this can be resolved with the use of both CAD and BIM tools to achieve more flexibility. Masson et al., (2011) states that "*proposed synthetic models of existing objects, so-called 'object models'*" can be used to creatively design new objects to some extent. This implies that existing BIM tool objects can be modified and reinitiated to produce new and original work of art. Table 2 shows the negative and positive impact of BIM tools on design creativity.

. *Table 2: BIM tools impact on design creativity.*

BIM Impact on Design			
Reference	Positive	Reference	Negative
Reddy, (2011)	States that "BIM provides architects with infinite freedom to showcase their creativity".	Hu and Guo, (2011)	States that BIM tools are so precise that design creativity is limited at the early design stages.
Zarzycki. (2010)	States that "a BIM tool allows technical thinking and creativity bridging".	Zarzycki. (2011)	Notes that "presently, BIM based tools lack significant generative design modules, become peripheral within creative process".
Zarzcki, (2009)	States that "new digital tools allow for broader reading of architecture, resulting in innovative designs and new expectations towards space and form".	Wei, (2010)	States that creativity allows freeform designs, there student easily acknowledge the limitation of BIM tools.
Oxman, (2008)	States that digital design tools increases design ideas.	Park and Lee, (2010)	Describes that "the clumsiness of current BIM applications still draws the limitation of BIM in the creativity, especially in making various descriptive geometric models".
Park, (2010)	Notes that "the early adoption of BIM increases not only productivity but also creativity in building design process".	Moreira et al., (2010)	States that there is a need to examine the influence of BIM tools on design creativity; BIM will change traditional design methods.
Vandezande et al., (2012)	States that some schools accept BIM tools as a medium that challenges and improves student's creativity.	Nardi and O`Day,(1999:27)	Describes that, with regards to design tools "We are adapting to technology rather than controlling its fruitful and pleasurable use".
Meneely and Danko, (2007)	Describes that "because digital sketching allows ideas to be quickly explored without the expense of paper or physical media, students may feel more comfortable making mistakes and taking creative risks when they draw".	Logan and Smithers, (1993)	Notes that BIM could be restrictive towards achieving creativity.
Piedmont-Palladino, (2007)	States that Frank Gehry used design technology tools to achieve his imaginations to the fullest.	Authors	There are too many different design tools to choose from. (Myth).
Authors	BIM allows design concepts to be explored in 3D with ease.	Authors	A times details are required at early design stages when sketching with BIM tools. (Myth).

Hu and Guo, (2011); Meenely and Danko, (2007); Wei, (2010); and Park and Lee, (2010) are concerned that BIM tools could hinder design creativity at the conceptual design phase, while Zarzycki, (2010); Oxman, (2008); Park, (2010); and Vandezande et al., (2012) agrees that BIM tools do not hinder design creativity. The effectiveness of the myth included in Table 2 are not yet proven, but arises within architectural academics and architectural professionals. It is proven from literature that many professionals within the AEC Industry struggle to accept change, as they feel safer and more comfortable with their traditional processes, while others just find it difficult to use sophisticated digital design tools. Park and Lee, (2010) explored the usage of BIM tools, by analysing the amount of hours and percentages of BIM tools been used in the design and construction process and during the design phase. Park and Lee, (2010) conducted a survey and found out that BIM tools have a higher usage in construction compared to design; and also conceptual design had a higher BIM usage compared to schematic design and documentation.

Research Methodology

A literature review was used to define creativity and also describe its various features and attributes. A questionnaire survey was used to collect primary data; the UK top 100 architectural firms, based on the Building Magazine of 2011 (group one), and CNBR Yahoo group (group two) were selected as questionnaire respondents. Questionnaire questions were developed from literature review and distributed via email. A Microsoft word document and an online survey link were provided for alternative means of completing the questionnaire; both questions were identical. Respondents were asked to indicate their degree of agreement/disagreement that BIM tools hinder design creativity. The questionnaire from group one had a 10% response rate, from a total of 100 selected respondents; all respondents were architects in profession. Finding shows a high number of respondents disagreed that BIM tools impedes design creativity. Questionnaire from group two had 48 respondents. For further verification, a mean of all responses was calculated in Figure 5. Scores 1-6 was labelled against strongly disagree to strongly agree on a Likert scale for the purposes of the mean tabulation. Figure 1 shows the questionnaire response for group one. Figure 2 shows various professions of respondents in group two, and Figure 3 shows their questionnaire responses.

Questionnaire findings

1. Top 100 UK Architectural firms (group one)

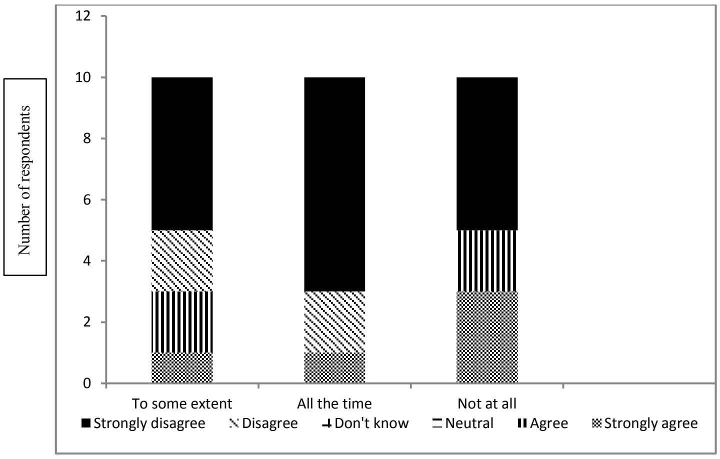


Figure 1: Responses indicating degree of (dis) agreement that "BIM tools hinder design innovation and creativity"

2. CNBR Yahoo Groups (Group two)

While group one shows findings from the perspective of architectural practices (all architect participants), group two respondents show multiple professionals within the building industry participating in the questionnaire survey. As BIM is changing the traditional design process to a more integrated approach; the input of various professionals will help identify views on design creativity with BM tools from different perspectives.

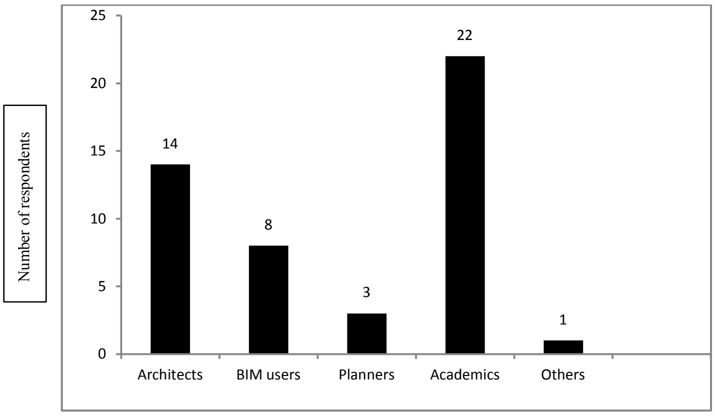


Figure 2: Profession of questionnaire respondent

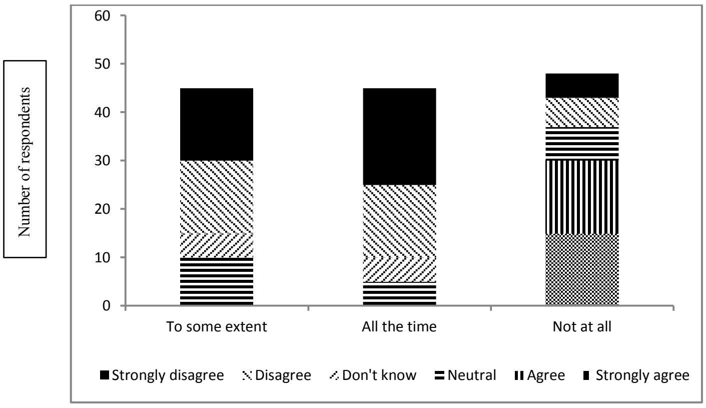


Figure 3: Indicating your degree of (dis) agreement that "BIM tools hinder design innovation and creativity"?

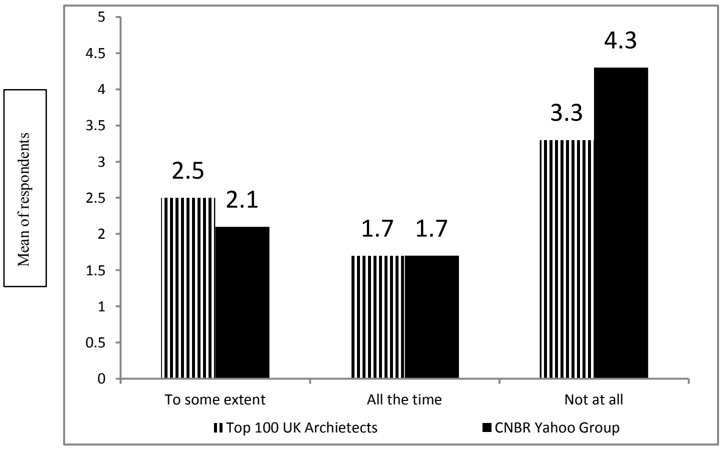


Figure 4: shows comparability between the two different groups of respondents (average mean).

Figure 4 shows a higher mean of responses from both groups, agreeing with each other's opinion that BIM tools do not hinder design creativity, by ticking (not at all). But in the opinion of some respondents, BIM tools hinder design creativity to some extent, while the lowest mean of respondents opt for (all the time). Therefore this research will further look at possible strategies of overcoming the possible limitation of applying BIM tools to achieve design creativity.

Guides for Creative Application of BIM Tools

The focus of creativity is discussed in the context of architectural design; it is not normally commended in literature to limit the scope of creativity as it applies to all disciplines and life applications. The analysis of this research limits the concept and evaluation of creativity to the realm of design in architecture. Some designers have concerns over the application of BIM tools in the early design phases. Pederson and Burton, (2009) quotes Kim et al., (2007:598) that "*designers generate diverse ideas at the early process phase, and then (find) a solution by evaluating and revising those ideas*". Table 4 identifies ways of attaining awareness while using BIM tools to achieve design creativity and originality during the early design phase and beyond. To create and develop awareness for the strength and weaknesses of using BIM tools for design creativity, Meneely and Danko, (2007) states that one should not just question the tools but the designer as well.

Table 4: Clarifying some constraints of BIM

Modified from Meneely and Danko, (2007)			
	Questions	**Tasks**	**Clarification**
Motive	What do you expect from a specific/selected BIM tool?	Define BIM goals.	Identify BIM reality from BIM fiction.
Mind	Are you sacrificing any design details due to limited flexibility in the use of BIM tools?	Identify how to use BIM tools to achieve desired creativity.	Identifying and monitoring any possible limitation of BIM.
Media	Are there any attributes or features of BIM tool objects that can affect the final product?	Identify limitations and strength of BIM tools.	Identifying what BIM tools can do for you.

Discussion

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. Piedmont-Palladino, (2007) stated that "*if technology is always a step ahead of society, creativity is always one step ahead of technology*". The designer is expected to be creative, while technology such as BIM tools empowers the designer to achieve his/her conceptual imaginations. BIM tools allow: greater detailing design in virtual building models and simulation; extracting different views from models; collaborative work; automation; and analysing and evaluating models to save project time and cost; while the major BIM tool challenge is interoperatability. However, this research will focus on Creativity issues with BIM tools. Hu and Guo, (2011); Meenely and Danko, (2007); Wei, (2010); and Park and Lee, (2010) are concerned that BIM tools could hinder design creativity at the conceptual design phase. Reddy, (2011); Zarzycki, (2009) agrees that BIM allows imaginative freedom for form and space exploration in 3d, while Wei, (2010) is of the view that BIM limits free form design capability. Logan and Smithers, (1993) agrees with Hu and Guo that BIM limits design creativity, while Zarzycki, (2010); Oxman, (2008); Park, (2010); and Vandezande et al., (2012) agrees that BIM tools does not hinder design creativity. The questionnaire results show that the highest average of respondents disagreed that BIM tools hinder design creativity, but there are still some questionnaire respondents that are of the view that BIM tools affect design creativity to some extent. The questionnaire survey from group one and two therefore coincides with literature, that BIM tools empower the designer to achieve creativity and also hinders design creativity to some extent. To clarify this problem, Table 5 shows a modified approach adopted from Meneely and Danko, (2007), describing strategies of creating awareness of the mind, by raising specific issues to enquiry, questioning both the BIM tools and designers. Three key issues were identified: *motive,* as what a designer expects to do with the BIM tool; *mind*, as how the designer expects to use the BIM tool; and *media*, to understand how the BIM tool can empower the designer. With these three guides, the designer will be able to create awareness when using BIM tools to achieve design creativity.

Conclusion

Creativity is the ability to achieve originality, ideas, new knowledge, product or process for useful development, while BIM tools are technological software used for exploring, analysing and evaluating ideas; there are also tools used and controlled by the designer, to achieve creative artistry. Creativity can be effectively and efficiently attained with BIM tools; their applicability allows imaginative originality and resourcefulness. Zarzycki, (2009) states that "*New design technology allows the possibility to purse imaginative designs that were not possible in the past*". Imaginative ideas comes from the designer, while BIM tool, as a technological platform allows these ideas to be created, first in the virtual world and then later in the real world. Although there are some concerns that BIM tools could hinder design creativity, but the benefits outweigh the impediments; a good designer with BIM tools experience, has the potential to achieve creativity. To draw a conclusion, BIM tools do not hinder design creativity but rather empowers the designer with digital technology to achieve imaginative ideas. Nevertheless, when the designer lacks the aptitude to use BIM tools effectively and efficiently; that could hinder design creativity. Meneely and Danko, (2007) described that creativity lies in the ability of the designer to use technology adequately towards inventive ends. With awareness of the strength and weakness of BIM tools, a designer can easily manipulate BIM tools to achieve imaginative conceptual ideas that can be constructed in the real world. Hence, the limitations of BIM tools on design creativity can therefore be reduced to its minimal. Findings from this paper will be further used in an on-going research, to create a flexible "space design" framework using building information modelling.

References

Aranda, M. G., Chevez, A., Crawford, J. R., Wakefield, R., Froese, T., Frazer, J. H., Nielsen, D., & Gard, S. (2008). *Business Drivers for Building Information Modelling,* Cooperative Research Centre (CRC) Report - Construction Innovation.

Boden, M. A. (1998). What is Creativity? In: Mithens, S. J. (Ed.). *Creativity in Human Evolution and Prehistory*. USA: Routledge.

Boden, M. A. (1994). *Dimensions of Creativity*. United States of America: MIT Press.

Ching, F. (2003). *Architectural Graphics*. (4th Ed.). New York: John Wiley & Sons.

Feldman, D. H. (1994). Creativity: Dreams, insights, and transformations, in Felman, D. H., Csikszentmihalyi, M., & Gardner, H. (Eds.). Changing the world: A framework for the study of Creativity. 85-102. Westport, CT: Praeger.

Hu, W., & Guo, S. (2011). Visualisation and Collaboration of On-Site Environments Based on Building Information Model for Construction Project Class Zhu, M. (Ed.) *Information and Management Engineering International Conference*. 288-295.

Ibrahim, R & Rahimian, F. P. (2010) Comparison of CAD and Manual Sketching Tools for Teaching Architectural Design. *Automation in Construction*, 19 (8), 978-987

Kim, M. H., Kim, Y. S., Lee, H. S., & Park, J A. (2007). An Underlying Cognitive Aspect of Design Creativity: Limited Commitment Mode Control Strategy. Design Studies, 21, 437-449.

Logan, B., & Smithers, T. (1993). Creativity and Design as Exploration in Gero, J., & Maher, M. L.

(Eds.). *Modeling Creativity and Knowledge-Based Creative Design*. New Jersey: Lawrence Earlbaum and Associates.

Masson, P. L., Hatchuel, A., & Weil, B. (2011). The Interplay between Creativity Issues and Design Theories: A New Perspective for Design Management Studies? *Creativity and Innovation Management*, 20(4), 217-237.

Martin, M. W. (2007). Creativity: *Ethics and Excellence in Science*. United Kingdom: A Division of Rowman and Littlefield Publishers Inc.

Meenly, J., & Danko, S. (2007). Motive, mind and Media: Digital Sketching in the Creative Culture of

Design. *Journal of Interior Design*, 32(3), 69-90.

Moreira, P. F., Silva, N. F., & Lima, E. M. (2010). Impact of Building Information Modelling on the Architectural Design Process. *Advanced Techniques in Computing Sciences and Software Engineering*, 527-532.

Mumford, M. D. (2003). Where Have We Been, Where Are We Going? Taking Stock in Creativity Research. *Creativity Research Journal*, 15, 107–120.

Nagel, S. S. (2000). Creativity: *Being Usefully Innovative in Solving Diverse Problems*. United States: Nova Science Publishers.

Nardi, B., & O`Day, V. (1999). Information Ecologies: Using Technology with Heart. Cambridge, UK:

Cambridge University Press.

Owen, C. L. (1992). Context for Creativity. *Design Studies*, 13(3), 216-228.

Oxman, R. (2008). Digital Architecture as a challenge for Design Pedagogy: Theory, Knowledge, Models

and Mediums. *Design Studies*, 29(2), 99-120.

Palladino-Piedmont, S. (2007). *Tools of the Imagination: Drawing Tools and Technologies from the Eighteenth Century to the Present*. New York: Princeton Architectural Press.

Park, H. J., & Lee, J. H. (2010). Exploring Integrated Design Strategies for the Optimal Use of BIM. *Architectural Research,* 12(2), 9-14.

Pederson, E L., & Burton K L. (2009). A Concept Analysis of Creativity: Uses of Creativity in Selected

Design Journals. *Journal of Interior Design*, 35(1), 15-32.

Reddy, P. K. (2011). *BIM for Building Owners and Developers: Making a Business Case for Using BIM*

on Projects. New Jersey: John Wiley and Sons.

Runco, M. A. (2006). Personal Creativity: Definition and Development Issues. *New Directions for Child*

and Adolescent Development, 1996, (72), 3-30.

Sternberg, R.J. (2006). The Nature of Creativity. *Creativity Research Journal*, 18 (1), 87-98.

Vandezande, J., Read, P., & Krygiel, E. (2012). *Mastering Autodesk Revit Architecture*. Canada: Wiley

Publishing.

Wei, Y. (2010). Teaching Building Information at Undergraduate and Graduate Level. Schmitt, G., Hovestadt, L. V. C., Bosche, F., Burkhard, R., Coleman, S., Halatsch, J., Hansmeyer, M., Komsorski-Lang, S., Kunze, A., & Sehmi-Luck, M. (Eds.). *eCAADe Conference*, 97-106.

Zarzycki, A. (2010). Exploring Parametric BIM as a Conceptual Tool for Design and Building

Technology Teaching. *Spring Simulation Multiconference,* 194.

Zarzycki, A. (2009). BIM as Design Exploration Tool in Architecture. ASEE Northeast Section Conference.

Zarzycki, A. (2011). Designing with Constraints: Parametric BIM. *International Conference on Computer Graphics and Interactive Techniques*, 7-11.

APPENDIX 4: PAPER 4

IMPACT OF SPACE FLEXIBILITY AND STANDARDISATION ON HEALTHCARE DELIVERY

Abstract

Space flexibility and space standardisation can be applied in healthcare buildings to improve the design, construction and service delivery. The concepts of flexibility and standardisation have been implemented globally across different sectors and industries. However, an important question emerges relating to healthcare facilities: how do flexibility and standardisation impact healthcare staff workflow and patient care? It is appropriate to apply them simultaneously in the physical space, as they collectively improve efficiency in healthcare delivery. This paper aims to identify the impact of space flexibility and space standardisation (as space attributes) on healthcare delivery with an emphasis on the RIBA Stages of Concept Design and Developed Design. The synergies and tensions between both *space attributes* are explored. A questionnaire survey was conducted with experienced healthcare professionals that included: architects, health planners and project managers. A total of 200 questionnaires were sent out; a 35% response rate was recorded. The questionnaire survey respondents felt that space flexibility can improve facility adaptability and it is more effective when applied on a long-term basis, whilst space standardisation can improve the quality of healthcare facilities and it is more effective when applied to healthcare rooms.

Keywords: healthcare facility, space standardisation; space flexibility; space; staff and patient.

*Corresponding author

Email address: A.M.Ahmad@lboro.ac.uk

1. Introduction

This paper is a continuation of the research conducted by Price and Lu, (2012); which explored the impact of hospital space standardisation on patient health and safety while this paper explores the impact of the combined application of space flexibility and space standardisation on healthcare delivery with an emphasis on the design of the physical space. The RIBA Plan of Work, (2013) described six stages in the design process. These are: 0: Strategic Definition, 1: Preparation and Brief, 2: Concept Design, 3: Developed Design, and 4: Technical Design. The outcome of this paper is intended to facilitate Stages 2 and 3 of the RIBA Plan of Work; for this reason, data was collected from experienced designers in the healthcare sector. Campbell *et al.*, (2002: 359) noted that information from stakeholders varies "*Healthcare professionals tend to focus on professional standards, healthcare outcomes, and efficiency. Patients often relate quality to an understanding attitude, communication skills, and clinical performance*". Perhaps, findings from healthcare facility users such as medical staff, administrative staff, other staff and patients can facilitate Stages 0 and 1 of the RIBA Plan of Work to inform the briefing process. Flexibility helps to simplify healthcare tasks by allowing spaces to multi-function. The National Health Service (NHS) Estates, (2004:12) warned that "*For maximum flexibility, some of the bed spaces in the recovery unit should be equipped to accommodate a critically ill patient*". Despite the impact of flexibility and standardisation, a balanced consideration of standardisation must be allowed and this research attempts this. It was described by the NHS, the National Patient Safety Agency, (2010a:16) stated that "*Designs should aim at maximum standardisation of hospital infrastructure technology, equipment, computer systems, electrical equipment layouts, interfaces, room design, storage and navigation, systems and processes*" while Mourshed and Zhao, (2012) indicated that past research on the design of the physical environment of hospitals lays emphasises on user satisfaction to explore the relationship of design factors with demographic and work variables; to achieve a harmonious relationship between these factors, key findings from healthcare providers were identified as achieving good spatial spaces, maintenance and environmental design. Flexibility and standardisation can help to organise, design and maintain healthcare spaces through the use of available, tested and peer reviewed standards that can be customised for the flexible use of space. Healthcare space is a vital delivery component in every hospital design. It provides the environment for healthcare services to be performed and it links one functional space to the next. Healthcare spaces are complex entities due to: the range of services and technologies they support; the number, variety, quality of requirement and the rapid changing nature of healthcare environments. Healthcare spaces can be designed to multifunction in order to adapt to changing conditions. There is a need for more standardisation, as it supports staff performance by reducing the reliance on memory, thus reducing human error. Standardised equipment, furniture, spaces and processes helps to improve the quality of healthcare spaces. A standardised product can be a device, equipment or furniture, while a standardised facility is a structured building with most of the elements within its physical space specified. A standardised process within a given space is a procedure performed sequentially within a specific time for a specific purpose. Nevertheless, one of the main question that emerge from this research is how healthcare designers and planers manage flexibility and standardisation with constraints such as diversity in patient and staff needs, and the lack of frequent updates in healthcare standardisation tools such as the Healthcare Building Notes (HBN), and Activity Data Base (ADB)? Pati *et al*., (2008) stated that the use of generic spaces is encouraged in the design of healthcare facilities as they allow flexibility and adaptability. However, different types of healthcare facilities, such as acute hospitals, mental hospitals and community hospitals have different needs and requirements. This research is centred on the impact of both *space attributes* on healthcare delivery and considers the possibility of merging the two *space attributes* to optimise space design; a questionnaire survey was conducted to study their impact on healthcare delivery.

1.1 A Brief history of healthcare facilities in the UK

The NHS was established in 1948, as a provider of healthcare services to the general public funded from taxation and provided free at the point of use. This idea by Aneurin Bevan was described by Webster, (2002) as "*the most civilised achievement of modern Government*". The Department of Health, (DH) is responsible for providing and improving health and social services to the people of England (Smith and Pollock, 2006). The NHS system is fully funded by the tax system of England for its endowment. With this funding, it provides walk in centres, treatment centres, NHS Trusts, primary cares (pharmacist, dentist, opticians, and GPs units) and hospitals, around the UK. These facilities accommodate medical professionals and their associates, it is important that all necessary measures are taken into consideration when designing and constructing them. All the stakeholders involved should be considered when providing appropriate standards for healthcare staff to deliver effective and efficient services to patients.

1.2 **Special needs of healthcare facilities**

What are quality standards in healthcare design? According to Purves, (2009) important quality standards include space utilisation, space functionality, energy efficiency and compliance with statutory regulations; cost is also an important factor to consider when designing healthcare facilities. One of the main problems discussed in this research is space utilisation; the more the space, the more the cost. Value for money is required by the UK Government; hence an innovative application has to be considered. Perhaps, the innovative use of space flexibility and space standardisation can be combined.

1.3 Space and its impact on healthcare delivery

Space is a key feature of all building types. Healthcare space design and utilisation is important due to the rapid changing environment manifesting from: a growing and ageing population (changing demography); innovation and developments in medical equipment and treatment (changing technology); flexible care pathways; and modern healthcare delivery systems. Space is vital to the performance of healthcare facilities; it provides the basis for all functional activities of medical staff to deliver state of the art services to patients. Space has to be properly designed to achieve good design outcomes, it is a key element to architectural designers and healthcare planners; it links, locates, adapts and provides functional locations and relationships between building units. Poorly designed and unsuitable spaces can have a significant constraint on the performance of healthcare facilities; they can affect the method of healthcare treatment through disruption of staff routine tasks. For example, healthcare delivery is inefficiently conducted in an inadequate space. Unsuitable spaces for patient use can lead to accidents. For example, older patients can experience more falls due to the lack of hand railings (Behan *et al*., 2009). Inadequate use of space, can easily lead to space redundancy, hindering staff services and *most important of all* affect patient care. It therefore, faces the staggering challenge of providing the required relationships between mutual spaces, whilst being aesthetically pleasing to users. Table 1 categorises all drivers for space design. Staff performance and patient care are grouped under both "*organisational*" and "*safety and wellbeing*" categories.

Table 1: Space layout drivers (Zhao *et al*., 2009).

Space layout planning drivers				
User satisfaction	Safety and well being	Energy and environment	Organisational	Spatial configuration
Positive distraction	Prevention of patient fall	Cost of energy	Staff productivity	Different patient accommodations
Way finding facility usability	Patient dignity	Co2 emission	Building adaptability to future changes	Proximity to nursing unit
Environment that support family members	Staff safety and well being	Energy management	Reduction in medical error	Reduced patient and staff travelled
Hygiene	Patient safety and security	sustainability	Staff confidence	Adjacency and ease of access
Acoustic	Appropriate illumination for patient	Climate change reduction		

1.4 The need for space flexibility and space standardisation

Zhao *et al*., (2009) stated that *"patients expect more from hospitals in addition to the high quality of services provided by healthcare staff*", there is a need for flexibility and standardisation in healthcare facilities due to the highly interrelated problems of adaptation, rapidly changing spaces and functions and user satisfaction. It was also noted by Jones and Bullard, (1993) that patient privacy and dignity should be considered important in same sex wards or units. Torrington, (2007) stated that the physical environment can affect the quality of life, and healthcare designers should acknowledge and accommodate users' needs and appeals. There is a gap in literature, as it is still unknown how healthcare designers and planners manage flexibility and standardisation, mainly due to complexity and restrictions caused by the need to support different clinical needs for different healthcare environments. A major restriction to applying standardisation is the constraints caused by existing buildings when re-designing and re-configuring healthcare spaces. Perhaps flexible and adaptable spaces can improve the quality and life span of buildings by converting, expanding, contracting or adapting to immediate and future healthcare facility's needs. This research focuses closely on the application of both *space attributes* for optimum space utilisation in healthcare buildings.

2. Understanding space flexibility and space standardisation *space attributes*

Flexibility is the capability of living things or non-living things to change and return to their original form when required, without causing any damage or disruption; it is an option that can be switched on and off when required, while standardisation is defined as a process (pattern) or a specified product (space/device/furniture). Space flexibility and space standardisation in the context of this research attempts to respond to the changing conditions of healthcare spaces. It is more difficult for standardised spaces to be flexible compared to flexible spaces to be standardised. Standardisation deems to be average, best, useful, achievable and standard guides, but could be more flexible when customised. Space can have an impact on staff performance, and effective staff performance improves patient care. In many reports published, patient safety is one of the most important factors of healthcare facilities. As a result, patient safety in healthcare is introduced into this research.

Flexibility has been defined in different ways; Holt *et al*., (2008:2) defined it *"as mobility, compliance, and alternatively as the reciprocal counterpart*". Pati *et al*., (2008) stated that flexibility means different things to different people. For example: "management" describes flexibility as ability to manipulate higher level resources such as staffing and teaming to tackle uncertainties; "direct caregivers" define flexibility as the ability to multi-task task and multi-skill to optimise and maximise efficiency; while "non-nursing staff" labels flexibility as the ability to manipulate resources to effectively manage patients' needs and appeals. Flexibility can improve productivity and save time by allowing different functions to take place within an intelligent multi-purpose space. Flexibility is a broad topic; it covers different aspects of life, but in this research it is explored within the context of healthcare facility design to accommodate future changes that include an ageing and growing population, advance and changing healthcare technology. Carthey *et al*., (2009) stated that there are more challenges apart from the rapid changing nature of healthcare buildings and unforeseen conditions surrounding healthcare environments; they described that some hospitals have bad designs (existing) that do not allow further alterations, and such are Private Finance Initiative (PFI) structures; also quotes RIBA, (2005) stating that due to the rigidity and basis of PFI structures contracts, they do not allow changes to take place at a later stage.

Neufville *et al*., (2008) described flexibility as an alternative approach to achieving desired project outcomes, which can be switched on or off when required. They also classified flexibility into the following.

- **Operational flexibility**: this is a short-term flexibility that can be subsequently accomplished within a very limited time frame. For example, the use of a flexible furniture/ward equipped to conveniently accommodate different type of patients at a very short notice.
- **Tactical flexibility:** this is a long-term flexibility that requires time to be accomplished within a healthcare facility. For example, the use of shell spaces or a flexible foundation that can accommodate growth or change.
- **Strategic flexibility:** this is a much longer and slower option to adopt; it could take many years to implement. This sort of flexibility enables healthcare facilities to increase their life span. For example, buying a neighbouring land to expand a facility in the near future.

Flexibility is at its best when adapting to changes; the process of adaptability in most cases requires no structural construction cost; specific functions can easily change/reposition to adjust to users' needs. Flexible spaces are designed to flex and change while addressing comfort in the way we live our live. Designs take into account, future needs of users with ergonomic footprint to achieve required and desired building functions.

What is a flexible space or space flexibility? This is a space that simply changes with time, function or requirements for specific purposes. These include adapting to future changes and needs of facility users. Pati *et al*., (2008) described nine attributes of an adaptable healthcare space as: to categorise possible healthcare flexible spaces; increase patients visibility (distinguishability); group staff into teams to easily tackle healthcare uncertainties; to increase the closeness of patient to healthcare support at all times; zoning and accessibility of functional units; ability of units/departments to exchange functions; and to embed flexibility and expandability support systems. Flexibility is also achieved through: the concept of modularity; partial or fully interstitial spaces; and the categorisation and separation of functions.

Standardisation does not only deal with the specifications of the physical space, but involves the organisation of individuals and the pattern of work flow. Standardisation is attributed to specification, definition, quality and reduction of errors due to repeatability; standardisation features such as pattern, specificity, accuracy and precision aid in establishing understanding and development between parties, schemes and principles with mutual focus. It can, based on these descriptions, be applied globally in various industries to achieve a simpler standardised process or product. Egan, (1998) noted that pre-assembly of prefabricated parts of private hospitals use a sequential set of standardised rooms; he also stated that standardisation works more effectively at a room level. Edum-Fotwe *et al*., (2004) are of the view that standardisation reduces errors and promotes safety when conducting healthcare tasks. Standardisation has gained mainstream flare in healthcare; specific organisations are providing specific standardised units/spaces for specific purposes in their specific organisations for their specific needs; this could be adopted elsewhere based on suitability and adaptability. Examples of healthcare standardisation stated by the National Patient Safety Agency, (2010) include: the creation of the Avanti Architect`s standardised toilet; the standardised single rooms at Pembury New Hospital; and Arup`s standardised space layout, set with space around the bed for patient movement and accommodating visitors. Building Design Partnership (BDP, 2004) stated that most hospital buildings in France are built with standard elements and systems, which are prefabricated to ease the building process.

What is a standardised space or space standardisation? It can be described as a controlled space in so much that many aspects are entirely defined. Price and Lu, (2012) described features of a standardised space as: ergonomics specifications; modular units; standardising room sizes; creating similar room patterns; and modular detailing. Reiling *et al*., (2004) noted that standardisation of workflow reduces reliance on memory, and allows people unacquainted with a specific process or product to use it in a safe and efficient manner that improves quality and productivity. Standardisation aids in making a given process more reliable, simple, preferable, desirable, appropriate and achievable. This becomes interesting, and serves as an enticement when presented as a standard. It is easier for staff to work within a standardised space due to a continuous routine of use; when a nurse comes into a patient`s room, due to familiarity of use, it becomes clear and simple to perform a task. Many elements and functions are standardised according to specific uses. Within a standardised room: size; shape; layout; size and orientation of windows; location of doors; direction of openings; location of toilets; and the amount of treatment space required for staff to use their medical equipment and deliver healthcare services are all a time specified. With considerable focus on standardised rooms, Price and Lu, (2012) stated that it is vital to acknowledge that room shape as well as room size is important.

2.1 Space and healthcare delivery

Space has a major influence on the quality of both staff performance and patient care. Good staff performance leads to better healthcare delivery to patients. But how does space influence staff performance? Quality designs enable good flow of healthcare delivery by providing: good circulation space; ease in way-finding; creation of allowable space to perform healthcare tasks; and linking facility to the natural environment. A good functional healthcare space aids staff to work efficiently and effectively. For example, designing functional nursing units close to patients unit reduces travel distance for staff to deliver health services, and provides patients with increased confident due to the proximity of care. A multi-functional space allows patients to be treated at similar places. It reduces patient transfer times; consequently, putting less pressure on patients by mitigating the hurdles and risks involved when transferring sensitive or fragile patients.

2.2 Staff performance, patient care and management of healthcare spaces

Effective and efficient healthcare treatment resorts to quality healthcare delivery to patients. Other factors that have an impact on the quality of service delivery were described by Price and Lu, (2012) as: space size; space layout; way finding; homelike spaces; and space zoning. Staff performance is significantly affected by the quality of healthcare space; well-designed spaces simplify healthcare tasks through the organisation of spaces that are functionally interrelated. Both staff and patients require safety as one of the main priorities of a healthcare facility design. Sine and Hunt, (2009) suggested zoning of healthcare spaces with reference to priority of supervision to improve safety; five zones were described with different level of safety considerations. These are: 1: restrictions, access and zoning of staff, patient and visitors areas; 2: high priority supervision of specific patient areas; 3: general supervision of areas; 4: identifying less or no supervision areas such as patient toilets; and 5: administrative areas. Safety management can be easily achieved when the different healthcare spaces within hospitals are categorised into their appropriate priority levels.

2.3 The Impact of space flexibility and space standardisation on healthcare staff and patients

Staff efficiency and patient safety are two of the key drivers for achieving both *space attributes*. Pati *et al*., (2008) stated that space flexibility helps in securing the future of facilities by allowing staff to work in a flexible environment that adapts to future changes. Findings from Egan, (1998) suggests that space standardisation helps to standardise procedures, making it easier to remember; thus reducing the reliance on memory to perform a large number of healthcare tasks. It also reduces the possibility of error occurrence due to consistency in a standard routine, but at some point these procedures have to be improved and changed periodically to avoid the use of out-dated procedures.

The National Patents Safety Agency, (2010:16) stated that standardisation "*reduces costs, reduce mental workload, reduce errors and deviations from normal working easier to detect*". It also facilitates the transfer of skills between different organisations, eventually improving staff performance. Table 2 shows the impact and category of space layout drivers, while Table 3 shows impact of both *space attributes*.

Table 2: Focus of both *space attributes*. Modified from Ahmad *et al*., (2011).

"Space attributes"	Focus	Impact
Space flexibility	Physical space	Growth
		Uncertainties
Space standardisation	Physical space	Staff performance
	Procedural process	Patient care

Table 3: Impact of both *space attributes* on healthcare staff and patients

"Space attributes"	Impact on staff	Impact on patient
Space flexibility	Gallant *et al*., (2001) stated that flexibility saves staff time by providing multi-functional rooms.	Hendrich, *et al*., (2004) stated that multi-functional spaces reduce the rate of medical errors and transportation of patients.
	Pati et *al*. (2008) described that peer line of sight, (flexible nurses) allows (nurse teaming); this increases staff confidence and stress mitigation for healthcare delivery uncertainties.	Pati *et al*., (2008) described that multi-functional spaces reduces the stress of moving patient.
	Kobus *et al*. (2008); Reiling (2007); Pati *et al*. (2008); and NHS Estates, (2005:50-55 agrees that flexible spaces reduce travelling distance for staff.	Kobus *et al*. (2008); Reiling, (2007); Pati *et al*. (2008); and NHS Estates, (2005:50-55 agrees that flexible spaces reduce travelling distance for patients.
	NHS Estates, (2005:50-55) flexibility enables staff to manage bed availability and some patient's needs.	NHS Estates, (2005:50-55) stated that flexibility supports the process of ward allocation to patients.
Space standardisation	Joint Commission Resources (2004) and Reiling (2007) stated that standardisation reduces staff errors.	Standards adapt to patient needs.
	Malone *et al*. (2007) notes that standardised workflow contribute to patient care efficiency and safety.	Reiling (2007) Standards improves the care patients receive from staff.
	Standards, guides health delivery procedures, enabling staff to easily reuse facility.	With standardisation, patients easily reuse facility.
	Reiling *et al*., (2004) states that standardisation reduces reliance on memory.	Standards, helps in organising patient's activities in healthcare facilities.
	Sexton, (2000) recommended standardisation, as it improves (safety in general) staff safety.	Sexton, (2000) recommended standardisation, as it improves (safety in general) patient safety.
	NHS Estates, (2005:40) stated standardisation allows the minimum required space for staff to conduct their services effectively.	NHS Estates, (2005:40) stated standardisation allows the minimum required space to create patient comfort.

2.4 Importance and motivation for the research

The main aim of this research is to explore the two *space attributes*: space flexibility and space standardisation, and their impact on healthcare delivery with a focus on staff and patients. Space serves as a main connector between flexibility; standardisation, staff and patient. The literature review findings presented in this research showed that both space flexibility and space standardisation can improve the efficiency of staff performance and quality of patient care. One of the key objectives of this research was to determine if the application of space flexibility and space standardisation can be balanced within the design of a healthcare facility. It is clear that the quality of staff performance will enhance patient care. This research addresses the following questions.

1. How does space flexibility impact staff performance and patient care?
2. How does space standardisation impact staff performance and patient care?
3. What is the impact of space on health delivery?
4. Is there a balance between space flexibility and space standardisation?

3.1 Research methodology

Two research methods were used to collect data for the purpose of this paper research. These are literature review and a questionnaire survey. There is a rationale for the choice of the population questionnaire survey sample frame; this research focuses on the use of flexibility and standardisation within the Concept Design and Developed Design Stages of the RIBA Plan of Work to inform healthcare professionals enabling pathways of executing healthcare project briefs. User participation is closely related to designing the project briefs. Therefore, the questionnaire survey sample size was based on the supply delivery category (industry practitioners) rather than the demand category (facility users) or both categories. Allsop and Taket, (2004) and Blyth and Worthington, (2010: xvii) agrees with Barrett and Baldry, (2003: 104), who stated that appropriate user involvement is important in the briefing stage to meet the needs of the end users.

The method dispensed for measuring quality in this research was based on the usage of data from literature and a questionnaire survey. The information used for measuring quality indicators can be systematic or non-systematic. Non-systematic approach can be from case studies, while systematic approach "*can be based directly on scientific evidence by combining available evidence with expert opinion, or they can be based on clinical guidelines*" (Campbell *et al*., 2002: 358). For this reason, findings from experts in the healthcare sector (questionnaire survey) were backed with literature review were appropriate to support the claim that space flexibility and space standardisation has an impact on healthcare delivery.

3.1.1 Literature review

Literature from healthcare design practitioners was used to construct the questionnaire survey for this research; literature was also used to defining both space flexibility and space standardisation, and describes their key drivers, major barriers, and their impact on healthcare staff and patient. Journal papers, conference papers, NHS reports and Books relating to the physical space, flexibility, standardisation and healthcare delivery were reviewed for the purpose of this research.

3.1.2 Questionnaire survey

Lists of healthcare practitioners collaborating with Health and Care Infrastructure Research and Innovative Centre (HaCIRIC) were collected from several of its members. A questionnaire was issued out to 200 potential respondents. A total of seventy responses were returned giving a response rate of 35%. Respondents were chosen based on their experience in healthcare facility design. Professionals included healthcare: architects; planners; and project managers. Respondents came from different parts of the world, comprising UK, Europe, North America, Africa, Far East and the Middle East. Half of the respondents (50%) had over 10 years working experience on new built hospital projects, while 41% of the respondents had over 10 years working experience on refurbished hospital projects. The questionnaire survey respondents were asked to indicate their degree of agreement/disagreement with certain statements on a 5 point Likert scale. The questionnaire survey had no mandatory questions. The questionnaires were issued out to respondents via e-mail. The collected data was analysed using descriptive statistics techniques. Figures 2 and 3 illustrates the geographical locations and professional roles of the questionnaire survey respondents

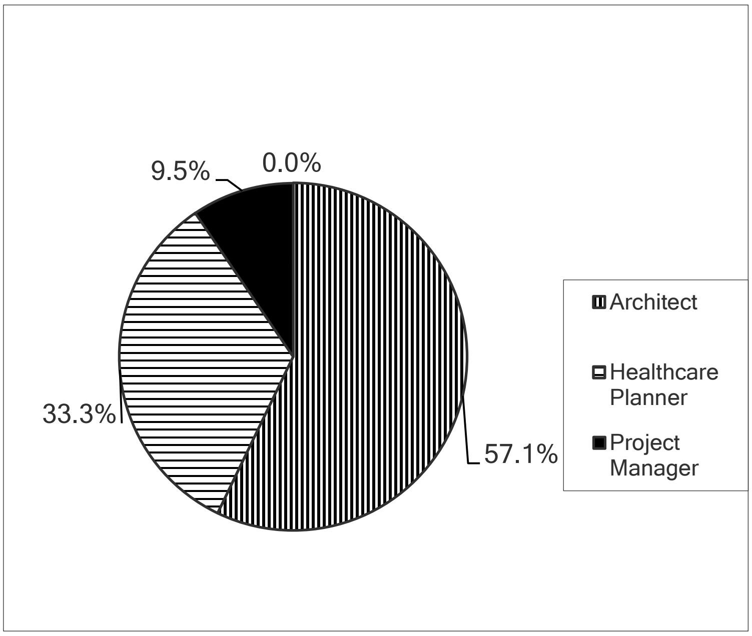


Figure 1: Professional role of questionnaire survey respondents**.**

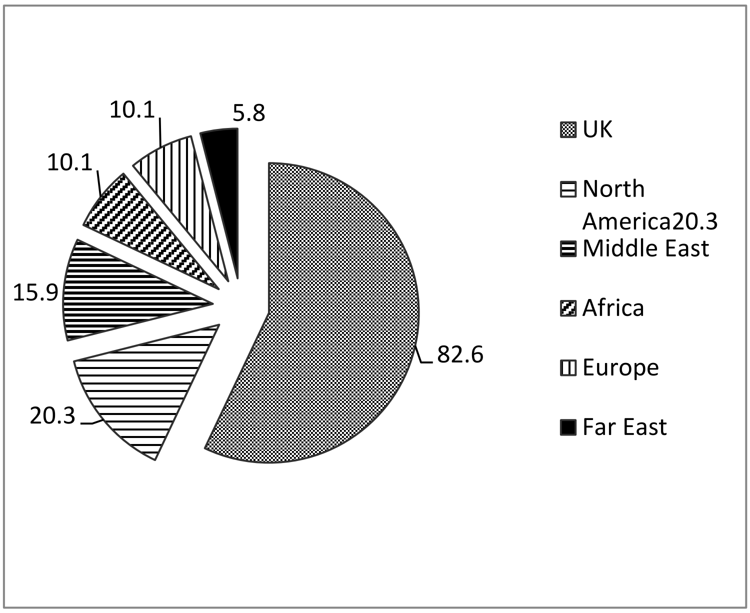


Figure 2: Geographical location of questionnaire survey respondents**.**

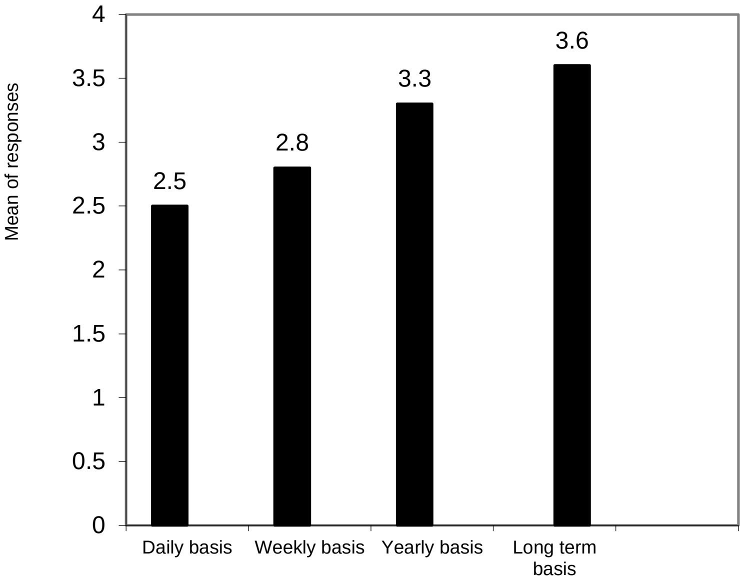
4. Findings (space flexibility and space standardisation)

4.1 Findings (Space flexibility)

The notion of flexibility is broad and complex. Therefore, for the purpose of this research flexibility is centred on healthcare facilities. The findings relating to flexibility are categorised into short-term and long-term applications in healthcare facilities. The various changes occurring in healthcare facilities require different inputs to obtain desired project outcomes; some inputs may involve gradual intervention, while in other cases an immediate response may be required. Findings show effectiveness of space flexibility at different levels. These are presented below.

4.1.1 At what level are there more opportunities to implement cost effective space flexibility at ward/department level in healthcare design?

Figure 3 illustrates the responses to the above question. This question required a broader view and understanding of space flexibility at ward/department level. Options were categorised into: daily basis; weekly basis; yearly basis and long-term basis. Finding shows that the questionnaire survey respondents were of the view that it is easier to implement cost effective space flexibility on a long-term basis within a ward/departmental level, while it is more difficult to implement it on a daily basis (short-term). This can be attributed to the rapid changing nature of healthcare facilities; Pommer *et al*., (2010:1383) noted that *"Hospitals are constantly under construction with on-going renovation and expansion to accommodate new modalities, new protocol, new technologies"*. These factors challenge the ability to implement flexibility on a short-term basis.

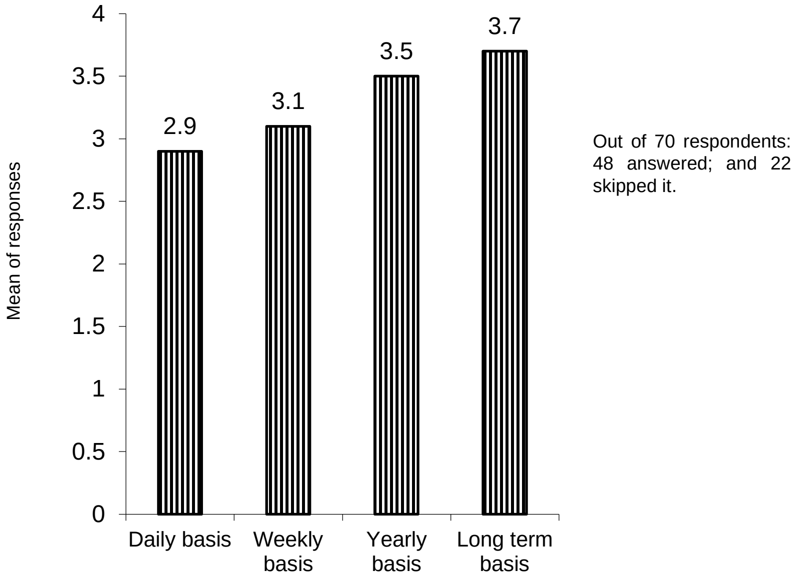


Out of 70 respondents: 48 answered; and 22 skipped it.

Figure 3: Questionnaire survey responses on space flexibility at departmental/ward level.

4.1.2. At what level are there more opportunities to implement cost effective flexibility at specific areas/room level in healthcare facility design?

Figure 4 illustrates the responses to the above question. This question had the same options as the question before it, with opportunities on daily basis; weekly basis; yearly basis and long-term basis. Even though rooms and specific areas had fewer issues to consider compared to healthcare wards and departments, the questionnaire survey respondents were of the opinion that it is easier to implement cost effective flexibility at specific areas or room levels on a long-term basis, while it is difficult to adopt space flexibility on a short-term basis. Some respondents made extra comments that it is *possible* to implement cost effective space flexibility on a short-term basis, but it is more challenging as it allows little time to adapt to changes.

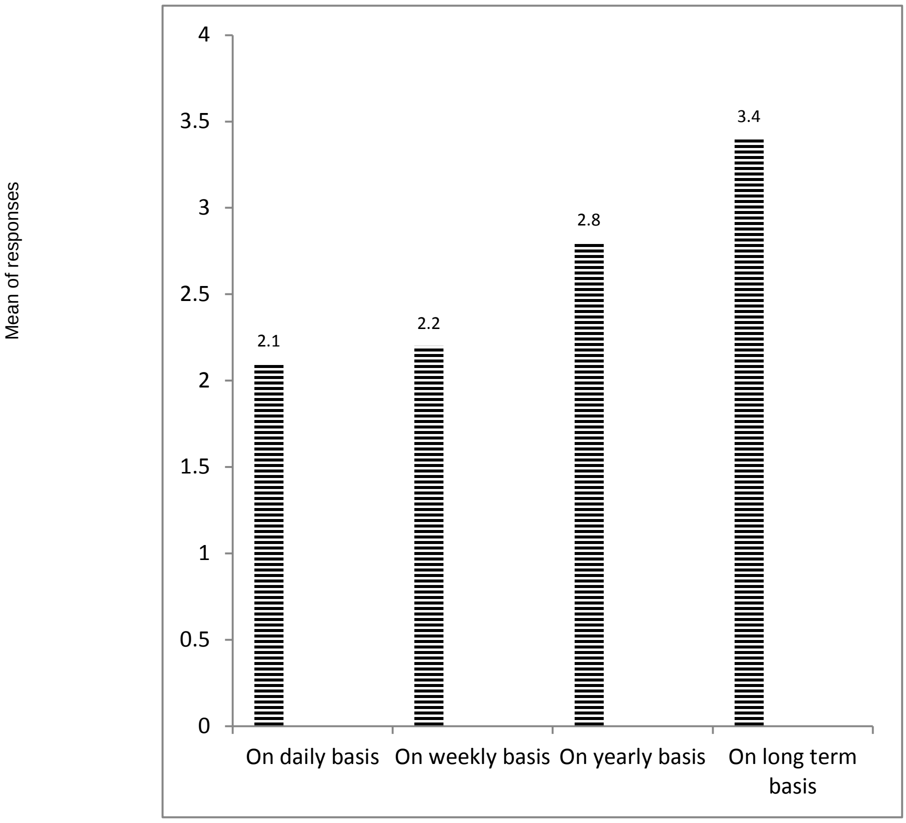


Out of 70 respondents: 48 answered; and 22 skipped it.

Figure 4: Questionnaire survey responses on space flexibility at specific area/room level.

4.1.3. At what levels are there more opportunities to implement cost effective space flexibility on the entire building/site area in healthcare facility design?

Figure 5 illustrates the responses to the above question. The questionnaire survey respondents indicated that space flexibility within an entire building/site level in healthcare facility design is easily achieved on a long-term basis. It is more cost effective and useful to apply space flexibility over a long period. The more the space, diversity and flexibility required, the more the cost of the project. An entire flexible site will take a longer time to construct compared to a flexible unit/building floor area.



Out of 70 respondents: 48 answered; and 22 skipped it.

Figure 5: Questionnaire survey responses on space flexibility at building/site level.

Figure 6 presents the summary of Figures 3, 4, and 5; it shows that the questionnaire survey respondents are of the opinion that space flexibility can be implemented effectively on a long-term basis with regards to the entire site, building level, departmental level, ward level, patient bedroom level or a specific area within a given healthcare facility. This can be taken into consideration when conceptualising and developing a specific design for the effective and efficient application of flexibility (Ahmad *et al*., 2011). Neufville *et al*., (2008) stated that strategic flexibility is suitable on a long-term basis; this coincides with the opinion of the questionnaire survey respondents. Figures 3, 4 and 5 showed that it is easier to achieve cost effective space flexibility on a long-term basis.

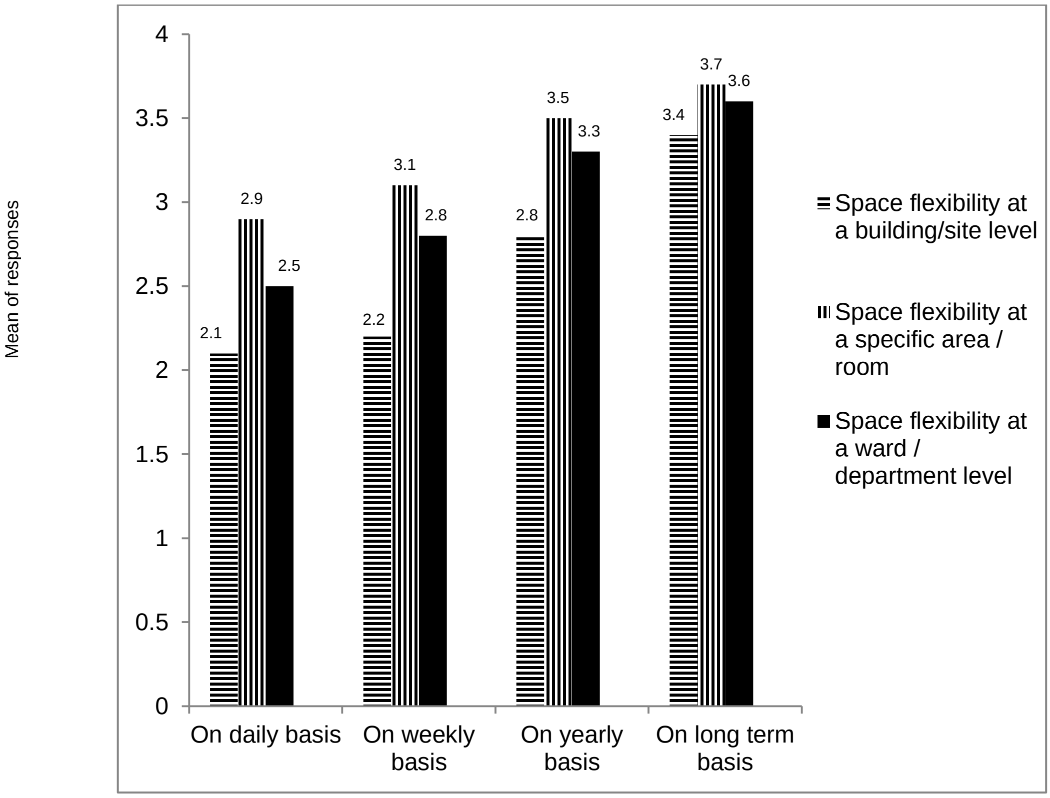
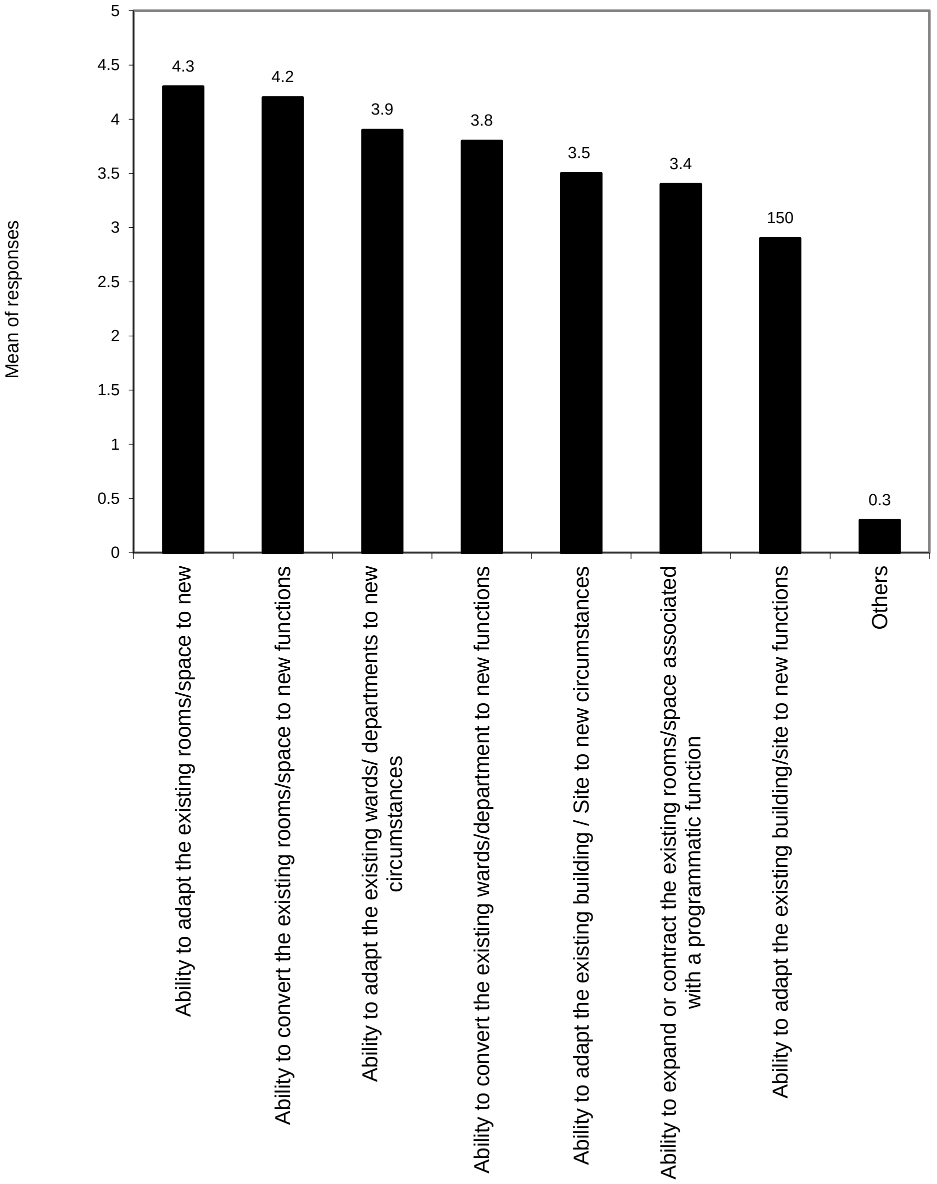


Figure 6: The combination of questionnaire survey responses (Figure 3, 4 and 5): showing the cost effectiveness of space flexibility at three different scenarios.

4.1.4 What are the most important types of space flexibility in healthcare facility design?

Figure 7 illustrates the responses to the question above. There are different types of space flexibility. This question was asked to determine which type of space flexibility is important in healthcare facility design? The most important type of space flexibility in the opinion of the questionnaire survey respondents was the ability to adapt existing room/space to meet new needs, while the ability to adapt the existing building/site to new functions had the least rating. The process of adapting existing spaces requires precise interventions especially during refurbishment, as many spaces will have different functions. Creating new functions close to existing function has to be innovatively and effectively planned to achieve a good flow between the existing and new spaces.



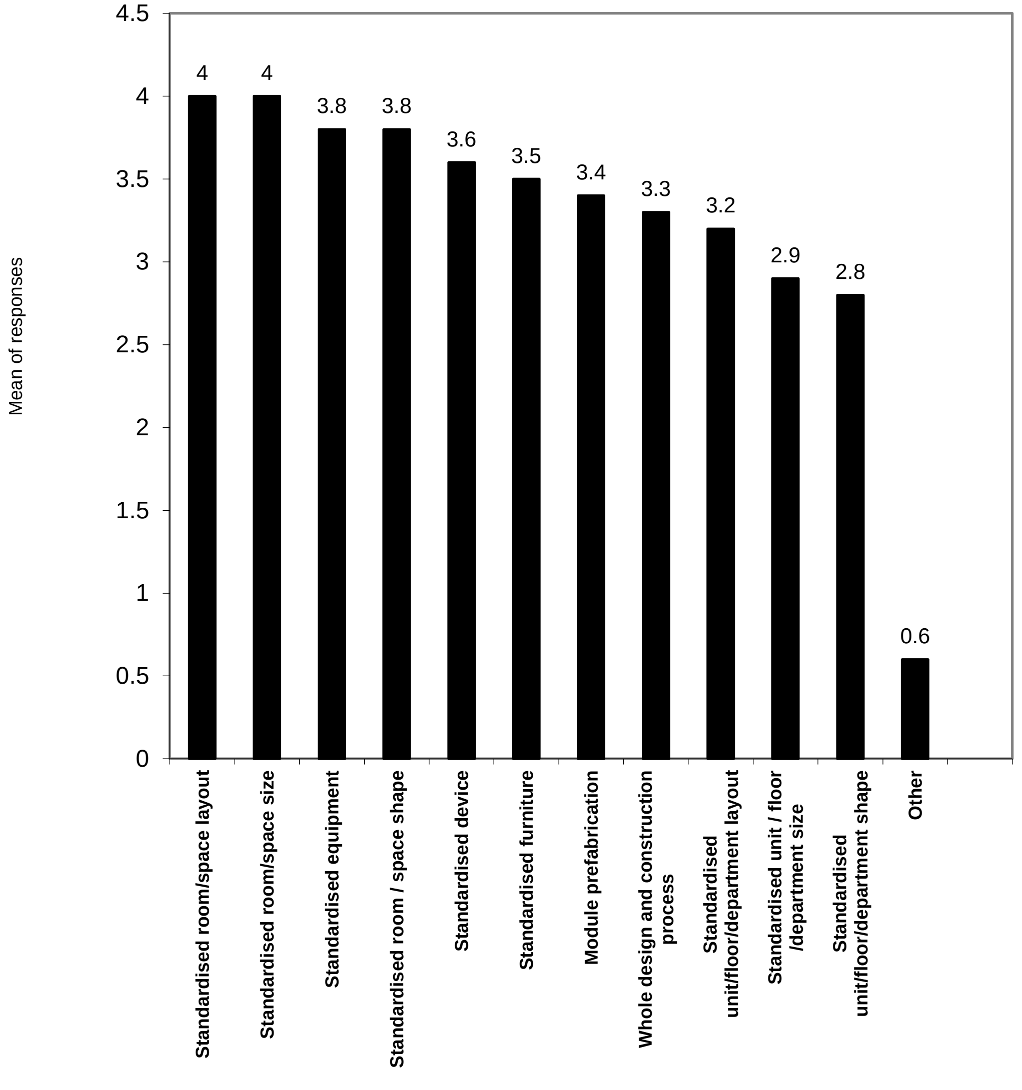
Out of 70 respondents: 51 answered; and 19 skipped it.

Figure 7: Questionnaire survey responses on the different types of space flexibility**.**

4.2 Findings (Space standardisation)

4.2.1 What is the most important type of (space standardisation) in healthcare facility design?

Figure 8 illustrates the responses to the question above. It was described by the questionnaire survey respondents that the most important type of standardised *space* in healthcare is standardised room/space, while standardised unit/floor/department layout was identified as the least important type of standardised space when designing healthcare spaces. During the design process, Standardisation can be successfully applied to rooms as it is efficient and effective in improving healthcare staff and patients' activities. Egan (1998) noted that pre-assembly of prefabricated parts of private hospitals use a sequential set of standardised rooms. Sine and Hunt, (2009) stated that patients expect more quality in healthcare bedrooms, perhaps the features of these rooms should be standardised. Pickard, (2005:10) stated that "*total standardisation may sometimes be appropriate for small buildings, but the most common and effective application of standardisation is to room layouts and assemblies of furniture and equipment such as the NHS Estates Activity DataBase*". This coincides with the opinion of the questionnaire survey respondents to standardised single rooms for the effective application of standards in healthcare facilities. The Activity DataBase (ADB) is a healthcare briefing and design software tool used for providing healthcare data for the design and construction of healthcare facilities.



Out of 70 respondents: 53 answered; and 17 skipped it.

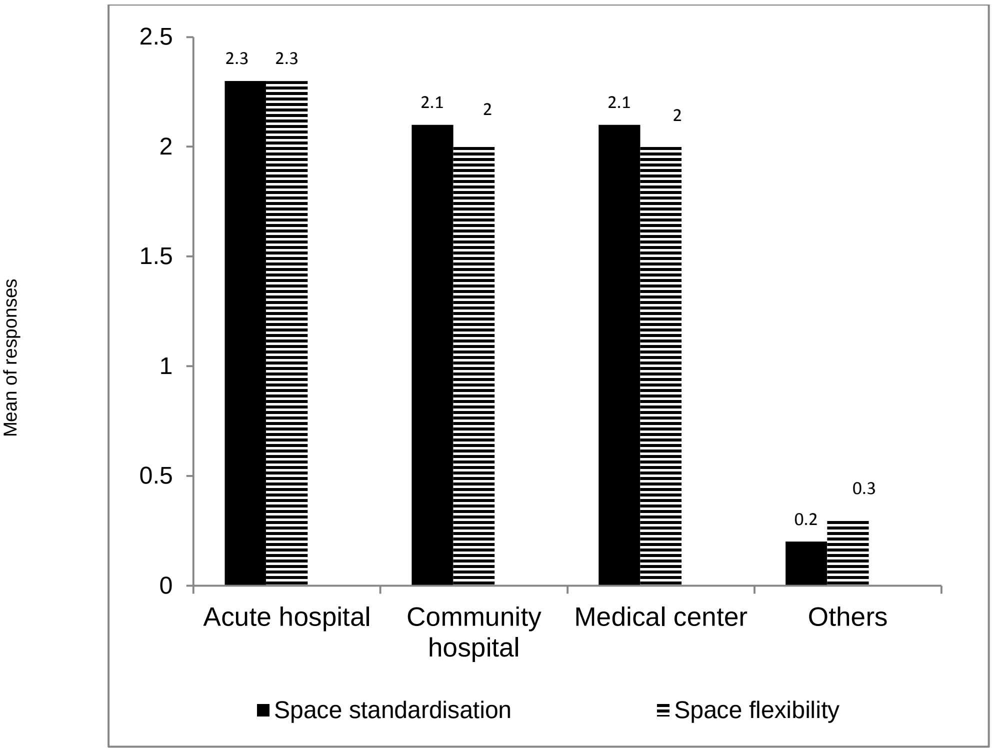
Figure 8: Questionnaire survey responses on the different types of space standardisation.

4.3 Relationship between space flexibility and space standardisations

This section explores the possible relationships between space flexibility and space standardisation within the questionnaire survey responses. The effectiveness of the two *space attributes* were compared in regards to healthcare delivery. The limitation of combining the questionnaire survey questions in this way is that different numbers of respondents responded to each question. However, the *space attributes* where compared to explore their relationships. Swayne *et al*., (2006) asked the question, is there a possible balance between space flexibility and space standardisation? Price and Lu, (2012) stated that there is no specific optimum ratio for the application of both *space attributes*; flexibility can complement standardisations, and when trying to find a balance between both *space attributes*, space standardisation should be implemented first, then space flexibility can be used were standardisation has lapses; space standardisation can be customised to suit user`s needs.

4.3.1 What is the relationship between the areas/spaces/units that provide the best opportunity for both *space attributes*?

Figure 9 illustrates the responses to the question above. The respondents were asked to state the name of room type/area that provides the best opportunity for space flexibility? In another question; the respondents were asked to state the name of room type or area that provides the best opportunity for space standardisation? The questionnaire survey findings show that respondents are of the view that acute hospitals are healthcare spaces that provide the best opportunities for both *space attributes* to be implemented. Pickard, (2005:10) described that "*the design of Acute hospitals are different in most cases, due to their complexity and technicalities; it is advised to standardised design of part of these hospitals, which can frequently be updated in light of experience*"; he also advised "*to standardise the design of parts of hospital, or even in a few cases of whole hospital…the greatest danger is the use of standard solution in an unimaginative or bureaucratic manner, when it is inappropriate to the needs of the project, or when it has become functionally obsolete*".



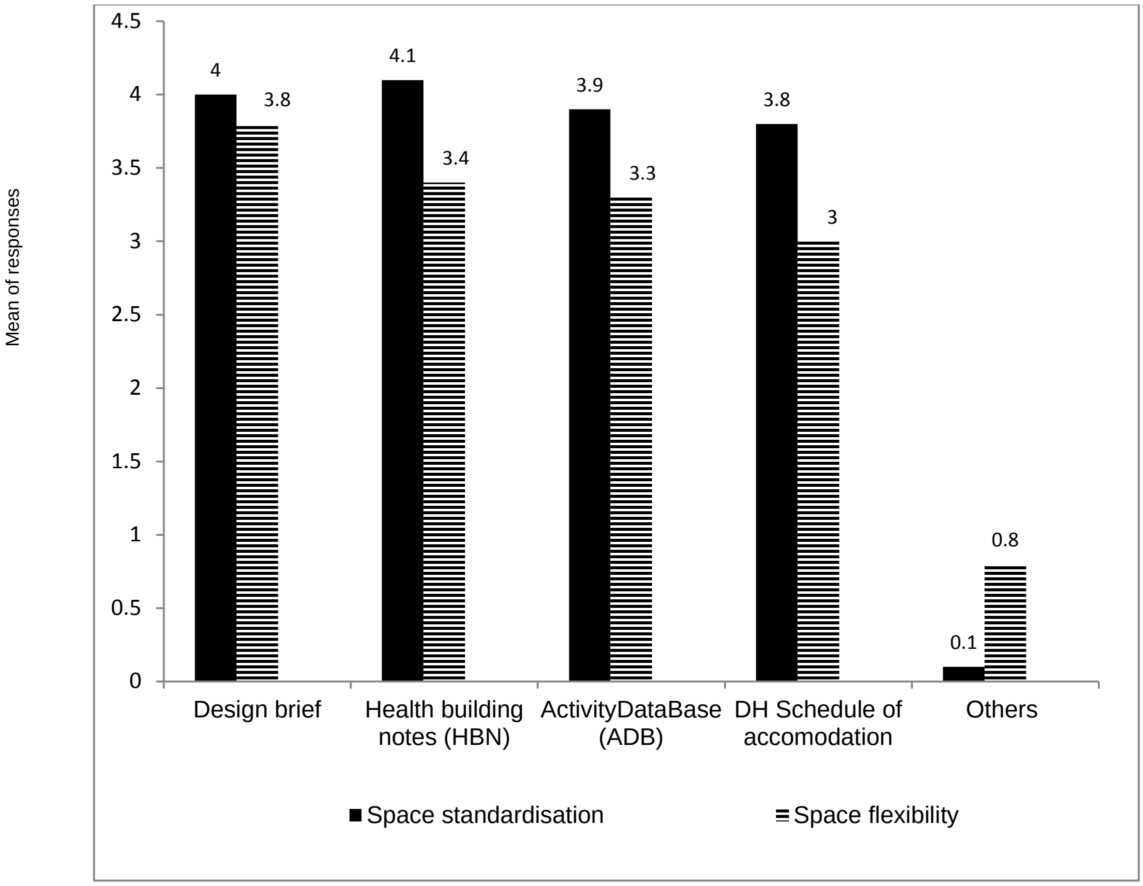
Out of 70 respondents: 41 answered; and 29 skipped it. (Space standardisation).

Out of 70 respondents: 44 answered; and 26 skipped it. (Space flexibility).

Figure 9: Questionnaire survey responses on the best opportunities for both *space attributes*.

4.3.2 What is the relationship between the most important tools used to achieve both *space attributes*?

Figure 10 illustrates the responses to the above question. The questionnaire survey respondents were asked: what are the most important tools used to achieve space flexibility in healthcare facilities? Another question was asked: what are the most important tools used to achieve space standardisation? The mean was tabulated for each of the *space attributes* in Figure 10; it shows that the questionnaire survey respondents are more comfortable using tools/guidance/software to achieve space standardisation rather than space flexibility. The questionnaire survey respondents reported serious concern with standards such as Health Building Notes (HBN) and Health Technical Notes (HTN) that a time they are outdated and can introduce inefficiencies before the facility is even handed over for use.



Out of 70 respondents: 53 answered; and 17 skipped it. (Space standardisation).

Out of 70 respondents: 49 answered; and 21 skipped it. (Space flexibility).

Figure 10: Questionnaire survey responses on tools/guidance/software used for both *space attributes*.

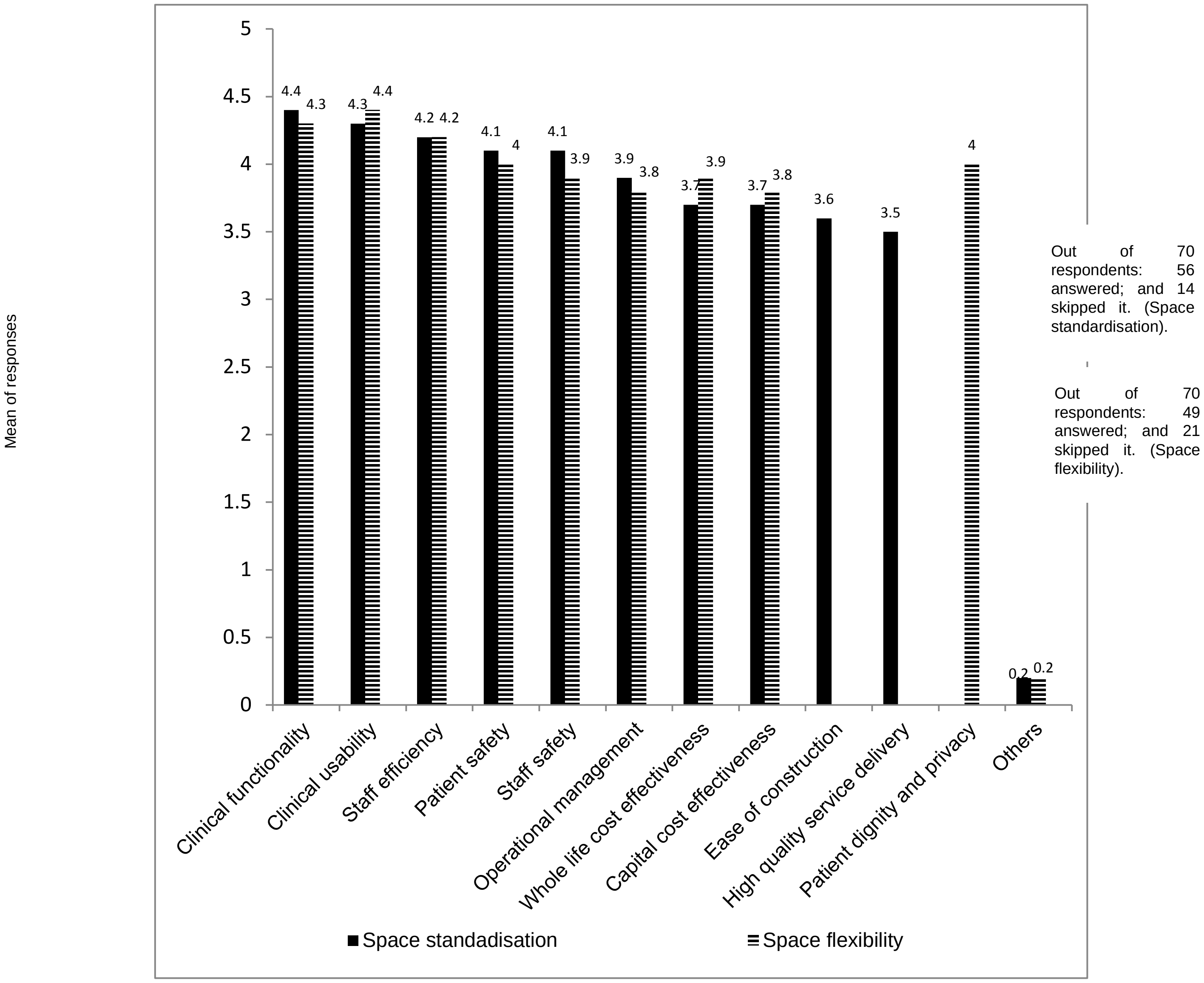
From the questionnaire survey findings, four key tools have been agreed to be the most efficient tools that help in achieving both *space attributes*. These are:

- Activity DataBase (ADB);
- Health Building Notes (HBN);
- DH Schedule of Accommodation; and
- Design Brief.

Software used for achieving both *space attributes* depends on the user's ability to understand and use a given application. Software tools such as ADB will not help to solve a problem, but will provide professionals with relevant information to design and construct healthcare facilities. There are concerns of out-dated guidance and the availability of different standards for the same purpose, at time there are duplications in standards provided. Finding from the Department of Health showed that there are more than 1240 different room specifications. Hignett and Lu, (2007) noted that there is a lack of confidence in the availability of information, and that there is conflict between the information focus for patient (care) and staff (efficiency) to be applied in a facility design. Therefore, both healthcare staff and patients are required to participate in the design of healthcare standards.

4.3.3 What is the relationship between the degrees of agreement/disagreement to achieving the drivers of both *space attributes*?

Figure 11 illustrates the responses to the question above. The questionnaire survey respondents were asked: to indicate their degree of agreement/disagreement that the following are key drivers for achieving space flexibility? The respondents were also asked: to indicate their degree of agreement/disagreement that the following are key drivers for achieving space standardisation? Both *space attributes* had a high number of responses; but findings showed that space standardisation is more efficient in dealing with clinical issues in healthcare facility design. When designing healthcare spaces, clinical areas can be fully standardised while other non-clinical areas can be partially standardised. Table 4 shows the impact of space flexibility and space standardisation drivers.



Out of 70 respondents: 56 answered; and 14 skipped it. (Space standardisation).

Out of 70 respondents: 49 answered; and 21 skipped it. (Space flexibility).

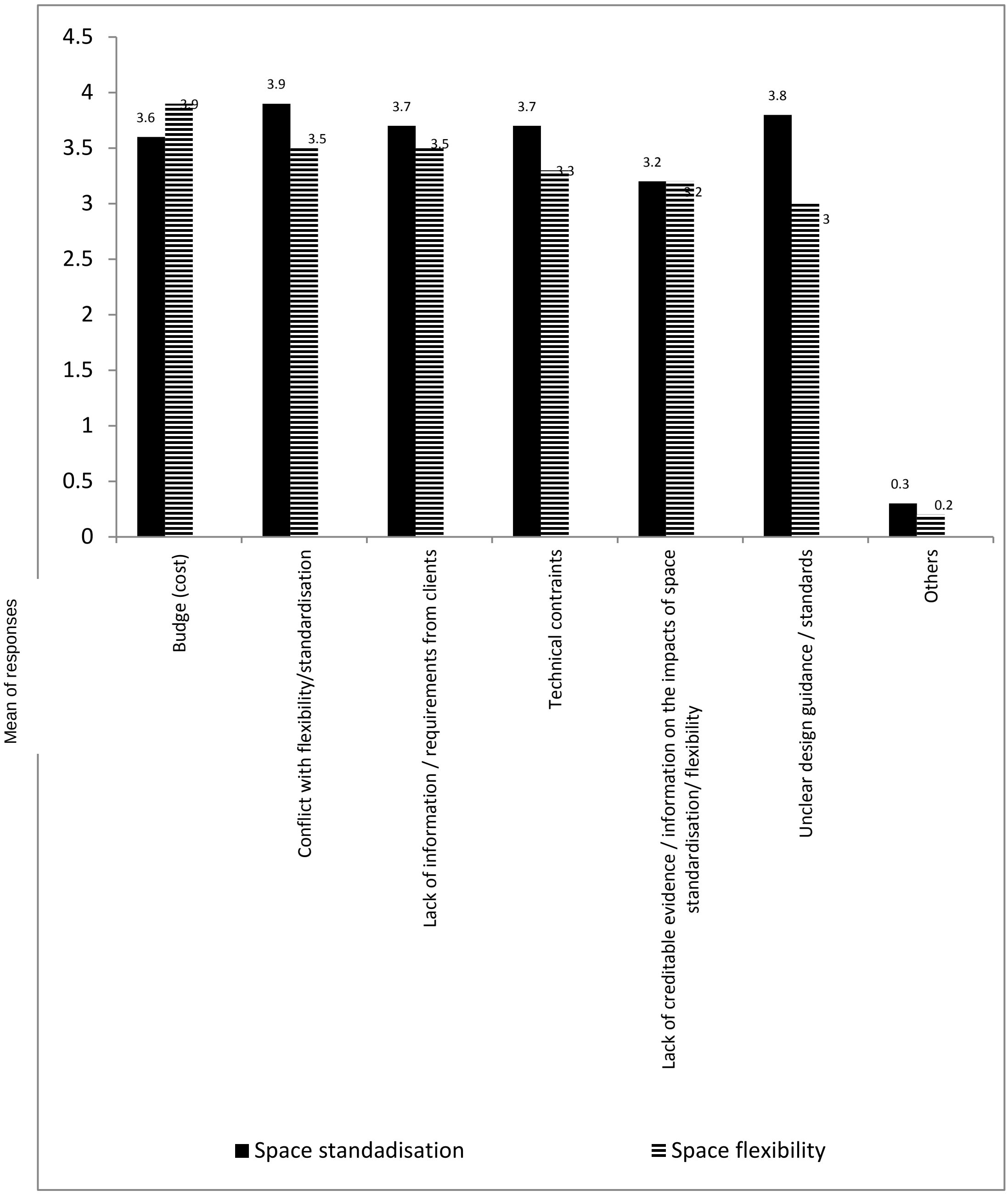
Figure 11: Questionnaire survey responses on key drivers for both *space attributes*.

Table 4: Impact of space flexibility and space standardisation drivers on healthcare facility design and users.

Drivers	**Direct (impact)**	**Space Flexibility Driver**	**Space Standardisation Driver**
Staff safety	Staff	✓	✓
Patient safety	Patient	✓	✓
Staff efficiency	Staff and patient	✓	✓
Patient dignity and privacy	Patient	✓	
High quality service delivery	Patient and staff		✓
Clinical functionality	Patient and Staff	✓	✓
Operational management	Facility	✓	✓
Capital cost effectiveness	Facility	✓	✓
Whole life cost effectiveness	Facility	✓	✓
Clinical usability	Patient and staff	✓	✓
Ease of construction	Facility		✓

4.3.4 What is the relationship between the degrees of agreement/disagreement to the different barriers for both *space attributes*?

Figure 12 illustrates the responses to the above question. The respondents were asked: to indicate their degree of agreement/disagreement that the following are major barriers for achieving space flexibility? They were also asked: to indicate their degree of agreement/disagreement that the following are major barriers of space standardisation? It is significant to note that space standardisation has more conflict with space flexibility, while space flexibility has less conflicting issues with space standardisation in the opinion of the questionnaire survey respondents. Budget is more of an issue to space flexibility compared to space standardisation; embedding facility flexibility comes with a price. A financial feasibility study is required to make a business case for implementing flexibility in any given facility. Table 5 shows barriers for both *space attributes* and their impact on facility design and users.



Out of 70 respondents: 53 answered; and 17 skipped it. (Space standardisation).

Out of 70 respondents: 50 answered; and 20 skipped it. (Space flexibility).

Figure 12: Questionnaire survey responses on the major barriers to achieving both *space attributes*.

Table 5: Impact of space flexibility and space standardisation barriers on healthcare facility design and users.

Drivers	**Direct (impact)**	**Space Flexibility Barrier**	**Space Standardisation Barrier**
Culture	Patient and staff	✓	✓
People diversity	Patient and staff	✓	✓
Unclear design guidance	Facility design	✓	✓
Technical constraints	Facility design	✓	
Lack of credible evidence	Facility design	✓	✓
Loss of creativity	Facility design		✓
Conflict with standardisation	Facility design	✓	
Conflict with flexibility	Facility design		✓
Budget	Facility design	✓	✓

Key considerations stated by some of the respondents within the 70 participants were mostly centred on standardisation. These comments were written in the space provided "*others*" for additional information. Some of the findings coincided with Pickard (2005); he stated that standardisation is better in clinical areas and should be encouraged by stating its benefits in the Design Brief Stage. Hignet and Lu, (2007) stated that one of the barriers of standardisation is that; there is a lack of confidence in information provided for specifications, and a time these standards are rarely updated. This coincides with additional comments made by some of the questionnaire survey respondents; the comments were centred on the barriers to achieving standardisation in healthcare facilities.

Questionnaire survey respondents with similar suggestions regarding standardisation:

- Standardisation should be prescribed for space function and layout: *three respondents.*
- Standardisation should be the Design Brief: *three respondents*.
- Standardisation is better in clinical areas: *one respondent.*
- Due to the constraints of existing structures during refurbishment, standardisation should be guides not rules: *one respondent*.
- Standardisation should be affordable: *one respondent*.

Respondents' concerns regarding Standardisation:

1. Creativity may be affected: *three respondents.*
2. The process of achieving desired clinical output can lead to standardisation in healthcare buildings: *two respondents.*
3. Standardisation will depend on the type of building in context (new built / refurbished): *two respondents.*

4. It is difficult to standardise due to the different requirement of different projects: *one respondent.*
5. Standardisation could lead to one size fits all, which is not a good approach: *one respondent.*
6. How will standards adapt to future needs? *one respondent*.
7. A time it is difficult to fulfil the Design Brief within a specific cost target or existing area/site*: two respondents*.
8. Standardisation could make buildings old before they are even lunched for use, due to the use of out-dated standards: *two respondents.*
9. Some companies produce their own standards due to contradiction in the publications of some standards: *three respondents*.
10. The ADB at time has conflicts with building standards: *2 respondents.*

Discussion and conclusions

The outcome of this research is intended to inform the Concept Design and the Developed Design Stages of the RIBA Plan of Work. Space flexibility for the purposes of this research focuses on the physical space/equipment/furniture (product) only. Space standardisation focuses on both the physical space (product) and sequential (process). This research has cited the works of professionals from the Architecture Engineering and Construction (AEC) industry and the NHS promoting the application of flexibility and standardisation in healthcare facilities, such as: NHS Estates, (2004); NHS Estates, (2005); and National Patient Safety Agency, (2010). One of the questionnaire survey findings coincides with Neufville *et al*., (2008) that flexibility is more effective on a long-term basis due to the rapid changing nature of healthcare facilities. These changes are instigated by an ageing and growing population, and the changing nature of healthcare treatment (process and equipment). These factors make it difficult for healthcare spaces to adapt to changes within a short time-frame. Most of the concerns raised by the questionnaire survey respondents were centred on flexibility, standardisation and quality of information; these concerns were listed from one to 11 and grouped into three categories. These are:

1- Constraints of existing spaces (1/3/5/8)
2- The ability to be flexible (2/4/7)
3- Information reliability (11/10/9)

The constraint of existing site functions and spaces poses a great challenge to space flexibility and space standardisation. The existing spaces a time comes with their corresponding functions, flow, circulation and more. The specifications or requirements for these spaces may also vary depending on facility type and use. Despite the different space requirements, healthcare spaces are a time designed with ADB standards. It was stated on the ADB website that the ADB, a healthcare briefing and design software tool is estimated to be applied in more than 90% of healthcare facilities in the UK; it provides healthcare information for the design and construction of healthcare projects and is being updated for information reliability and adaptability. The question is how frequent does the software needs updating to adapt to the frequent changing needs and requirements of healthcare facilities?

One of the questionnaire survey findings on space standardisation coincides with Pickard, (2005) and Price and Lu, (2012) that standardisation is more effective when applied to healthcare rooms. For example, a single bed in a hospital is designed in so much that almost the entire room is specified. This includes the windows and door sizes, finishing materials, room size, shape, layout and more. Perhaps an efficient healthcare facility that focuses on staff and patients should integrate both space flexibility and space standardisation. Although it has been acknowledged that there are some similar problems to their combined application. These include: budget; dealing with diversity; and different cultures, while their similar advantages are operational efficiency, clinical usability, clinical functionality, staff and patient safety and healthcare staff efficiency. Nevertheless, the combined application of space flexibility and space standardisation is still encouraged, as their advantages outweigh their disadvantages. The advantages of both *space attributes* can be achieved using certain tools, among the different tools for both *space attributes*, the Design Brief was considered as the most common tool for designing healthcare facilities in the opinion of the questionnaire survey respondents. Another question emerged, how does this research impacts the practical implementation of space flexibility and space standardisation in healthcare delivery and improves the quality of healthcare facility design? The drivers for both *space attributes* can motivate their implementation in healthcare facilities. Standardisation allows flexibility to take place. For example, most windows are usually designed in a multiple of 300 millimetres (mm) standard for ease of industrial manufacturing and flexibility in their various applications. Hence, different flexible sizes in the multiple of 300 mm specification can be used. For example, 900 mm x 600 mm, 1200 mm x 1500 mm or 900 mm x 1200 mm. the NHS Estates, (2004:20) have encouraged healthcare design professionals to increase spaces in operating theatres for maximum flexibility. They also stated that "*a standard of 55m2 is recommended for all in-patient operating theatres*". This implies that standards can complement flexibility in some cases.

This research has identified both positive and negative factors to consider when applying space flexibility and space standardisation in the design process. The questionnaire survey findings for both *space attributes* are found to have an impact on staff performance and patient safety by improving the quality of healthcare delivery. When implementing space flexibility and space standardisation together, there is no specific (ratio) of their combined application, the strategy for combining space flexibility and space standardisation findings was to explore their relationship, this can allow the use of space standardisation where space flexibility is less effective and vice versa. Both *space attributes* have an opportunity to be executed in an Acute, Mental or Community hospital, but space flexibility has the highest opportunity to be applied in most of the healthcare facilities specified compared to space standardisation in the opinion of the questionnaire survey respondents. Both *space attributes* can be applied in the design of the physical healthcare space to achieve optimum performance. The findings of this research suggests that flexibility should not be applied without standards, perhaps space flexibility and space standardisation can complement each other in their applications. These findings can be applied in both the Concept Design and Developed Design Stages of the RIBA Plan of Work. When conceptualising the design, the application of flexibility and standardisation in healthcare can be strategically applied where they are more effective to achieve desired project outcomes; flexibility is more effective on a long-term basis, while standardisation is more effective when fully applied to rooms.

How will the dynamics of flexibility and standardisation change over time? Standards will always need updating due to Government policies, healthcare treatment needs and quality standards required or set by the NHS. While flexibility will always require changes to take place in order to adapt to user's needs and appeals. This research concludes that due to the changing nature of demography and technology; healthcare spaces should be flexible and standardised. During the Concept Design and Develop Design Stages, flexibility can be achieved through the application of flexible concepts, while standardisation can be attained by specifying features of spaces, building elements and functions within a healthcare facility. The use of repeat procedures (standardisation) for optimum uniformity helps in conducting healthcare tasks effectively. The use of common spaces for multiple-purpose functions (flexibility) reduces the travelling distance for both staff and patient, and mitigates the pressure on transferring fragile patients from one functional space to the next for healthcare treatment. This research creates an opportunity to integrate both *space attributes* into the design process to improve the quality and efficiency of healthcare facilities. The comparison of the questionnaire survey findings showed that most of the respondents were of the view that space flexibility has lesser conflicting issues with space standardisation, whilst space standardisation has more conflicting issues with space flexibility when applied together simultaneously. Therefore, space standardisation should be used where it is more effective than space flexibility and vice versa to achieve optimum healthcare delivery outcome. Individual surveys can be done to build on this research for a more harmonious and effective integration of both *space attributes*.

Limitations of research

When comparing space flexibility and space standardisation, the number of people who answered and skipped some questions varies. Therefore, the comparison does not reflect equal sum of individual responses for each question. The logic is to compare the pattern of findings from each question. When comparing the space flexibility and space standardisation Figures, the y-axis annotates the mean of responses; a similar pattern was discovered (i.e. increasing or decreasing in the same direction). Even though findings are collected from experienced healthcare professionals; most findings are subjective perceptions. This research acknowledged the existences of more than two space attributes, but focuses on flexibility and standardisation to enable the design of buildings that are efficient and effective. Flexibility was centred on the physical space, while standardisation was focused on both the specification of space and the process of healthcare delivery including flow, function, sequences, arrangements and more. This research also focused on the supply chain more closely compared to the demand chain; perhaps findings from both supply and demand sample would have covered the entire design process, but focusing on the demand chain could change the focus of this research. Therefore, it focused on findings from the project delivery teams. Further research can look into the demand chain to get feedback from healthcare facility users to inform the briefing stage.

References

Ahmad, M.A., Price, A.D.F., Demian, P. and Lu, J. 2011. Space Standardisation and Flexibility on Healthcare Refurbishment. In: Michael, D.G. and Kendall, S. (eds) Architecture in the Fourth Dimension: Methods and Practices for a Sustainable Building Stock. *Proceedings of the Joint Conference of CIB W104 and W110*, Boston, MA, USA, 250-257.

Allsop, J. and Taket, A. 2004. Evaluating User Involvement in Primary Healthcare. *International Journal of Healthcare Technology and Management*. 5 (1), 34-44.

Barrett, P. and Baldry, D. 2003. *Facilities Management: Towards Best Practice*. 2nd (ed). Oxford: Blackwell Publishing.

Behan, J., Dishongh T., O`Donovan K., Burn A. and Roberts S. 2009. *Monitoring Handrails to Reduce Falls*. United States: Patent Application Publication.

Blyth, A. and Worthington, J. 2010. *Managing the Brief for Better Design*. 2nd (ed). USA: Routledge.

Building Design Partnership. 2004. *Learning from French Hospital Design*. Internal Report, BDP. Available from:

http://www.wales.nhs.uk/sites3/Documents/254/BDPFrenchHosp.pdf [Accessed on: 15th August 2011].

Campbell, S.M., Braspenning, J., Hutchinson, A. and Marshall, M. 2002. Research Methods Used In Developing and Applying Quality Indicators in Primary Care. *Quality and Safety in Healthcare*. 11 (4), 358-364.

Carthey, J., Chow, V., Jung, Y.M. and Mills, S. 2009. *Flexibility and Adaptability Report*: An International Review for the NSV Context. Sydney: Centre for Health Assets Austrasia (CHAA), Built Environment,

Gallant, D. and Lanning, K. 2001. Streamlining Patient Care Processes Through Flexible Room and Equipment Design. *Critical Care Nursing Quarterly*, 24 (3), 59-76.

Hendrich, A. L., Fay, J. and Sorrells, A.K. 2004. Effects of Acuity-Adaptable Rooms on Flow of Patients and Delivery of Care. *American Journal of Critical Care,* (13), 35-45.

Hignett, S and Lu, J. 2007. An Investigation of the Use of Health Building Notes by UK Healthcare Building Designers. *Applied Ergonomics*, 40 (4), 608-616.

Holt, L.E., Pelham, T.W. and Holt, J. 2008. Flexibility: *A Concise Guide to Conditioning, Performance, Enhancement, Injury Prevention and Rehabilitation*. New Jersey: Humana Press.

Joint Commission Resources. 2004. *Joint Commission Guide to Priority Focus Areas*. US: The Joint Commission on the Accreditation of Healthcare Organisations.

Kobus, R.L *et al*. 2008. *Building Type Basics for Healthcare Facilities*. 2nd (ed). New Jersey: John Wiley.

Malone J.R., Fontenla, M., Bick, D. and Seers, K. 2007. *Protocol Based Care Evaluation Project 1: Report for the National Co-ordinating Centre for NHS Service Delivery and Organisation R&D* (NCCSDO) SDO/78/2004. [Accessed on: 15th August, 2011]. http://www.sdo.nihr.ac.uk/files/project/78-final-report.pdf

Mourshed, M. and Zhao, Y. 2012. Healthcare Providers` Perception of Design Factors Related to Physical Environments in Hospitals. *Journal of Environmental Psychology*, 32 (4), 362-370.

National Patient Safety Agency. 2010. New hospital at Pembury: *Learning from the Experiences during the Design Stage for the New Hospital at Pembury*. Summary Report. www.nrls.npsa.nhs.uk/EasySiteWeb/getresource.axd?AssetID. [Accessed on: 15th August, 2011].

National Patient Safety Agency. 2010a. *Lessons from High Hazard Industries for Healthcare*. National Reporting and Learning Service. NHS. Full Report. London: ISBN:978-1-906624-13-2.

Neufville, R. D., Lee, Y. S. and Scholtes, S. 2008. Flexibility in Hospital Infrastructure Design. *The IEEE Conference on Infrastructure System*.

NHS Estates. 2005. *Ward Layouts with Single Rooms and Space for Flexibility*. UK: The Stationery Office (TSO).

NHS Estates. 2004. *HBN 26: Facilities for Surgical Procedures*. Volume 1.UK: The Stationery Office (TSO).

Pati, D., Harvey, T. and Cason, C. 2008. Inpatient Unit Flexibility: Design Characteristics of a Successful Flexible Unit. *Environment and Behaviour*, 40 (2), 205-232.

Pickard, Q. 2005. *The Architects` Handbook*. United Kingdom: Blackwell

Publishing.

Pommer, E.E., Horman, M.J., Messner, J.I. and Riley, D. 2010. A Unified Process Approach to Healthcare Project Delivery: Synergies between Greening Strategies, Lean Principles and BIM. In: Ruwanpura, J., Mohamed, Y. and Lee, S. (eds) Innovation for Reshaping Construction Practice. Proceedings of the 2010 *Construction Research Congress*, Volume 1. Canada May, 2010. Virginia: Construction Institute.

Price, A.D.F. and Lu, J. 2012. Impact of Hospital Space Standardisation on Patient Health and Safety. *Architecture, Engineering and Design Management* (AEDM), 9 (1), 49-61.

Purves, G. 2009. *Primary Care Centres: A Guide to Health Care Design*. United Kingdom: Elsevier Ltd.

Reiling, J.G., *et al*. 2004. Enhancing the Traditional Hospital Design Process - A Focus on Patient Safety. *Joint Commission Journal of Quality and Safety*, 30 (3), 115-124.

Reiling, J. 2007. *Safe by Design: Designing Safety in Health Care Facilities, Processes and Culture*. USA: The Joint Commission on the Accreditation of Healthcare Organisations.

Swayne, L.E., Duncan, J.W. and Ginter, P.M. 2006. *Strategic Management of Health Care Organizations*. USA: Blackwell Publishing.

Sine, M D. and Hunt, M. J. 2009. *Design Guide for the Built Environment of Behavioural Health Facilities*. 3rd (ed) NAPHS, Available from: http://www.naphs.org/teleconference/documents/DesignGuide3.0FINALSpring2009.pdf

Smith A.T. and Pollock, A. M. 2006. *The New NHS: A Guide*. New York: Routledge.

Torrington, J. 2007. Evaluating Quality of Life in Residential Care Buildings. *Building Research and Information*, 35 (5), 514-528.

Webster, C. 2002. *The National Health Service: A Political History*. Oxford: Oxford University Press.

Zhao, Y., Moushed, M. and Wright, J. 2009. Factors Influencing the Design of Spatial Layouts in Healthcare Buildings, in: Dainty, A.R.J. (ed) Proceedings of the 25th Annual *ARCOM Conference*. Nottingham, September, Reading.

APPENDIX 5: PAPER 5

USING BIM TO DESIGN FLEXIBLE SPACES AND APPLY DESIGN STANDARDS IN HEALTHCARE FACILITIES

A. M. AHMAD[1], I. KRYSTALLIS[1], P. DEMIAN[1] AND A.D.F. PRICE[1]

[1]School of Civil and Building Engineering, Loughborough University, Loughborough, UK

Purpose of the paper: The paper reports research to explore key factors that can enhance the designer`s role when designing space for flexibility with the focal use of BIM and design standardisation.

Methodology: An exploratory study was conducted using a questionnaire survey. First 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.

Findings: 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, in terms of designing different design options and scheduling design tasks within different time periods. 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.

Research limitations/implications: 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.

Originality/value: The aim of the exploratory study was to elicit the opinion of experienced healthcare designers and planners on the application of standardisation and BIM when designing flexible healthcare spaces.

Keywords: conceptual phase, BIM, flexibility, healthcare design, standardisation.

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 (Brand, 1995). 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 (Kendall, 2005). 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*" (Kendall, 2005, p.273).

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 (Kendall, 2005); the Addenbrooke's Hospital in Cambridge, UK (de Neufville et al., 2008); the St Olav's Hospital in Trondheim, Norway (Hansen & Olsson, 2011) and the Health Care Service Corporation Building in Chicago, USA (Guma et al., 2009) 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 (Cabinet Office, 2011); 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, BIM is expected to be adopted by the Architectural, Engineering and Construction (AEC) industry by 2016 (Becerik-Gerber & Kensek, 2010). Additionally, there is little research regarding the impact of healthcare space standardisation on hospital designs (Price & Lu, 2013).

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 that design standardisation and BIM as individual concepts can add value to the design of healthcare facilities. Driven by this notion, a hypothesis is framed that designers with healthcare and BIM experience are of the view that the applications of standardisation and BIM can enhance flexible space design. This was tested in linear correlation. 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.

Literature review

Towards Flexible healthcare facilities

The Department of Health, (DH, 2009, p.10) stated that when a facility is empowered by flexibility an "*annual savings of up to £1.8billion are achievable*". Pommer *et al*., (2010, p.1383) 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*., (2007) 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, (2008) 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 (de Neufville et al., 2008). 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.*, (2008) 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.*, (2010) 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, (2001) 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.* (2008) and Kronenburg, (2007) 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.

Impact of BIM in Design Creativity

Reddy, (2011, p.26) stated that "*BIM provides architects with infinite freedom to showcase their creativity*". Lee, (2010) stated that the early adoption of BIM increases not only productivity but also creativity in building design process. While Moreira *et al.*, (2010) 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 (Ahmad et al., 2012). 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*. (2011) described that alternative designs can be generated using "*what if*" scenarios with different BIM tools. For example the DProfiler^{TM} 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.

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"* (NHS, 2011). Additionally, the Health Building Notes (HBN) (DH, n.d.) 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) (DH, n.d.) identifies healthcare specific standards for building components as well as the design and operation of engineering services. The Activity DataBase (ADB) (DH, n.d.) 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 (Price & Lu, 2013). Reiling, (2004) 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.

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: i. background information of the respondents; ii. designing flexible healthcare spaces; iii. standardisation of healthcare space; and iv. 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 (2012) 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 "*(t)o say that data are interval, we must be certain that equal intervals on the scale represent equal differences in the property being measured*" (Moore et al., 2005). 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. Due to that 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*" (Moore et al., 2005).

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. *Location of this sample:* 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 response from this sample:* there were a total of 48 responses. 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.

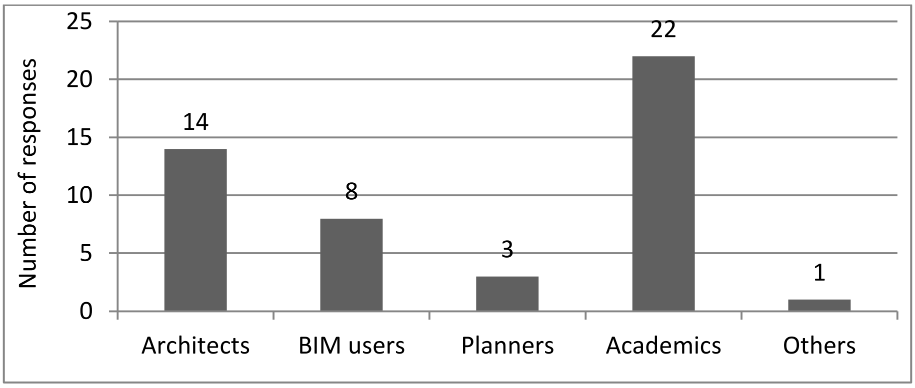


Figure 3: Profession most relates to Web-based Group (48 total).

Figure 3 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.

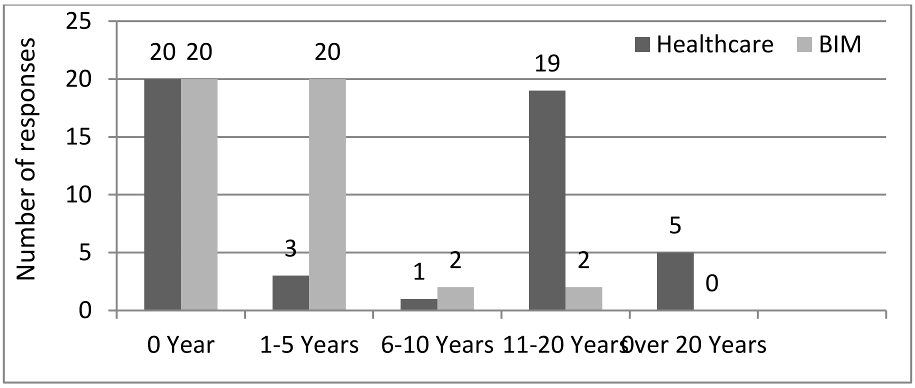


Figure 4: Years of healthcare experience within Web-based Group.

Figure 4 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.

Pilot study findings and analysis

Designing flexible healthcare spaces

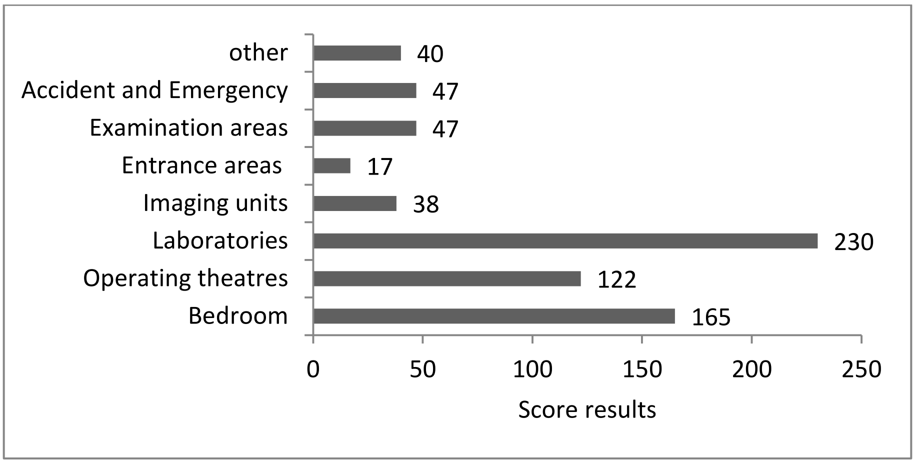


Figure 5: Spaces that frequently change in healthcare facilities (Web-based Group).

The pilot study respondents were asked to rank the spaces that rapidly change in healthcare facilities. Based on the code list for ADB rooms (DH, 2012), 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 showed that "*laboratories*" are ranked first, followed by "*bedrooms*" and "*operating theatres*" (Figure 5).

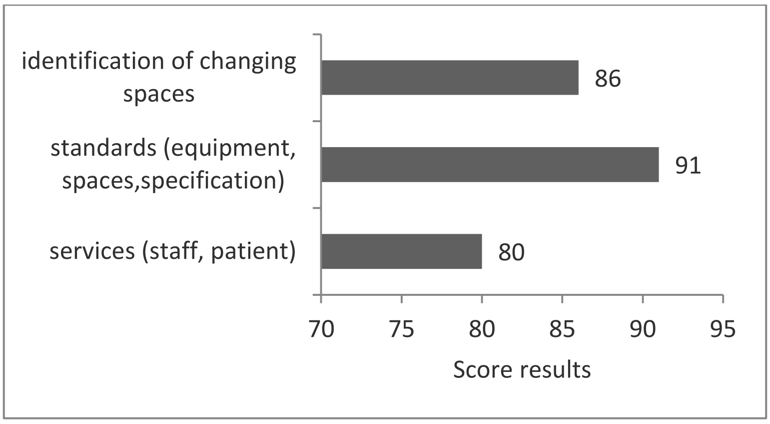


Figure 6: Top three important considerations for designing flexible spaces (Web-based Group).

Similarly, they were asked to identify the top three important considerations for designing flexible spaces. 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 "*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 10 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 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 10.

Table 10: 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

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 11) 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.

Table 11: 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

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 12 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.

Table 12: 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

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 13) 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.

Table 13: 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

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.

Table 14: Proportions and confidence intervals for pilot sample on the degree of dis (agreement) that BIM tools hinder design innovation and creativity.

Web-based Group	**95% confidence interval results**		
	Upper limit	Lower limit	Sample proportion
All the time	0.855	0.603	0.729

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 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 15.

Table 15: 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

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 to use BIM for analysing and evaluating flexible healthcare spaces for 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.

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 (Oppenheim, 1992). 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 ranked by *Building Magazine*, (2010) were chosen which was based on the highest number of UK chartered architects within UK firms. They were selected for their practical experience in the design of buildings in and outside the UK as described by *Building Magazine,* (2010). 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%).

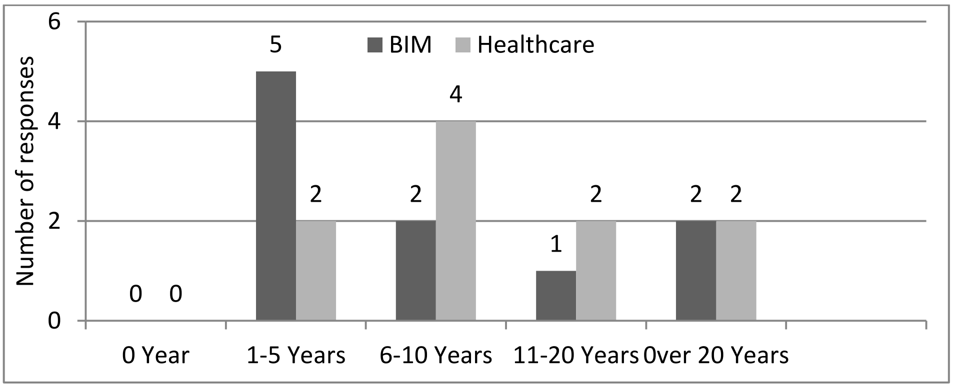


Figure 7: Years of BIM and Healthcare experience within main sample.

Background information

Error! Reference source not found. presents the years of healthcare and BIM experience for the main sample. The level 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.

Analysis of questionnaire findings

Designing flexible healthcare spaces

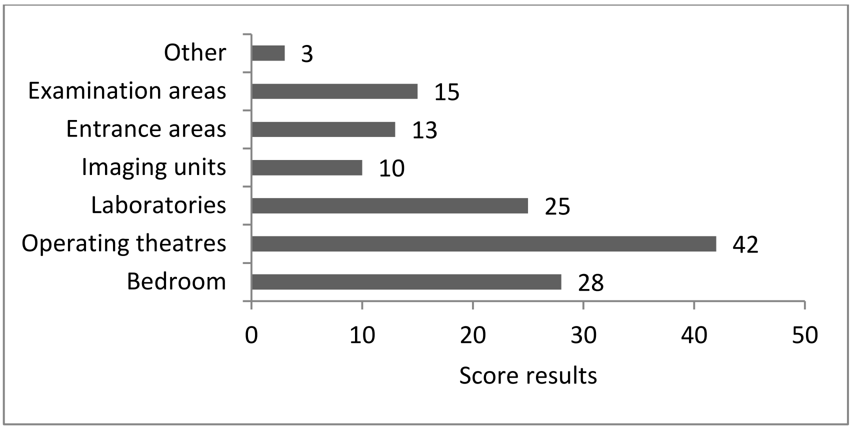


Figure 8: Spaces that frequently change in healthcare facilities.

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 Figure 8. It is noteworthy to understand that the same three categories were identified by the Web-based group but in a slightly different order.

Figure 9: Top three important considerations for designing flexible spaces.

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 (**Error! Reference source not found.**). Table 16 presents the degree of effectiveness of six flexibility concepts. 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.

Table 16: 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	.674	.857	-.467	.180
Shell space	1.000	.674	.857	-.082	.431
Flexible curtain walls	.951	.478	.714	-.140	-.629
Flexible furniture/equipment	.894	.392	.643	-.018	-.204
Multipurpose foundations	1.000	.674	.857	-.612	-.157
Flexible partitions/internal walls	1.000	.571	.786	.063	.179

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 16). Further correlation tests between the six flexibility concepts revealed that there are strong correlations among the concepts: "*flexible partition*"; and "*shell space*" ($r_s(10)=.913$, p.000); "*flexible partition*" and "*flexible furniture*" ($r_s(10)=-.922$, $p=.000$); and finally, "*flexible furniture*" and "*shell space*" with ($r_s(10)=-.866$, $p=.001$). A detailed list of the analysis results is shown in

Table 17.

Furthermore, this study explored the opinion of architects about 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. There is a need to explore the application of standardisation in flexible healthcare spaces to achieve added value, cost effectiveness and cost efficiency (Price & Lu, 2013).

			Modular design	Shell space	Flexible curtain walls	Flexible furniture	Multipurpose foundation	Flexible partition
Spearman's rho	Modular design	Correlation Coefficient	1.000	$.764^{*}$	-.375	$-.661^{*}$	.218	$.697^{*}$
		Sig. (2-tailed)		.010	.286	.037	.545	.025

Table 17: Spearman’s rho coefficient among flexibility concepts.

	N	10	10	10	10	10	10
Shell space	Correlation Coefficient	.764*	1.000	-.764*	-.866**	.048	.913**
	Sig. (2-tailed)	.010		.010	.001	.896	.000
	N	10	10	10	10	10	10
Flexible curtain walls	Correlation Coefficient	-.375	-.764*	1.000	.661*	.327	-.697*
	Sig. (2-tailed)	.286	.010		.037	.356	.025
	N	10	10	10	10	10	10
Flexible furniture	Correlation Coefficient	-.661*	-.866**	.661*	1.000	.082	-.922**
	Sig. (2-tailed)	.037	.001	.037		.821	.000
	N	10	10	10	10	10	10
Multipurpose foundation	Correlation Coefficient	.218	.048	.327	.082	1.000	-.174
	Sig. (2-tailed)	.545	.896	.356	.821		.631
	N	10	10	10	10	10	10
Flexible partition	Correlation Coefficient	.697*	.913**	-.697*	-.922**	-.174	1.000
	Sig. (2-tailed)	.025	.000	.025	.000	.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).

Standardisation of healthcare spaces

Most of the respondents agreed that standardisation could affect flexibility in all three categories "*some of the time*" (Figure 10). 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 18.

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 ($r_s(10)=-.633$, $p=.049$) for the respondents with high BIM experience that believed BIM is effective to inform decisions on short-term basis.

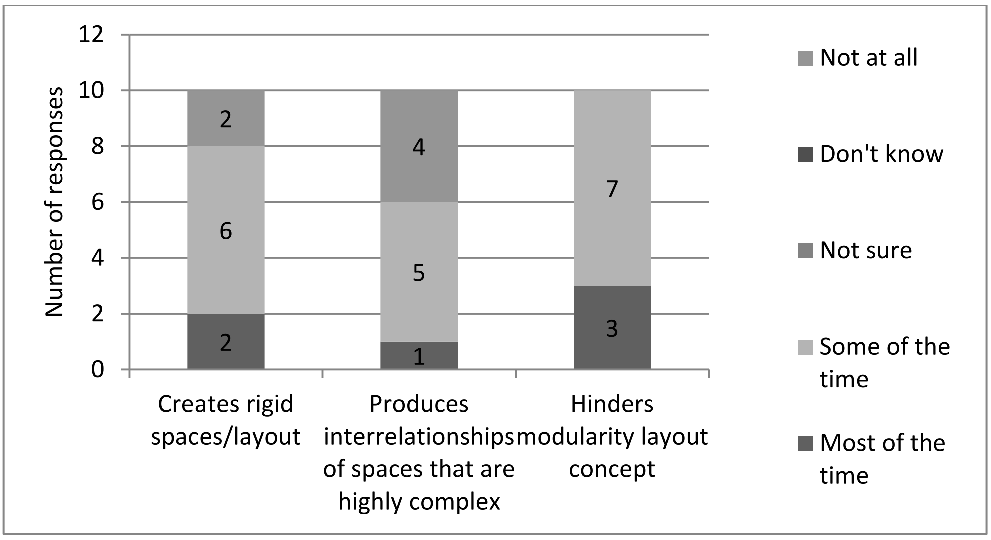


Figure 10: Opinion of respondents on standardisation impeding flexible space opportunities.

Finally, no evidence suggests 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 19.

Table 18: 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	.951	.478	.714	.384	.000
Produces interrelationships of spaces that are highly complex	.831	.312	.571	.119	.156
Hinders modularity layout concept	1.000	.640	.857	.204	-.157

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 20).

Table 19: 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	1.000	0.571	0.786	-0.633*	0.304
Sig. (2-tailed)				.049	
Long-term basis	1.000	.674	.857	-.326	.157

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

The respondents were then asked to agree or disagree that BIM tools hinder design innovation and creativity (Table 21). The results showed that the population would believe BIM tools hinder innovation and creativity "*all the time*" (57.1%-100% with 95% confidence). Spearman's tests revealed there is strong degreasing correlation ($r_s(10)=-.638$, p=.047) for the respondents who Strongly agree/agree that BIM tools hinder design innovation and creativity "*all the time*" with experience in healthcare design.

Table 20: 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	.762	.238	.500	-.148	.204
Long-term basis	1.000	.674	.857	.490	.039

Table 21: 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	1.000	.571	.786	.133	-.638*
Sig. (2-tailed)					.047

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

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 21. 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 22: 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 experience
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

Conclusions and Future Research

The study's final qualitative 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, (2001): spatial, flow; and structural are features of a rapid changing space, but if one asks what spaces are these in a healthcare facility, what would be the answer? Both samples identified *"bedrooms"*, *"0perating 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 type of room to be applied in a healthcare facility and so on. Another concept that was ranked as important was *"services"* which calls for identifying practices and operations required by facility users (staff and patients) at early design stages during the project's lifecycle; 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 for the early design stage of a project. One effective method in construction management that is 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 18 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 16. Modular design supports standardised units or standardised dimensions to support construction (Waskett, 2001). Modular design or prefabrication is described as an advanced construction technology that allows a building to be flexible in short notices while keeping cost as a primary concern. In Addenbrooke Hospital, the use of such methods was applied and significant time efficiency was noted (de Neufville *et al.*, 2008). 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 on a *"long-term basis"* regarding the design of healthcare facilities (Table 19 and

Table 20). Regarding the application 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 a 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 17) 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.

References

Adams, A., 2008. *Medicine by design: the architect and the modern hospital, 1893-1943*. Minneapolis: University of Minnesota Press.

Ahmad, A.M., Demian, P. & Price, A.D.F., 2012. Creativity with Building Information Modelling Tools. In Greenwood, D., ed. *First UK Academic Conference on BIM*. Newcastle, 2012.

Becerik-Gerber, B. & Kensek, K., 2010. Building Information Modeling in Architecture, Engineering, and Construction: Emerging Research Directions and Trends. *Journal of Professional Issues in Engineering Education and Practice*, 136, p.139.

Brand, S., 1995. *How buildings learn: what happens after theyre built*. Penguin Books.

Cabinet Office, 2011. *Government Construction Strategy*. London.

Carthey, J., Chow, V., Jung, Y. & Mills, S., 2010. Achieving flexible and adaptable healthcare facilities--findings from a systematic literature review. In *HaCIRIC International Conference*., 2010.

de Neufville, R., Lee, Y.S. & Scholtes, S., 2008. Using flexibility to improve value-for-money in hospital infrastructure investments. In *Infrastructure Systems and Services: Building Networks for a Brighter Future (INFRA)*. Rotterdam, 2008.

DH, 2009. *NHS 2010-2015: From Good to Great. Perventative, People Centred, Productive*. Norwich: The Stationery Office Department of Health.

DH, 2012. *Activity DataBase 2012 Room Coding List*. [Online] Available at: http://webarchive.nationalarchives.gov.uk/ [Accessed 14 February 2013].

DH, n.d. *Activity database 2012 software release*. [Online] Available at: https://www.gov.uk/government/publications/activity-database-2012-software-release [Accessed 19 April 2013].

DH, n.d. *Series: DH Health Building Notes*. [Online] Department of Health Available at: https://www.gov.uk/government/organisations/department-of-health/series/health-building-notes-core-elements [Accessed 22 April 2013].

DH, n.d. *Series: Health technical memoranda*. [Online] Department of Health Available at: https://www.gov.uk/government/organisations/department-of-health/series/health-technical-memorandum-disinfection-and-sterilization [Accessed 4 June 2013].

Eastman, C., Teicholz, P., Sacks, R. & Liston, K., 2011. *BIM handbook: A guide to building information modeling for owners, managers, architects, engineers, contractors, and fabricators*. 2nd ed. Hoboken, NJ: John Wiley and Sons.

Enache-Pommer, E., Horman, M.J., Messner, J.I. & Riley, D., 2010. A Unified Process Approach to Healthcare Project Delivery: Synergies between Greening Strategies, Lean Principles and BIM. *Construction Research Congress*, pp.1376-85.

Guma, A. et al., 2009. Vertical phasing as a corporate real estate strategy and development option. *Journal of Corporate Real Estate*, 11(3), pp.144-57.

Gupta, K., 2007. *Modern trends in planning and designing of hospitals: Principles and practice*. New Delhi: Jaypee Brother Medical Publishers.

Hansen, G.K. & Olsson, N.O., 2011. Layered Project--Layered Process: Lean Thinking and Flexible Solutions. *Architectural Engineering and Design Management*, 7(2), pp.70-84.

Kendall, S., 2005. Open building: an architectural management paradigm for hospital architecture. *CIB W096 Architectural Management, Lyngby, Denmark, TU Denmark*.

Kronenburg, R., 2007. *Flexible: architecture that responds to change*. London: Laurence King Publishing.

Lee, J.-H., 2010. Exploring Integrated Design Strategies for the Optimal Use of BIM. *ARCHITECTURAL RESEARCH*, 12(2), pp.9-14.

Moore, D., MacCabe, G. & Craig, B., 2005. *Introduction to the practice of statistics*. 5th ed. New York: Freeman.

Moreira, T.P., Silva, N.F. & Lima, E.M., 2010. The Impact of Building Information Modeling on the Architectural Design Process. *Advanced Techniques in Computing Sciences and Software Engineering*, pp.527-31.

NHS, 2011. *The ProCure21+Guide-Achieving Excellence in NHS Construction*. Leeds: Department of Health.

Oppenheim, A.N., 1992. *Questionnaire Design, Interviewing, and Attitude Measurement*. New Edition ed. London and New York: Continuum International Publishing Group.

Pati, D., Harvey, T. & Cason, C., 2008. Inpatient Unit Flexibility. *Environment and Behavior*, 40(2), pp.205-32.

Price, A. & Lu, J., 2013. Impact of hospital space standardization on patient health and safety. *Architectural Engineering and Design Management*, 9(1), pp.49-61.

Reddy, K.P., 2011. *BIM for Building Owners and Developers: Making a Business Case for Using BIM on Projects*. New Jersey: John Wiley & Sons.

Reiling, J.G. et al., 2004. Enhancing the traditional hospital design process: a focus on patient safety. *Joint Commission Journal on Quality and Patient Safety*, 30(3), pp.1-10.

Slaughter, E.S., 2001. Design strategies to increase building flexibility. *Building Research & Information*, 29, pp.208--217.

Waskett, P., 2001. Current practice and potential uses of prefabrication. *BRE (Building Research Establishment): DTI (Department of Trade and Industry), project report*.

APPENDIX 6: QUESTIONNAIRE SURVEY MS WORD DOCUMENT

Research title:

Redefining the designer's role in optimising space flexibility and standardisation during healthcare facility refurbishment using Building Information Modelling (BIM)

Purpose of Survey

I (Ahmad) am currently undertaking doctoral research into using BIM to design for space flexibility and use standardisation during the refurbishment of healthcare facilities and would like to elicit your opinion about healthcare space design. The results of this questionnaire survey will help to shape the future of my doctoral research in this area. **Aim of research**: Is to explore key factors that can enhance the designer`s role when designing space flexibility in healthcare refurbishment using BIM.
Targeted respondents are architectural designers, healthcare planners and BIM users. This questionnaire should take about 20 minutes to complete.

Data collected will be treated as confidential and will be used only for the purposes of this research. Anonymity of individuals and organisations will be maintained.

Notes for completing the questionnaire

- Please complete this questionnaire and email it back by **Monday 20th March, 2012**.
- There are four sections in this questionnaire
  - E. Background information
  - F. Designing **flexible** healthcare space
  - G. **Standardisation** of healthcare space
  - H. Flexible space design with **BIM**

Ahmad Mohammad Ahmad:

Doctoral Research Student,

School of Civil and Building Engineering, Loughborough University, Epinal Way, Loughborough, LEICS, LE11 3TU.

Email: a.m.ahmad@lboro.ac.uk;

Phone: +447767757705; **Fax**: +44(0)1509 223981

1

Section A (Background information)

A1. What profession most relates to your main roles? (Please tick all boxes that apply).

Architect	BIM user	Planner	Academics	Other: please specify

A2. How many years have you been using BIM? (Please tick one box).

0 year	1 – 5 years	6 – 10 years	11 – 20 years	Over 20 years

A2.1. How many years have you worked on healthcare design? (Please tick one box).

0 years	1 – 5 years	6 – 10 years	11 – 20 years	Over 20 years

A3. On what percentage of your projects do you use BIM? (Please tick one box).

1-20 Percent	21-40 Percent	41-60 Percent	61-80 Percent	81-100 Percent

A4a. Indicate your involvement in the following type of projects. (Please tick all boxes that apply).

Type of projects	**Frequently**	**Some extent**
1. Commercial		
2. Industrial		
3. Residential		
4. Institutional		
5. Healthcare		
6. Other: please specify		

A4b. Please state your main roles in any of the following type of projects.

Type of projects	Your role (e.g. Chief Architect)
1. Commercial	
2. Industrial	
3. Residential	
4. Institutional	
5. Healthcare	
6. Other: please specify	

Section B (Flexible healthcare space design)

Neufville et al, (2008) described flexibility as an alternative to future accomplishment, which can be switched on or off when required. It is the ability to be adaptable, variable or responsive to changing conditions to some extent.

B1. Please identify the six areas/spaces in a hospital that change most rapidly. (Rank in the highest order please)

1. ____
2. ____
3. ____
4. ____
5. ____
6. ____

B2. Please state the four most important stakeholders making decisions during the design of "flexible healthcare spaces". (Rank in the highest order please)

1. ____
2. ____
3. ____
4. ____

Neufville, R. D., Lee, Y. S., and Scholtes, S. (2008). Flexibility in Hospital Infrastructure Design. Paper presented at the IEEE Conference on Infrastructure System.

B3. Please state the three design principles for achieving space flexibility.

1. ____________________
2. ____________________
3. ____________________

B4. Please state the three most important factors for architectural designers to consider when designing "space flexibility" during healthcare facility refurbishment. (Rank in the highest order please).

1. ____________________

____

2. ____________________

____

3. ____________________

____

B5. Please indicate (with an X) the degree of effectiveness of the following concepts when designing "flexible healthcare spaces".

Different types of flexible design concepts	**Degree of effectiveness**					
	Highly Effective	**Effective**	**Neutral**	**Don't Know**	**Ineffective**	**Highly Ineffective**
Modular designs						
Shell spaces						
Flexible curtain walls						
Flexible furniture and equipment						
Multipurpose foundations.						
Other, please specify:						

Section C. Healthcare space standardisation

A standardised space can be defined as: *"formulation, publication, and implementation of guidelines, rules, and specifications for common and repeated use, aimed at achieving optimum degree of order or uniformity in a given context, discipline, or field" (Business Dictionary, 2011),* for example, rooms or spaces are specified in standards such as the Healthcare Building Notes (HBN) and the Activity Database (ADB).

C1. Please state the four most important stakeholders making decisions during the selection of the most effective standards in healthcare projects. (Rank in the highest order please)

1. ______________________________
2. ______________________________
3. ______________________________
4. ______________________________

C2. Please state the three key issues used in selecting the most effective standard from available standards. (Rank in the highest order please)

1. ______________________________
____
2. ______________________________
____
3. ______________________________
____
____

C3. Please indicate your opinion. Standardisation impedes flexible healthcare space opportunities by providing specifications that could: (Please tick one of the boxes that apply).

Standardisation:	Some of the time	Most of the time	Not sure	Don't know	Not at all
Create rigid spaces/layout.					
Produce interrelationships of spaces that are highly complex.					
Hinder modularity concept layout.					

Section D. Building Information Modelling (BIM)

BIM is defined as *a tool and process (Eastman et al, 2011),* space flexibility can be improved with the use of BIM to model. *Jayaraman and Whittle, (2007)* states that visualisation and modelling *"allows stakeholders to explore "what if scenarios" as a way to test completeness and correctness*"

D1. Please identify the six BIM software that are used for modelling "flexible healthcare space" in your organisation.

1. __________ 3. __________ 5. __________

2. __________ 4. __________ 6. __________

D2. Please indicate your rating of <u>BIM's</u> effectiveness in <u>the analysis, evaluation and modelling</u> the design of "flexible healthcare space" to inform decision for short-term and long- term basis.

Time basis ↓	Highly Effective	Effective	Neutral	Don't know	Ineffective	Highly Ineffective
Short-term basis						
Long-term basis						

D3. Please indicate the degree of effectiveness of using "what if scenarios" with BIM in the design of "flexible healthcare spaces".

Time basis ↓	Highly Effective	Effective	Neutral	Don't know	Ineffective	Highly Ineffective
Short-term basis						
Long-term basis						

D4. Please state the three most important issues to consider when modelling "flexible spaces". (Rank in the highest order please)

1. ____

____

2. ____

____

3. ____

____

D5. How does creating flexible space design with "what if scenarios" affect the BIM work flow process between architectural designer and fellow BIM collaborators?

Fellow BIM collaborators For example. "Interior decorators"	**Effect on BIM workflow** For example: "Using "what if a scenario" enables designers to send variable room sizes to the interior decorators and to receive possible fittings specification from them more rapidly".
1. Estimators.	
2. Mechanical Electrical and Plumbing (MEP).	
3. Structural engineers.	
4. Contractors.	
5. Other. Please specify:	

1. Oxford Dictionary [Online] Available from: http://oxforddictionaries.com/definition/flexibility. [Accessed on: 13th July, 2011]. 2. Eastman, C.M., Eastman, C., Teicholz, P., Sacks, R., Liston, K., (2011). BIM Handbook: A Guide to Building Information Modelling for Owners, Managers, Designers, Engineers and Contractors, Canada. John Wiley and Sons. 3. Whittle, J & Jayaraman, P 2007, 'MATA: A Tool for Aspect-Oriented Modeling Based on Graph Transformation', Paper presented at MoDELS Workshops, 1/01/00, pp. 16-27.

D6. Please indicate your degree of (dis)agreement that "BIM tools hinder design innovation and creativity".

Standardisation:	Strongly Agree	Agree	Neutral	Don't know	Disagree	Strongly disagree
All the time						
To some extent						
Not at all						

D7. Please indicate the effectiveness of BIM use when modelling, analysing and evaluating facility space:

Flexible facility space: ↓	Highly Effective	Effective	Neutral	Don't Know	Ineffective	Highly Ineffective
Expanding						
Contracting						
Relocating						
Adapting						

D7a. Please state the two most important considerations for sharing information within an organisation using BIM, such as between (architectural designer- architectural designers). (Rank in the highest order please)

1. ____

____

2. ____

____

D7b. Please state the two most important considerations for sharing information with an external organisation using BIM, such as between (architectural designer-architectural designers). (Rank in the highest order please)

1. ____

____

2. ____

____

D8. Please state the two possible methods/strategies of sharing findings/design knowledge through BIM in current practice within an organisation.

1. ____________________

____

2. ____________________

____

D9. Please state the two possible methods/strategies of sharing findings/design knowledge through BIM in current practice with external organisations.

1. ____________________

____

2. ____________________

____

* * * * * * * * * * * *

Thank you for taking time to complete this questionnaire.

Please return it to **Ahmad M Ahmad** by email: **a.m.ahmad@lboro.ac.uk**.

Department of Civil and Building Engineering, Loughborough University, Ashby Road,
Loughborough, Leicestershire, LE11 3TU
Phone: +447767757705; Fax: +44(0)1509 223981

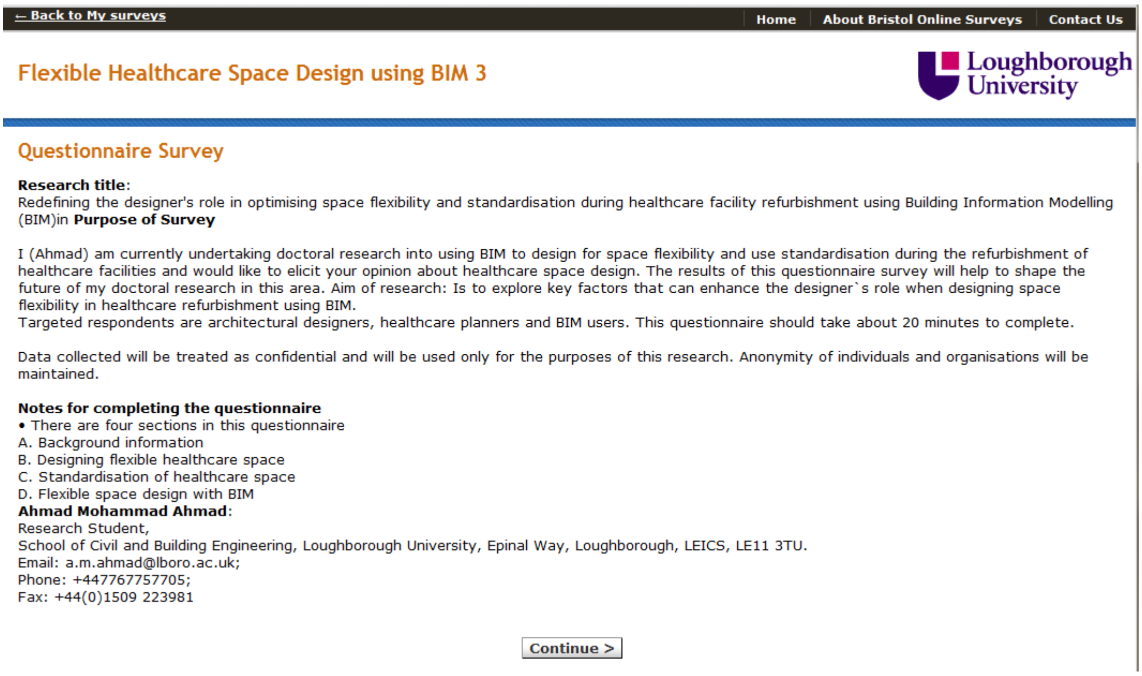
If you wish to receive a summary of the results of this questionnaire, kindly tick here … ☐

Name:	____________	Address:	____________
Tel:	____________	Email:	____________

Kindly tick here…. ☐ **If you are available to participate in a face-face/ phone interview, please provide your contact details above.**

Thank you very much for your time and effort.

APPENDIX 7: QUESTIONNAIRE SURVEY ONLINE VERSION



Flexible Healthcare Space Design using BIM 3

Questionnaire Survey

Research title:
Redefining the designer's role in optimising space flexibility and standardisation during healthcare facility refurbishment using Building Information Modelling (BIM)in **Purpose of Survey**

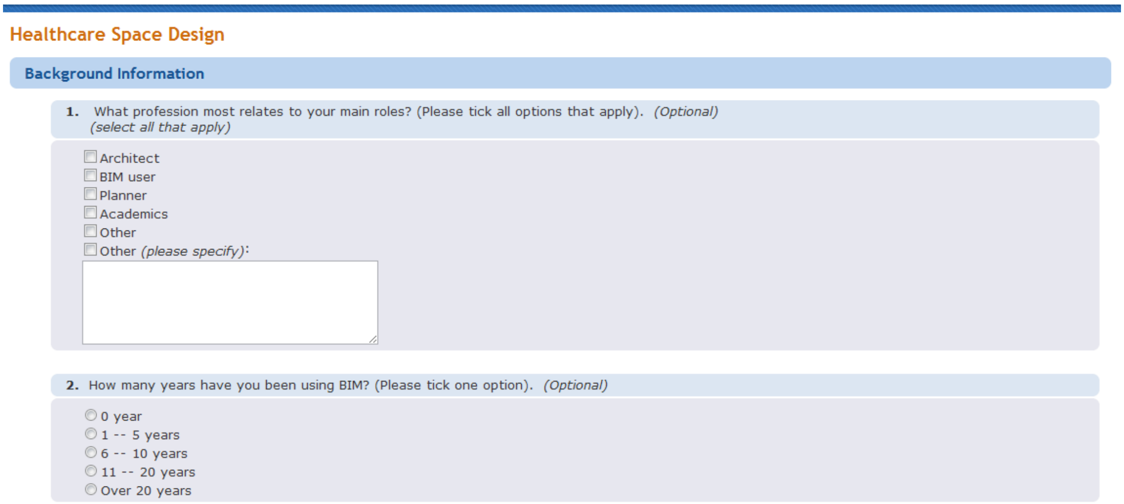
I (Ahmad) am currently undertaking doctoral research into using BIM to design for space flexibility and use standardisation during the refurbishment of healthcare facilities and would like to elicit your opinion about healthcare space design. The results of this questionnaire survey will help to shape the future of my doctoral research in this area. Aim of research: Is to explore key factors that can enhance the designer`s role when designing space flexibility in healthcare refurbishment using BIM.
Targeted respondents are architectural designers, healthcare planners and BIM users. This questionnaire should take about 20 minutes to complete.

Data collected will be treated as confidential and will be used only for the purposes of this research. Anonymity of individuals and organisations will be maintained.

Notes for completing the questionnaire
- There are four sections in this questionnaire

A. Background information
B. Designing flexible healthcare space
C. Standardisation of healthcare space
D. Flexible space design with BIM

Ahmad Mohammad Ahmad:
Research Student,
School of Civil and Building Engineering, Loughborough University, Epinal Way, Loughborough, LEICS, LE11 3TU.
Email: a.m.ahmad@lboro.ac.uk;
Phone: +447767757705;
Fax: +44(0)1509 223981



Healthcare Space Design

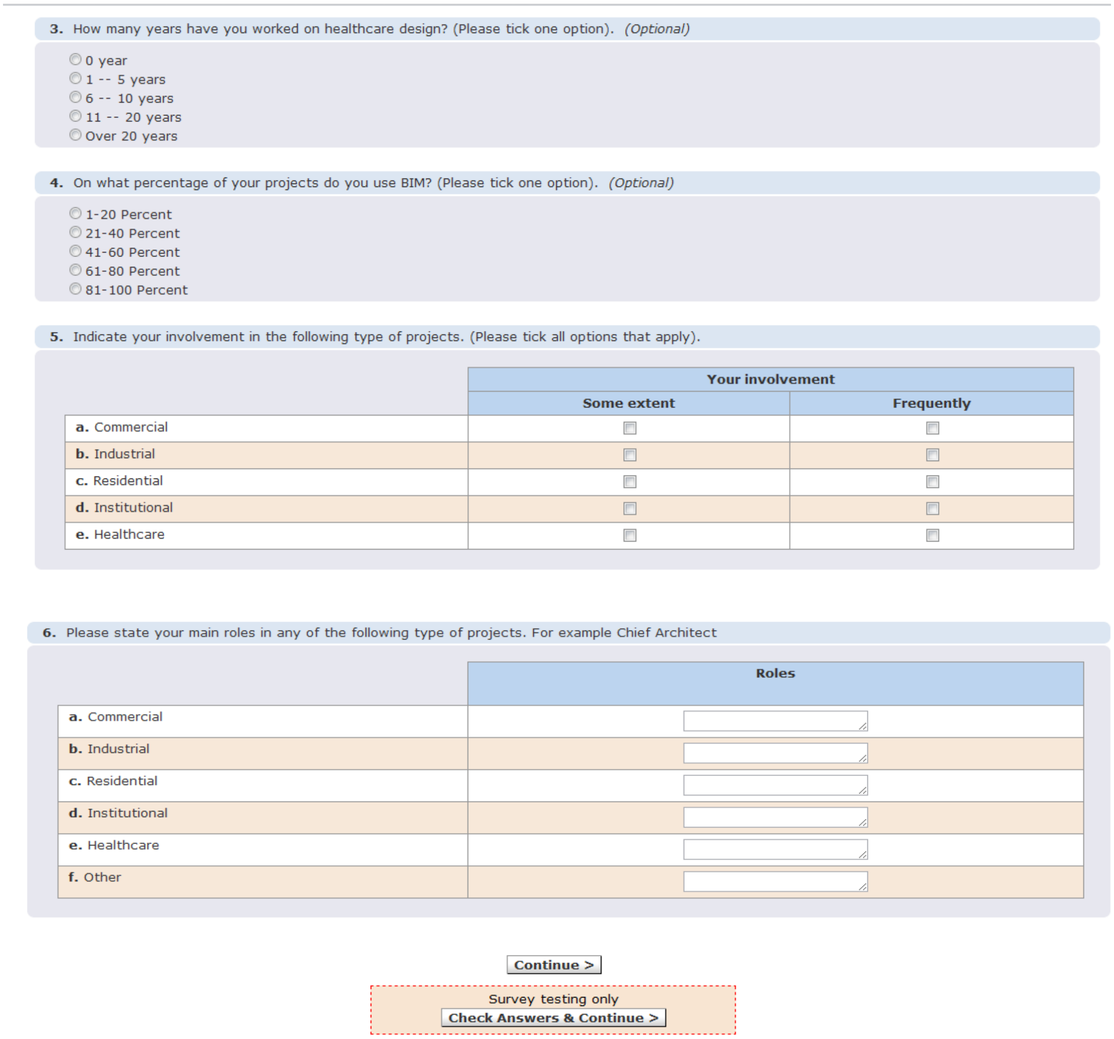
Background Information

1. What profession most relates to your main roles? (Please tick all options that apply). *(Optional)*
(select all that apply)

☐ Architect
☐ BIM user
☐ Planner
☐ Academics
☐ Other
☐ Other *(please specify)*:

2. How many years have you been using BIM? (Please tick one option). *(Optional)*

○ 0 year
○ 1 -- 5 years
○ 6 -- 10 years
○ 11 -- 20 years
○ Over 20 years



3. How many years have you worked on healthcare design? (Please tick one option). *(Optional)*

○ 0 year
○ 1 -- 5 years
○ 6 -- 10 years
○ 11 -- 20 years
○ Over 20 years

4. On what percentage of your projects do you use BIM? (Please tick one option). *(Optional)*

○ 1-20 Percent
○ 21-40 Percent
○ 41-60 Percent
○ 61-80 Percent
○ 81-100 Percent

5. Indicate your involvement in the following type of projects. (Please tick all options that apply).

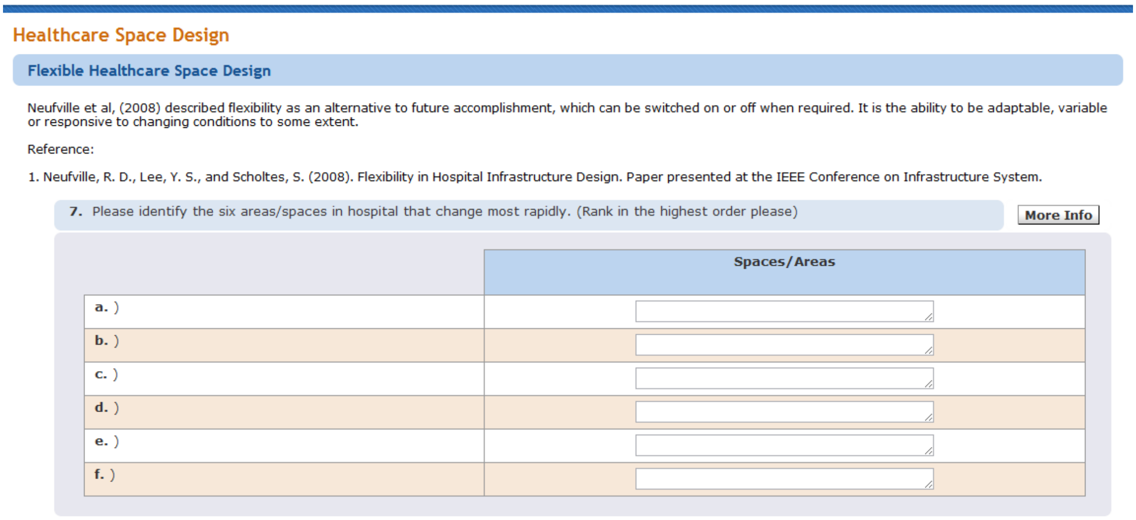
	Your involvement	
	Some extent	**Frequently**
a. Commercial	☐	☐
b. Industrial	☐	☐
c. Residential	☐	☐
d. Institutional	☐	☐
e. Healthcare	☐	☐

6. Please state your main roles in any of the following type of projects. For example Chief Architect

	Roles
a. Commercial	
b. Industrial	
c. Residential	
d. Institutional	
e. Healthcare	
f. Other	

Continue >

Survey testing only
Check Answers & Continue >



Healthcare Space Design

Flexible Healthcare Space Design

Neufville et al, (2008) described flexibility as an alternative to future accomplishment, which can be switched on or off when required. It is the ability to be adaptable, variable or responsive to changing conditions to some extent.

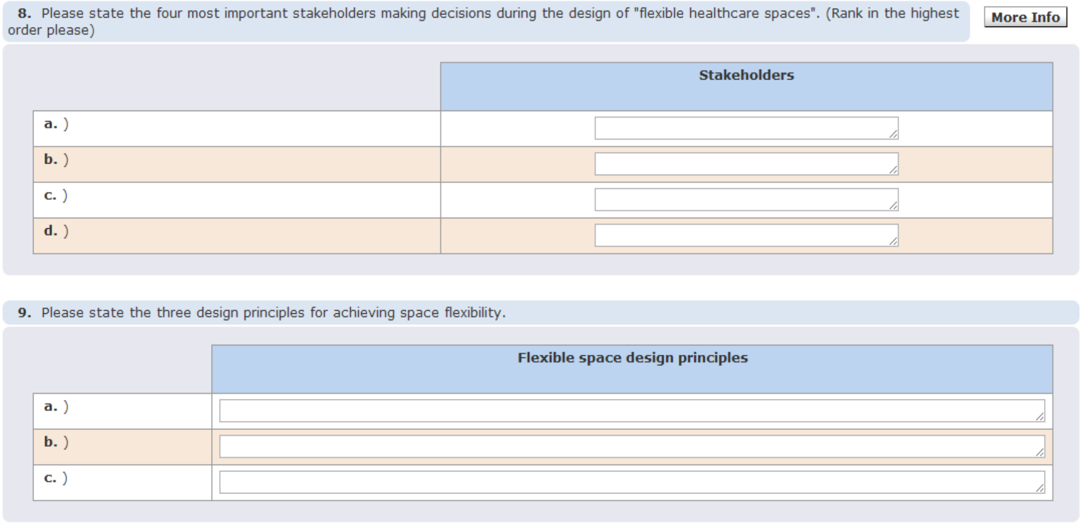
Reference:

1. Neufville, R. D., Lee, Y. S., and Scholtes, S. (2008). Flexibility in Hospital Infrastructure Design. Paper presented at the IEEE Conference on Infrastructure System.

7. Please identify the six areas/spaces in hospital that change most rapidly. (Rank in the highest order please)

More Info

	Spaces/Areas
a.)	
b.)	
c.)	
d.)	
e.)	
f.)	

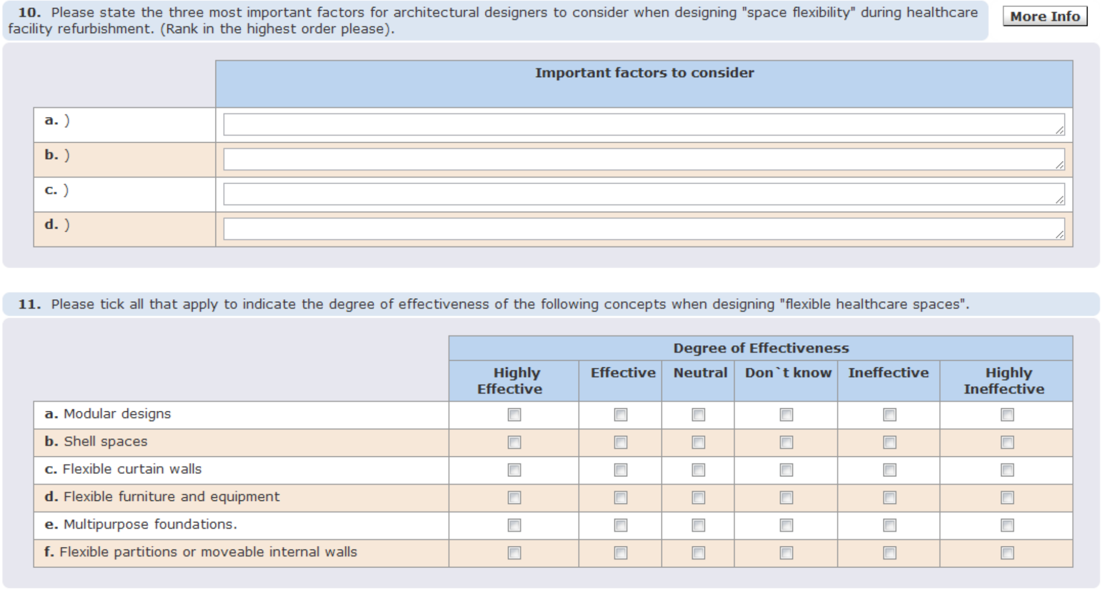


8. Please state the four most important stakeholders making decisions during the design of "flexible healthcare spaces". (Rank in the highest order please)

	Stakeholders
a.)	
b.)	
c.)	
d.)	

9. Please state the three design principles for achieving space flexibility.

	Flexible space design principles
a.)	
b.)	
c.)	

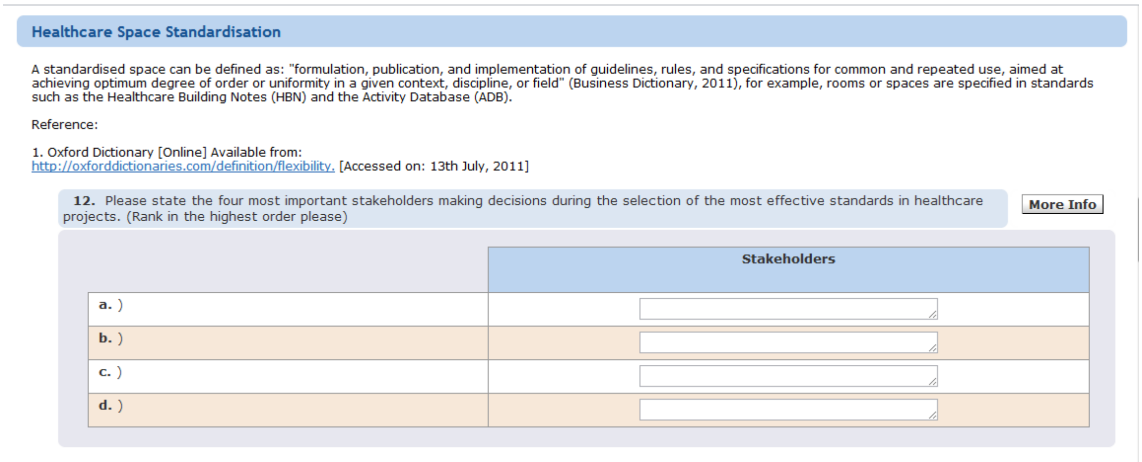


10. Please state the three most important factors for architectural designers to consider when designing "space flexibility" during healthcare facility refurbishment. (Rank in the highest order please).

	Important factors to consider
a.)	
b.)	
c.)	
d.)	

11. Please tick all that apply to indicate the degree of effectiveness of the following concepts when designing "flexible healthcare spaces".

	Degree of Effectiveness					
	Highly Effective	Effective	Neutral	Don`t know	Ineffective	Highly Ineffective
a. Modular designs	☐	☐	☐	☐	☐	☐
b. Shell spaces	☐	☐	☐	☐	☐	☐
c. Flexible curtain walls	☐	☐	☐	☐	☐	☐
d. Flexible furniture and equipment	☐	☐	☐	☐	☐	☐
e. Multipurpose foundations.	☐	☐	☐	☐	☐	☐
f. Flexible partitions or moveable internal walls	☐	☐	☐	☐	☐	☐



Healthcare Space Standardisation

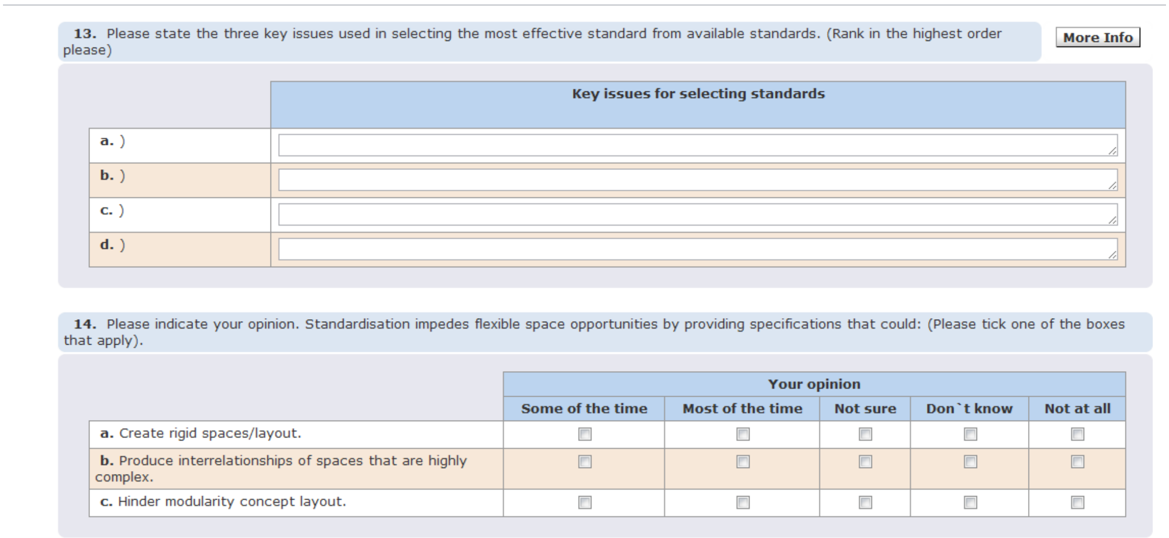
A standardised space can be defined as: "formulation, publication, and implementation of guidelines, rules, and specifications for common and repeated use, aimed at achieving optimum degree of order or uniformity in a given context, discipline, or field" (Business Dictionary, 2011), for example, rooms or spaces are specified in standards such as the Healthcare Building Notes (HBN) and the Activity Database (ADB).

Reference:

1. Oxford Dictionary [Online] Available from:
http://oxforddictionaries.com/definition/flexibility. [Accessed on: 13th July, 2011]

12. Please state the four most important stakeholders making decisions during the selection of the most effective standards in healthcare projects. (Rank in the highest order please)

	Stakeholders
a.)	
b.)	
c.)	
d.)	

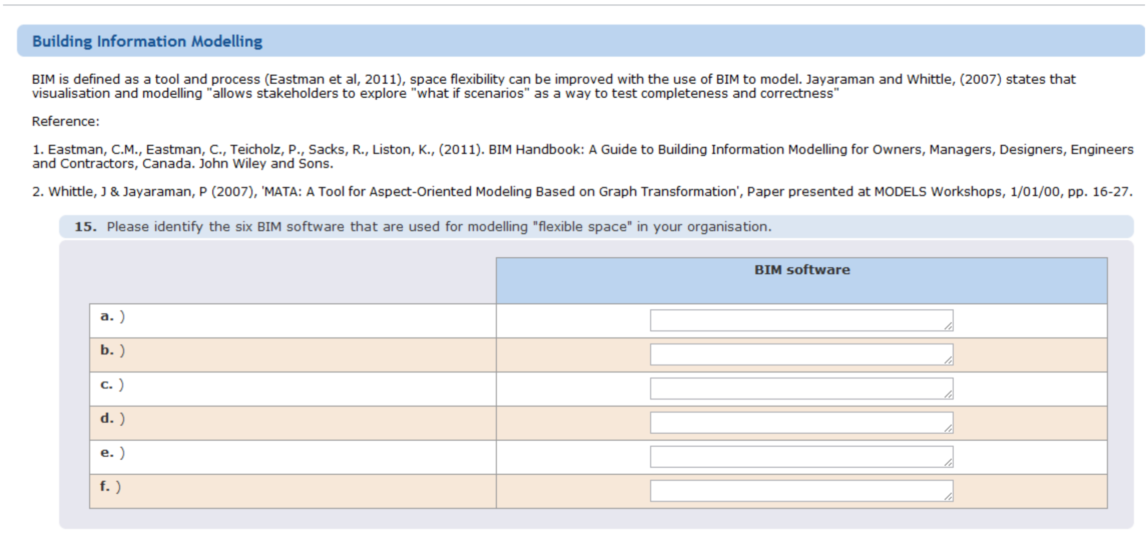


13. Please state the three key issues used in selecting the most effective standard from available standards. (Rank in the highest order please)

	Key issues for selecting standards
a.)	
b.)	
c.)	
d.)	

14. Please indicate your opinion. Standardisation impedes flexible space opportunities by providing specifications that could: (Please tick one of the boxes that apply).

	Your opinion				
	Some of the time	Most of the time	Not sure	Don`t know	Not at all
a. Create rigid spaces/layout.	☐	☐	☐	☐	☐
b. Produce interrelationships of spaces that are highly complex.	☐	☐	☐	☐	☐
c. Hinder modularity concept layout.	☐	☐	☐	☐	☐



Building Information Modelling

BIM is defined as a tool and process (Eastman et al, 2011), space flexibility can be improved with the use of BIM to model. Jayaraman and Whittle, (2007) states that visualisation and modelling "allows stakeholders to explore "what if scenarios" as a way to test completeness and correctness"

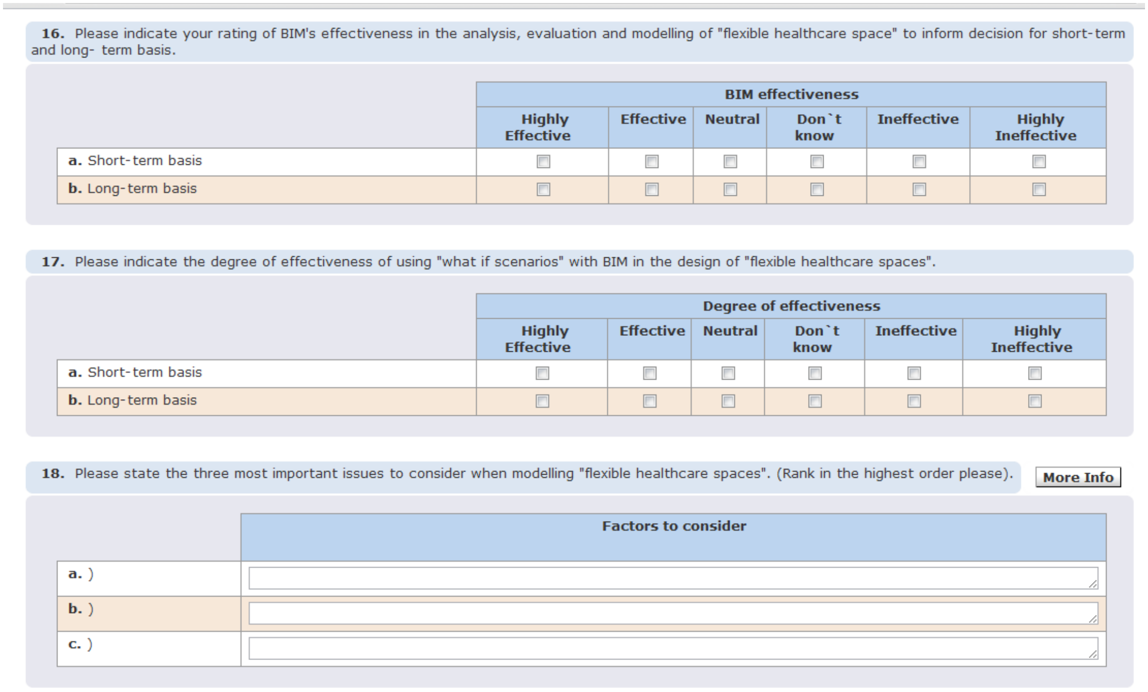
Reference:

1. Eastman, C.M., Eastman, C., Teicholz, P., Sacks, R., Liston, K., (2011). BIM Handbook: A Guide to Building Information Modelling for Owners, Managers, Designers, Engineers and Contractors, Canada. John Wiley and Sons.

2. Whittle, J & Jayaraman, P (2007), 'MATA: A Tool for Aspect-Oriented Modeling Based on Graph Transformation', Paper presented at MODELS Workshops, 1/01/00, pp. 16-27.

15. Please identify the six BIM software that are used for modelling "flexible space" in your organisation.

	BIM software
a.)	
b.)	
c.)	
d.)	
e.)	
f.)	



16. Please indicate your rating of BIM's effectiveness in the analysis, evaluation and modelling of "flexible healthcare space" to inform decision for short-term and long- term basis.

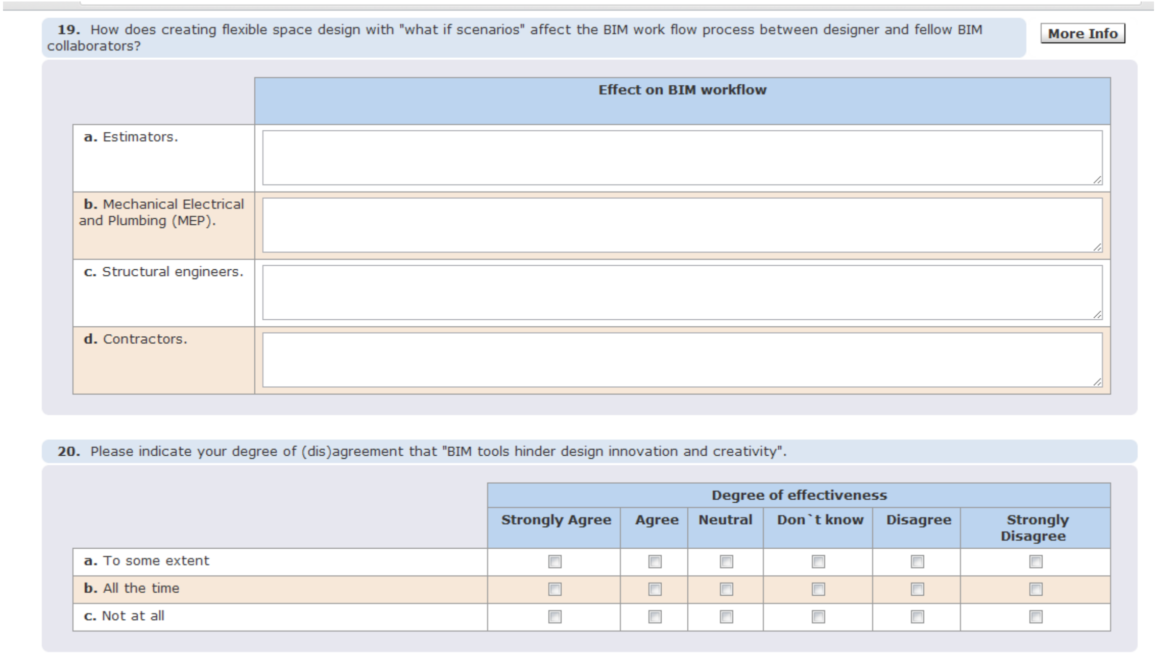
	BIM effectiveness					
	Highly Effective	Effective	Neutral	Don`t know	Ineffective	Highly Ineffective
a. Short-term basis	☐	☐	☐	☐	☐	☐
b. Long-term basis	☐	☐	☐	☐	☐	☐

17. Please indicate the degree of effectiveness of using "what if scenarios" with BIM in the design of "flexible healthcare spaces".

	Degree of effectiveness					
	Highly Effective	Effective	Neutral	Don`t know	Ineffective	Highly Ineffective
a. Short-term basis	☐	☐	☐	☐	☐	☐
b. Long-term basis	☐	☐	☐	☐	☐	☐

18. Please state the three most important issues to consider when modelling "flexible healthcare spaces". (Rank in the highest order please).

	Factors to consider
a.)	
b.)	
c.)	

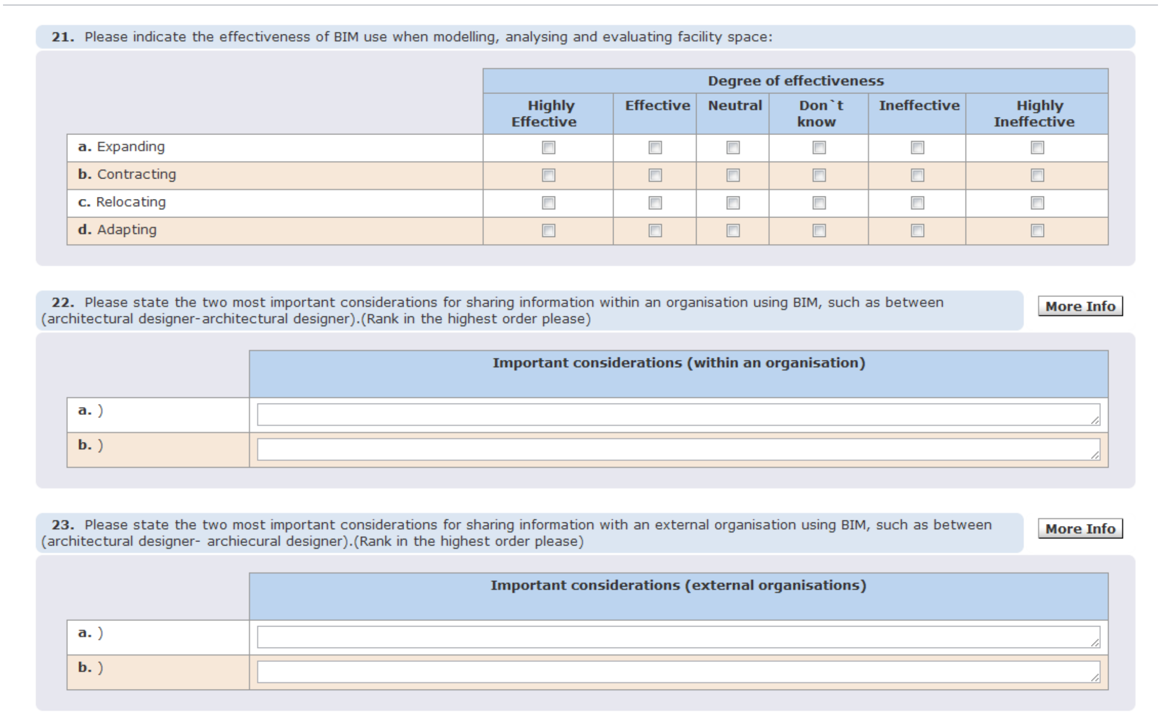


19. How does creating flexible space design with "what if scenarios" affect the BIM work flow process between designer and fellow BIM collaborators?

	Effect on BIM workflow
a. Estimators.	
b. Mechanical Electrical and Plumbing (MEP).	
c. Structural engineers.	
d. Contractors.	

20. Please indicate your degree of (dis)agreement that "BIM tools hinder design innovation and creativity".

	Degree of effectiveness					
	Strongly Agree	Agree	Neutral	Don`t know	Disagree	Strongly Disagree
a. To some extent	☐	☐	☐	☐	☐	☐
b. All the time	☐	☐	☐	☐	☐	☐
c. Not at all	☐	☐	☐	☐	☐	☐



21. Please indicate the effectiveness of BIM use when modelling, analysing and evaluating facility space:

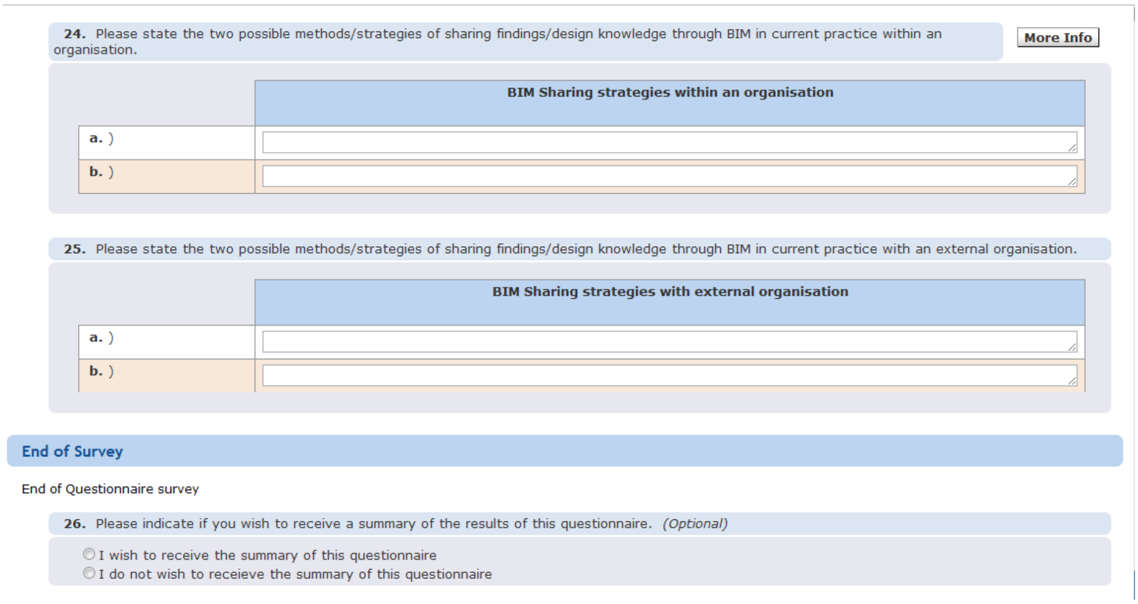
	Degree of effectiveness					
	Highly Effective	Effective	Neutral	Don`t know	Ineffective	Highly Ineffective
a. Expanding	☐	☐	☐	☐	☐	☐
b. Contracting	☐	☐	☐	☐	☐	☐
c. Relocating	☐	☐	☐	☐	☐	☐
d. Adapting	☐	☐	☐	☐	☐	☐

22. Please state the two most important considerations for sharing information within an organisation using BIM, such as between (architectural designer-architectural designer).(Rank in the highest order please)

	Important considerations (within an organisation)
a.)	
b.)	

23. Please state the two most important considerations for sharing information with an external organisation using BIM, such as between (architectural designer- archiecural designer).(Rank in the highest order please)

	Important considerations (external organisations)
a.)	
b.)	



24. Please state the two possible methods/strategies of sharing findings/design knowledge through BIM in current practice within an organisation.

	BIM Sharing strategies within an organisation
a.)	
b.)	

25. Please state the two possible methods/strategies of sharing findings/design knowledge through BIM in current practice with an external organisation.

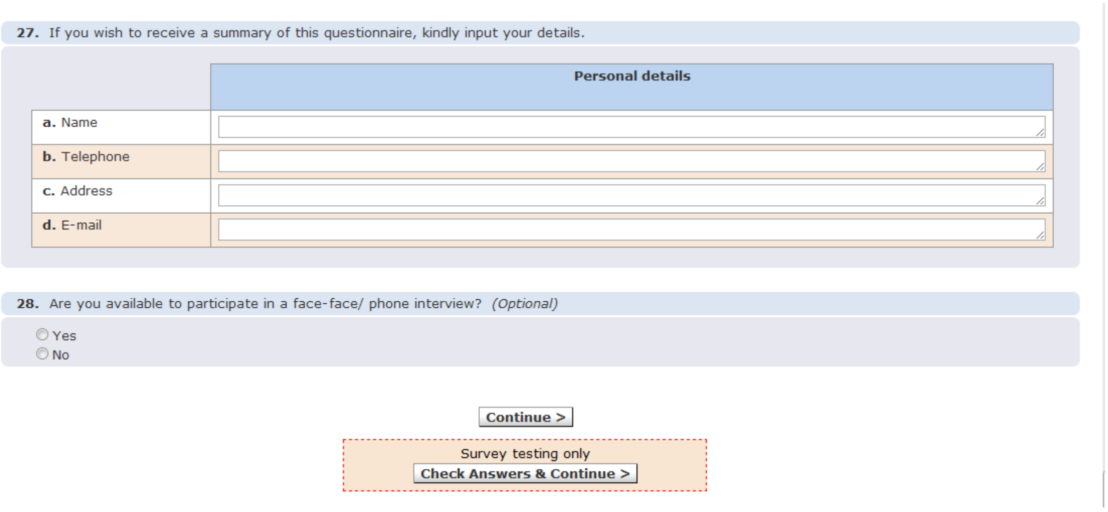
	BIM Sharing strategies with external organisation
a.)	
b.)	

End of Survey

End of Questionnaire survey

26. Please indicate if you wish to receive a summary of the results of this questionnaire. *(Optional)*

○ I wish to receive the summary of this questionnaire
○ I do not wish to receieve the summary of this questionnaire



27. If you wish to receive a summary of this questionnaire, kindly input your details.

	Personal details
a. Name	
b. Telephone	
c. Address	
d. E-mail	

28. Are you available to participate in a face-face/ phone interview? *(Optional)*

○ Yes
○ No

Survey testing only

APPENDIX 8: INTERVIEW INVITATION LETTER

Flexible space design with BIM for healthcare built environments in the UK

Participant Information Sheet

Researcher:
Ahmad Mohammad Ahmad
(A.M.Ahmad@lboro.ac.uk)

Supervisors:
Professor Andrew Price
Dr Peter Demian

School of Civil and Building Engineering, Loughborough University

Purpose of the study

We wish to explore with you effective practices for selecting either a standardised or innovative approach to flexible design. In particular, we want to understand better:

- The process;
- The role of designer; and
- Building information modelling (BIM) in embedding flexibility in healthcare buildings, while optimising the efficiency of space.

Key objectives:

Key facets will be explored to:

A. Better understand the decision-making process.
B. Capture the rationale for justifying a specific flexible design solution from various alternative designs (identifying: requirements, key factors, participants, activities, and standards/guidance or an innovative approach).
C. Highlight the effective process for analysing multiple “what if scenarios” with BIM.
D. Identify any success or failure.

E. Explore stakeholders' collaboration for effective implementation of flexibility design strategies with BIM.

Data collection method

Interview-

A detailed discussion with Architects/healthcare planners/healthcare managers will identify components or building systems/processes established where the design is successful or possess further opportunity for improvement and resulted from innovative and standardised approaches.

Who would participate?

Representative from the hospital trust, facility operator, architect/designer or healthcare planner will be invited to participate.

Why were you considered to participate?

With the state of the art healthcare delivery of your esteem firm, and high level of experience and successfully conducted projects in healthcare; you are invited to participate in this research.

Why participate?

- This would be a great opportunity for a robust discussion about their project and learn things out of it.
- This would also be a great opportunity explore possible flexibility solutions.
- Contributions will be used to improve current flexibility strategies.

What will happen to the results of the study?

Results will drive the direction of this research and will be included into a PhD thesis and in peer reviewed journal papers.

Kind regards,

Ahmad Mohammad Ahmad
Research Student
Tel: 009447767757705
Email: a.m.ahmad@lboro.ac.uk
Health and Care Infrastructure Research and Innovation Centre (HaCIRIC)
Loughborough University, UK.

APPENDIX 9: PARAMETERS FOR DESIGN OPTION SELECTION

Flexible design with BIM in the UK healthcare built environment:

Selection Parameters

Researcher:
Ahmad Mohammad Ahmad (contact: A.M.Ahmad@lboro.ac.uk or 07767757705)
Supervisors:
Professor Andrew Price
Dr Peter Demian

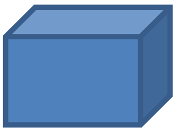
School of Civil and Building Engineering, Loughborough University

Instructions

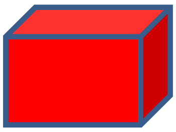
This study focuses on flexible design parameters that could help client and designers to select the most appropriate design within the different design options generated.

<u>One Design Brief</u>

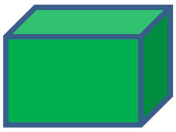
Three different design options



A



B



C

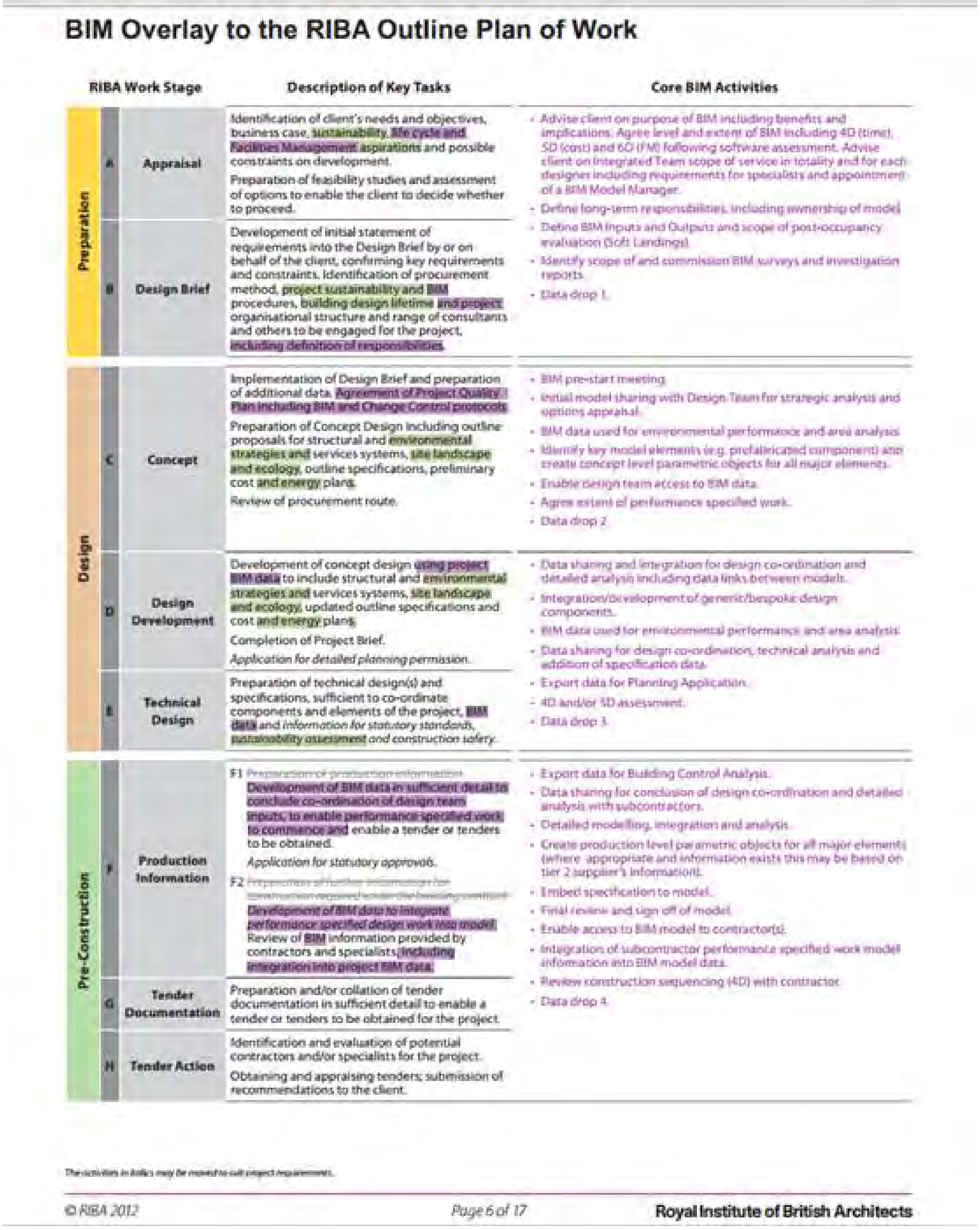
Kindly rate the parameters that can guide decision making for the selection of the most appropriate design option in a hierarchy order of 1 - 15

Flexible design selection parameters for cost effectiveness and efficiency				
Flexibility parameters	**Reference**	**Hierarchy order**	**Comments**	**Focus**
Type of flexibility: e.g.; expanding, contracting, adapting,	Pati et al, (2008). Cleveland clinic			Design feature
Classification of flexibility: Long-term/mid-term/short-term	Pati et al, (2008)			Design feature
Area of core spaces (primary +secondary space)	Kazanasmaz, (2006) Ilozor, (2001)			Operational management feature
Area of primary space (served area)	Kazanasmaz, (2006)			Operational management feature
Area of secondary space (serving area)	Kazanasmaz, (2006)			Operational management feature
Area of non-core spaces (circulation space)	Ilozor, (2001)			Design feature
Area of income generating space	Author			Operational management feature
Area of non-income generating space	Author			Design feature
Cost of entire building option	Cleveland clinic			Design feature
Cost of embedding flexibility	Cleveland clinic			Design feature
Number of flexible partitions	Author			Design feature
Number of functions design option adapts to (variety of scenarios)	Author			Operational management feature
Capacity of building	Author			Design feature
Percentage of natural lighting	Author			Design management feature
Design efficiency = core area/total building area	Ilzor, (2001)/ Hofer and Schendel, (1978)/ Hardy and Lammers, (1986)			Design feature

APPENDIX 10: KEY TERMINOLOGIES USED IN THIS RESEARCH

Terminology	Reference	Meaning
Proposed building	Author	Future, projected and recommended plan of a building
Guideline	Campbell *et al*. (2002)	Systematically developed statements to assist practitioners and patient decisions prospectively for specific clinical circumstances; in essence the “right thing to do”.
Healthcare refurbishment	Palgrave (2011, p. 5)	Extending the useful life of existing of buildings through the adaptation of their basic forms to provide a new or updated version of the original structure.
Healthcare facility	Author	A facility that provides accommodation for healthcare services to be delivered to the general public.
Interoperability	Succar (2009, p. 363)	The ability of two or more systems or components to exchange information and to use the information that has been exchanged.
Space flexibility	Author	A space that adapts to changes with time, requirement or needs.
Space standardisation	Price and Lu (2012)	A space that has ergonomics specification, modular units, standardised room with similar sizes, pattern and modular detailing.
Standard	Campbell *et al*. (2002)	The level of compliance with a criterion or indicator.
Existing facilities	Author	Current, standing constructed or remains of a building.
BIM maturity levels	UK Government Construction Strategy (2011, p.16)	Devised to ensure clear articulation of the levels of competency expected and the supporting standards and guidance notes.
Integrated project delivery	Dykstra (2011, p. 86)	A project delivery method in which all primary team members are brought on board at the same time (during design).
Delivery method	Dykstra (2011, p. 86)	The organisational structure for completing a project.
D and B	Dykstra (2011, p. 86)	A delivery method in which the owner has one contract with a single construction / design firm.
Traditional design method	Dykstra (2011, p. 86)	A delivery method which the GC is hired at the completion of design.
Adaptability	Tompkins *et al.* (2010)	This means taking into consideration the implications of calendars, cycles and peaks in facilities use
Flexibility	Tompkins *et al.* (2010)	They are able to handle a variety of requirements without being altered.
Modularity	Tompkins *et al*. (2010)	Those with systems that cooperate efficiently over a wide range of operating rates.

APPENDIX 11: RIBA PLAN OF WORK WITH BIM OVERLAY



BIM Overlay to the RIBA Outline Plan of Work

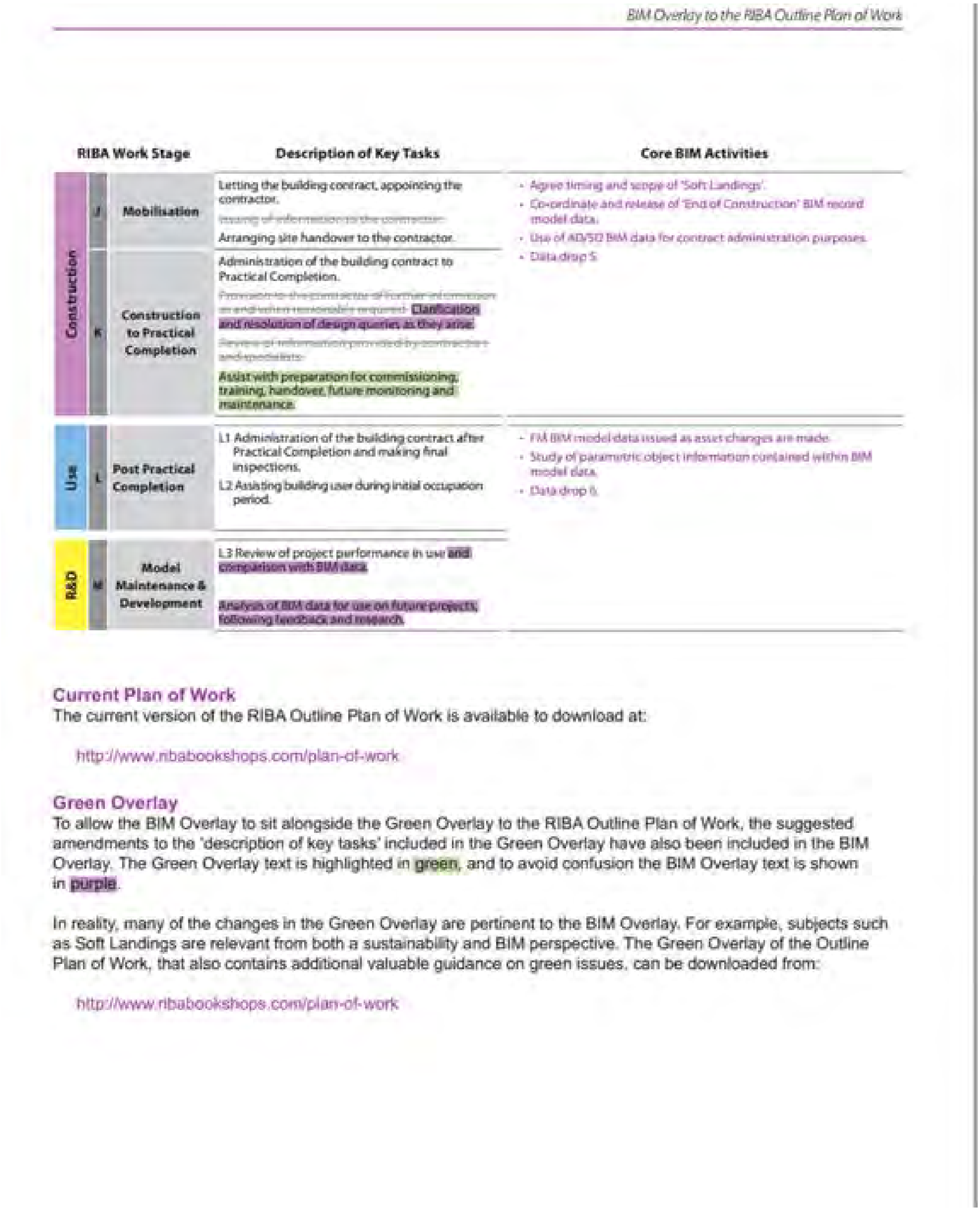
RIBA Work Stage			Description of Key Tasks	Core BIM Activities
Preparation	A	**Appraisal**	Identification of client's needs and objectives, business case, sustainability, life cycle and Facilities Management aspirations and possible constraints on development. Preparation of feasibility studies and assessment of options to enable the client to decide whether to proceed.	- Advise client on purpose of BIM including benefits and implications. Agree level and extent of BIM including 4D (time), 5D (cost) and 6D (FM) following software assessment. Advise client on Integrated Team scope of service in totality and for each designer including requirements for specialists and appointment of a BIM Model Manager. - Define long-term responsibilities, including ownership of model. - Define BIM Inputs and Outputs and scope of post-occupancy evaluation (Soft Landings). - Identify scope of and commission BIM surveys and investigation reports. - Data drop 1.
	B	**Design Brief**	Development of initial statement of requirements into the Design Brief by or on behalf of the client, confirming key requirements and constraints. Identification of procurement method, project sustainability and BIM procedures, building design lifetime and project organisational structure and range of consultants and others to be engaged for the project, including definition of responsibilities.	
Design	C	**Concept**	Implementation of Design Brief and preparation of additional data. Agreement of Project Quality Plan including BIM and Change Control protocols. Preparation of Concept Design including outline proposals for structural and environmental strategies and services systems, site landscape and ecology, outline specifications, preliminary cost and energy plans. Review of procurement route.	- BIM pre-start meeting. - Initial model sharing with Design Team for strategic analysis and options appraisal. - BIM data used for environmental performance and area analysis. - Identify key model elements (e.g. prefabricated component) and create concept level parametric objects for all major elements. - Enable design team access to BIM data. - Agree extent of performance specified work. - Data drop 2.
	D	**Design Development**	Development of concept design using project BIM data to include structural and environmental strategies and services systems, site landscape and ecology, updated outline specifications and cost and energy plans. Completion of Project Brief. *Application for detailed planning permission.*	- Data sharing and integration for design co-ordination and detailed analysis including data links between models. - Integration/development of generic/bespoke design components. - BIM data used for environmental performance and area analysis. - Data sharing for design co-ordination, technical analysis and addition of specification data. - Export data for Planning Application. - 4D and/or 5D assessment. - Data drop 3.
	E	**Technical Design**	Preparation of technical design(s) and specifications, sufficient to co-ordinate components and elements of the project, BIM data and *information for statutory standards,* *sustainability assessment and construction safety.*	
Pre-Construction	F	**Production Information**	F1 ~~Preparation of production information~~ Development of BIM data in sufficient detail to conclude co-ordination of design team inputs, to enable performance specified work to commence and enable a tender or tenders to be obtained. *Application for statutory approvals.* F2 ~~Preparation of further information for construction required under the building contract.~~ *Development of BIM data to integrate performance specified design work into model.* Review of BIM information provided by contractors and specialists, including integration into project BIM data.	- Export data for Building Control Analysis. - Data sharing for conclusion of design co-ordination and detailed analysis with subcontractors. - Detailed modelling, integration and analysis. - Create production level parametric objects for all major elements (where appropriate and information exists this may be based on tier 2 supplier's information). - Embed specification to model. - Final review and sign off of model. - Enable access to BIM model to contractor(s). - Integration of subcontractor performance specified work model information into BIM model data. - Review construction sequencing (4D) with contractor. - Data drop 4.
	G	**Tender Documentation**	Preparation and/or collation of tender documentation in sufficient detail to enable a tender or tenders to be obtained for the project.	
	H	**Tender Action**	Identification and evaluation of potential contractors and/or specialists for the project. Obtaining and appraising tenders; submission of recommendations to the client.	

The activities in italics may be moved to suit project requirements.

© RIBA 2012

Page 6 of 17

Royal Institute of British Architects



RIBA Work Stage			Description of Key Tasks	Core BIM Activities
Construction	**J**	**Mobilisation**	Letting the building contract, appointing the contractor. ~~Issuing of information to the contractor.~~ Arranging site handover to the contractor.	- Agree timing and scope of 'Soft Landings'. - Co-ordinate and release of 'End of Construction' BIM record model data. - Use of 4D/5D BIM data for contract administration purposes. - Data drop 5.
	K	**Construction to Practical Completion**	Administration of the building contract to Practical Completion. ~~Provision to the contractor of further information as and when reasonably required.~~ Clarification and resolution of design queries as they arise. ~~Review of information provided by contractors and specialists.~~ Assist with preparation for commissioning, training, handover, future monitoring and maintenance.	
Use	**L**	**Post Practical Completion**	L1 Administration of the building contract after Practical Completion and making final inspections. L2 Assisting building user during initial occupation period.	- FM BIM model data issued as asset changes are made. - Study of parametric object information contained within BIM model data. - Data drop 6.
R&D	**M**	**Model Maintenance & Development**	L3 Review of project performance in use and comparison with BIM data. Analysis of BIM data for use on future projects, following feedback and research.	

Current Plan of Work

The current version of the RIBA Outline Plan of Work is available to download at:

http://www.ribabookshops.com/plan-of-work

Green Overlay

To allow the BIM Overlay to sit alongside the Green Overlay to the RIBA Outline Plan of Work, the suggested amendments to the 'description of key tasks' included in the Green Overlay have also been included in the BIM Overlay. The Green Overlay text is highlighted in green, and to avoid confusion the BIM Overlay text is shown in purple.

In reality, many of the changes in the Green Overlay are pertinent to the BIM Overlay. For example, subjects such as Soft Landings are relevant from both a sustainability and BIM perspective. The Green Overlay of the Outline Plan of Work, that also contains additional valuable guidance on green issues, can be downloaded from:

http://www.ribabookshops.com/plan-of-work