# DEVELOPING BUILDING DESIGN RESILIENCE STRATEGIES TO CLIMATE CHANGE RISKS

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By

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## ABSTRACT

A resilient building design assessment tool is developed and presented to assist architects in preparing designs to meet the challenges of climate change. The tool incorporates a set of resilience factors that have been selected as a result of information gathered from an extensive literature review (from 1980 on) and a detailed questionnaire sent out to a sample of architects working in the field, together with a statistical analysis of the collected data.

Climate change poses the built environment with an increasing threat of more frequent and severe meteorological events, including heavy precipitation, flooding, powerful storms and winds, lengthy and intense heat waves, and globally rising temperatures. The literature review revealed that there have as yet been few attempts to develop systematically models that integrate climate change risks (CCRs) with corresponding resilience factors in order that CCR resilience can be included in all aspects of a building and its site from the outset.

The methodology adopted in this research is based on a critical analysis of the literature and the development of a prototype assessment model. Central to the success of this model is the capture of a set of resilience factors (SFs). As a first step, the researcher clustered climate change risks (CCRs) into four categories: physical, social, economic and management. Next, six aspects of resilience as applied to buildings were identified: site, layout, structure, envelope, system and operation. To ensure that appropriate resilience factors were chosen and incorporated into the model, the author extracted the most relevant factors from the review and divided them among the six key building aspects. In total 85 SFs were incorporated into the model.

A questionnaire was prepared and sent out to a large number of practicing and academic architects of differing levels of experience. A statistical analysis of the replies, which included a scoring by the respondents of the effectiveness of each resilience factor, was used to refine and reduce the number of resilience factors, to 28, for inclusion in the assessment tool. The tool was then trialled on three projects to demonstrate its capabilities and effectiveness in assessing the resilience of a building against CCRs. It is hoped that the tool described here will, with further refinements and improvements, become a practical aid to architects faced with designing buildings in a world of increasingly severe hydro-meteorological events.

# DECLARATION

I hereby declare that this is my own work and effort and that it has not been submitted anywhere for any award. Where other sources of information have been used, they have been acknowledged.

Signed …………………………………….......

Date ……………………………………………

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# Table of Contents

ABSTRACT ........ 2

ACKNOWLEDGEMENTS ........ 4

List of Abbreviations ........ 18

1 Chapter 1: Research Plan ........ 19

1.1 Introduction ........ 19

1.2 Rationale of this study and problem statement ........ 20

1.3 Research questions ........ 22

1.4 Research hypotheses ........ 22

1.5 Aim and objectives of this study ........ 23

1.5.1 Aim of the research ........ 23

1.5.2 Objectives of the research ........ 23

1.6 Scope of the study ........ 24

1.7 Significance of the study ........ 24

1.8 Definition of terms ........ 25

1.9 Methodology ........ 26

1.10 Outline of the thesis ........ 26

1.11 Summary ........ 30

2 Chapter 2: Research Methodology ........ 31

2.1 Introduction ........ 31

2.2 Research methodology theory ........ 32

2.3 Qualitative: critical literature review ........ 32

2.4 Quantitative: questionnaire design ........ 32

2.5 Rational for designing the survey ........ 33

2.6 Research method process ........ 34

2.6.1 Task 1: Initial research ........ 35

2.6.2 Task 2: Literature review ........ 35

2.6.3 Task 3: Questionnaire design and development ....40

2.6.4 Task 4: Data collection and analysis ....45

2.6.5 Task 5: Design Resilience Strategy Assessment tool ....46

2.6.6 Sub-task: Development of the Design Resilience Strategy Assessment tool ....46

2.6.7 Sub-task: Testing the tool ....46

2.6.8 Task 6: Discussion and conclusion chapter ....46

2.7 Summary ....47

3 Chapter 3: Climate Change Overview ....48

3.1 Introduction ....48

3.2 Evidence for anthropogenic climate change ....48

3.3 Events associated with climate ....50

3.4 Events associated with climate change ....52

3.4.1 Temperature extremes ....52

3.4.2 Precipitation ....52

3.4.3 Wind storms ....53

3.4.4 Sea-level rise ....53

3.4.5 Floods ....54

3.5 Summary ....55

4 Chapter 4: Climate Change Risks ....56

4.1.1 Introduction ....56

4.2 Built environment ....56

4.3 Climate change and the risks to buildings ....58

4.4 Classification of types of risks of climate change on buildings ....58

4.4.1 Classifications used in earlier studies ....58

4.4.2 Classification of climate change risks for buildings used in this research ....60

4.5 Risks of climate change on buildings ....61

4.5.1 Physical risks ....61

4.5.2 Economic risks from climate change ....72

4.5.3 Social risks from climate change ....76

4.5.4 Management risks from climate change on buildings ....81

4.5.5 Summary ....83

5 Chapter 5: Resilience Overview ....84

5.1 Introduction to resilience ....84

5.1.1 Concept of resilience ....84

5.1.2 Definitions of resilience ....84

5.2 Definition of resilience used in this research ....89

5.3 Resilience characteristics ....89

5.3.1 Robustness ....89

5.3.2 Redundancy ....89

5.3.3 Capacity for adaptation ....90

5.3.4 Environmental responsiveness ....90

5.4 Importance of a building's resilience ....91

5.5 Summary ....91

6 Chapter 6: Resilience Strategies ....92

6.1 Introduction ....92

6.2 Resilience design strategies ....92

6.3 Classification of resilience design strategies ....93

6.3.1 Site resilience design strategies ....94

6.3.2 Layout resilience design strategies ....98

6.3.3 Structure resilience design strategies ....104

6.3.4 Envelope resilience design strategies ....109

6.3.5 System resilience design strategies ....121

6.3.6 Operation resilience design strategies ....128

6.4 Summary ....130

7 Chapter 7: Mapping CCR to SFs ....................131

7.1 Introduction ....................131

7.2 Mapping of site resilience factors to climate change risks ....................132

7.3 Mapping of layout resilience factors to climate change risks ....................133

7.4 Mapping of structure resilience factors to climate change risks ....................134

7.5 Mapping of envelope resilience factors to climate change risks ....................136

7.6 Mapping of system resilience factors to climate change risks ....................138

7.7 Mapping of operation resilience factors to climate change risks ....................139

7.8 Physical risks and design building resilience strategies ....................141

7.9 Economic risks and design building resilience strategies ....................142

7.10 Social risks and design building resilience strategies ....................142

7.11 Management risks and design building resilience strategies ....................143

7.12 Building resilience characteristics and corresponding resilience factors ....................144

7.13 Summary ....................148

8 Chapter 8: Design Resilience Strategic Conceptual Model ....................149

8.1 Introduction ....................149

8.2 Components of the Model ....................149

8.3 Building Design Resilience Strategies ....................150

8.4 Compounds of building design resilience ....................151

8.4.1 Site design ....................151

8.4.2 Building layout design ....................153

8.4.3 Building structure design ....................155

8.4.4 Building envelope design ....................158

8.4.5 Building systems ....................160

8.4.6 Building operation ....................162

8.5 Resilience assessment ....................163

8.5.1 Robustness: ....................164

8.5.2 Redundancy: ....................................................................................164
8.5.3 Capacity for adaptation: ....................................................................165
8.5.4 Environmental responsiveness: ..........................................................165
8.6 Implementing the conceptual model ....................................................166
8.6.1 Preparation of the Resilience Brief .....................................................167
8.6.2 Resilience Design solutions ................................................................167
8.6.3 Assessment the of the design solutions to resilience ...........................169
8.7 Summary ..................................................................................................170
9 Chapter 9: Findings and Descriptive Analysis ............................................171
9.1 Introduction ..............................................................................................171
9.2 Restatement of the problem of the study .................................................171
9.3 Restatement of the research hypotheses ..................................................171
9.3.1 General architect perception ..............................................................171
9.3.2 Building resilience design attributes ...................................................172
9.3.3 Current practice ...................................................................................174
9.3.4 Description of participants' information .............................................175
9.3.5 Reliability Statistic ..............................................................................176
9.3.6 Questionnaire analysis ........................................................................177
9.4 Summary of this Chapter ..........................................................................201
10 Chapter 10: Ranking the Findings ..............................................................202
10.1 Introduction ............................................................................................202
10.2 Methodology ..........................................................................................202
10.3 Ranking and analysis of building resilience design factors ...................204
10.4 Ranking data based on experience and professional role .....................205
10.4.1 Site design resilience strategies ........................................................205
10.4.2 Layout design resilience strategies ....................................................206
10.4.3 Structure design resilience strategies .................................................207

10.4.4 Envelope design resilience strategies....209

10.4.5 System design resilience strategies....211

10.4.6 Operation design resilience strategies....212

10.5 Conclusion of overall ranking....213

10.6 Average severity indices of resilience building design aspects....215

10.7 Summary....216

11 Chapter 11: Hypothesis and Reliability Testing....217

11.1 Introduction....217

11.2 Method....217

11.3 Analysis of participants' responses based on their professional role....218

11.3.1 Site design resilience strategies....219

11.3.2 Layout design resilience strategies....219

11.3.3 Structure design resilience strategies....220

11.3.4 Envelope design resilience strategies....222

11.3.5 System design resilience strategies....223

11.3.6 Operation design resilience strategies....224

11.4 Analysis of participants' responses based on their experience....224

11.4.1 Site design resilience strategies....225

11.4.2 Layout design resilience strategies....225

11.4.3 Structure design resilience strategies....226

11.4.4 Envelope design resilience strategies....227

11.4.5 System design resilience strategies....227

11.4.6 Operation design resilience strategies....228

11.5 Discussion....229

11.6 Summary....230

12 Chapter 12: Design Resilience Strategic Assessment tool....231

12.1 Introduction....231

12.2 Review of existing assessment tools ....231

12.3 Comparisons ....232

12.4 Scoring system of other assessments ....235

12.5 Design quality indicator ....236

12.6 Data tool ....236

12.7 Developing the Design Resilience Strategy Assessment tool ....237

12.8 Scoring system ....237

12.9 Selection of factors ....238

12.10 Model testing ....239

12.11 Case studies ....240

12.11.1 Queens Court Project ....240

12.11.2 New Office for Unit Project in Portsmouth ....245

12.11.3 New Office for Unit Project in Stoke on Trent ....249

12.12 Implications and discussion ....253

12.13 Summary ....253

13 Chapter 13: Discussion ....254

13.1 Climate change ....254

13.1.1 Climate change risk classification ....255

13.2 Resilience characteristics classification ....255

13.3 Resilient design ....256

13.4 Mapping SFs to CCR ....256

13.5 Resilience building design conceptual model ....257

13.6 Data analysis discussion ....257

13.7 Comparing the results ....259

13.7.1 Ranking of site design resilience strategies ....259

13.7.2 Ranking of layout design resilience strategies ....260

13.7.3 Ranking of structure design resilience strategies ....261

13.7.4 Ranking of envelope design resilience strategies ....262

13.7.5 Ranking of system design resilience strategies ....263

13.8 Testing the hypotheses ....265

13.9 Resilience Building Design Assessment Tool ....267

13.10 The Issues That the Researcher Learned ....268

13.11 Implications ....269

13.12 Summary ....270

14 Chapter 14: Conclusions and Further Research ....271

14.1 Summary ....271

14.2 Contribution ....272

14.2.1 Climate change risks ....272

14.2.2 Design resilience strategies ....272

14.2.3 Mapping ....273

14.2.4 Building Design Resilience model ....273

14.2.5 Building Design Resilience assessment tool contribution ....273

14.2.6 Other contributions ....274

14.3 Limitations ....274

14.4 Recommendation and suggestions for further research ....275

14.5 Further research on the model: ....275

15 References ....276

16 Appendix A; Questionnaire ....296

17 Appendix B: Assessment Tool ....311

18 Appendix C: Publications ....314

19 Appendix D: Test Hypothesis ....315

20 Appendix F: Gephi Codes ....334

List of Figures

Figure 2-1: Research process. .......................................................... **Error! Bookmark not defined.**
Figure 2-2: Research process. ........................................................................................... 37
Figure 2-3: The process of the research methods to develop a building resilience design conceptual model. ......................................................................................................... 38
Figure 2-4: The total number of SFs. ................................................................................. 39
Figure 2-5: Sample of the first part of the design questionnaire. ....................................... 41
Figure 2-6: The second part of the design questionnaire collected personal information. ................. 42
Figure 2-7: Questionnaire design process. ........................................................................ 43
Figure 3-1: Climate events. .............................................................................................. 51
Figure 3-2: Global mean sea level between 1900 and 2001 (Church et al., 2004). ............................ 54
Figure 4-1: Main aspects of sustainability in the built environment (Lienert and Kropac, 2012). ....... 59
Figure 4-2: Main aspects of sustainability in the built environment (Design principles 2015) ........... 59
Figure 4-3: Impact of climate change on Canada’s forests (Williamson et al., 2009). ........................ 60
Figure 4-4: Classification of risks of climate change on aspects of buildings used in this research. ... 60
Figure 4-5: Main parts of a building as indicated by TURK Structure (2013). ................................. 62
Figure 4-6: The components of a building considered in the present study. ..................................... 62
Figure 4-7: Generalized schematic of storm surge heights relative to position, path and wind speeds of a tropical cyclone (Needham and Keim, 2011). ..................................................................... 63
Figure 4-8 Before storm, 2004 (USGS) ............................................................................. 65
Figure 4-9 Before storm, 2004 (USGS) ............................................................................. 65
Figure 4-10 Before storm, 2004 (USGS) ........................................................................... 65
Figure 4-11 After storm, 2004 (USGS) ............................................................................. 65
Figure 4-12 After storm, 2004 (USGS) ............................................................................. 65
Figure 4-13 After storm 2004 (USGS) ............................................................................... 65
Figure 4-14: Water incursion in a wall. Daniel et al. (2010). ............................................. 66
Figure 4-15: Difference in elevation between the water inside and outside of a structure (Munach, 2010). ............................................................................................................................ 69
Figure 4-16: Muncah (2010) Figure 4-17: Munach (2010) ................................................ 70
Figure 5-1: Characteristics of building’s resilience according to Bruneau et al. (2003). ................... 88
Figure 6-1: Classification of resilience design strategies. ................................................... 93
Figure 6-2: Different building orientations (Crobu, 2010). ................................................ 96
Figure 6-3: Elevating a building from flood. ..................................................................... 105
Figure 6-4: Improvements to building permeability (Keung, 2010). .................................. 106
Figure 6-5: Openings in the envelope for flood. ................................................................ 107
Figure 6-6: Use of removable flood barriers. ..................................................................... 107
Figure 6-7: Retaining walls. ............................................................................................. 108
Figure 6-8: Buildings with different forms (Sigg et al, 2006). ............................................ 113
Figure 6-9: Different types of shapes (Prom et al, 1989). ................................................... 114
Figure 6-10: Reduction of wind by shapes (Prom et al., 1989). .......................................... 114
Figure 7-1: Gephi map for site resilience factors and CCRs. .............................................. 133
Figure 7-2: Gephi map for layout resilience factors and CCRs. .......................................... 134

Figure 7-3: Gephi map for structure resilience factors and CCRs. ...................................................136
Figure 7-4; Gephi map for envelope resilience factors and CCRs....................................................137
Figure 7-5: Gephi map for system resilience factors and CCRs. .......................................................139
Figure 7-6; Gephi map for operation resilience factors and CCRs. ...................................................140
Figure 8-1: Building Design Resilience Conceptual Model ..............................................................150
Figure 8-2: Sub-Model Resilience Design Strategies' Dimensions ....................................................150
Figure 8-3..............................................................................................................................153
Figure 8-4..............................................................................................................................153
Figure 8-5: Sub-Model Site Design Dimension..................................................................................153
Figure 8-6: Sub-Model Building layout design Dimension.................................................................154
Figure 8-7: Elevate structure above flood level (Federal Emergency Management Agency (FEMA). 2014). ......................................................................................................................157
Figure 8-8: Sub-Model Building structure design dimension..............................................................157
Figure 8-9: Sub-Model Building envelope design Dimension ............................................................159
Figure 8-10: Cool or reflective roofing materials. (Hertfordshire County Council 2013).................160
Figure 8-11: Protect the main electrical system from drowning (Clay Nesler , 2012). ......................161
Figure 8-12: Sub-Model Building systems Dimension......................................................................162
Figure 8-13: Sub-Model Building operation Dimension ...................................................................163
Figure 8-14: Sub-Model Evaluation Process. ....................................................................................164
Figure 8-15: Application process of the conceptual model. ..............................................................167
Figure 10-1: The survey hierarchy.....................................................................................................202
Figure 10-2: Resilience building design aspects and sub-aspects......................................................203
Figure 10-3: Average severity indices of resilience building design aspects: 1 = resilience design site, 2 = resilience design layout, 3 = resilience design structure, 4 = resilience design envelope, 5 = resilience design system and 6 = resilience design operation............................................................215
Figure 12-1: Outline of AECOM tool methodology (Hughes and Healy 2014)................................233
Figure 12-2: Part of EVOLVE tool (Housing LIN, 2014). .................................................................234
Figure 12-3: The details of section of DQI (Gann et al., 2003). ........................................................237
Figure 12-4: Implementation rating of the assessment tool for this research. ...................................238
Figure 12-5: Queens Court Project (Arwa Alrkari, 2014). ................................................................240
Figure 12-6: Diagram for Queens Court Project................................................................................242
Figure 12-7: New Office for Unit Project (Glenwright, 2014). .........................................................245
Figure 12-8: New Office for Unit Project (Glenwright, 2014). .........................................................249
Figure 12-9: Diagram for New Office for Unit Project. ....................................................................251
Figure 16-1: Sample of mail that sends to the respondents. ..............................................................310

List of Table

Table 2-1: Research strategies in different of Relevant situations (Yin, 2003, p.5). ............................ 34
Table 2-2: Scale based on SF's effectiveness. ........................................................................ 40
Table 3-1: Phenomena linked to climate change. .................................................................. 55
Table 4-1: Physical Risks of CC on Building. W = windstorm, PC = precipitation, T = Temperature, F = Flood, SLR = Sea-Level Rise. ................................................................................ 71
Table 4-2: Economic Risks of CC on Building. ..................................................................... 76
Table 4-3: Social Risks of CC on Building. ........................................................................... 80
Table 4-4: Management Risks of CC on Building. ................................................................. 83
Table 5-1: Selected definitions of 'resilience'. 1 = adaptation, 2 = mitigation, 3 = recovery, 4 = Robustness, 5 = Environmental responsiveness, 6 = persistence, 7 = Redundancy. ............................ 85
Table 6-1: Site resilience design strategies. ........................................................................... 98
Table 6-2: Layout resilience design strategies. ..................................................................... 103
Table 6-3: Structure resilience design strategies. .................................................................. 109
Table 6-4: Envelope resilience design strategies (part 1) ...................................................... 119
Table 6-5: Envelope resilience design strategies (part 2) ...................................................... 120
Table 6-6: System resilience design strategies. ..................................................................... 127
Table 6-7: Operation resilience design strategies .................................................................. 129
Table 7-1: Connections between physical risks and design building resilience strategies. ................ 141
Table 7-2: Connections between economic risks and design building resilience strategies. .............. 142
Table 7-3; Connections between social risks and design building resilience strategies. .................... 142
Table 7-4: Connections between management risks and design building resilience strategies. ......... 143
Table 7-5: resilience characteristics of robustness and corresponding resilience factors. ................. 144
Table 7-6: resilience characteristics of redundancy and corresponding resilience factors. ................ 145
Table 7-7: resilience characteristics of Capacity for adaptation and corresponding resilience factors. ........................................................................................................................ 146
Table 7-8: resilience characteristics of Environmental responsiveness and corresponding resilience factors. ........................................................................................................................ 147
Table 8-1: Site resilience strategies. ..................................................................................... 152
Table 8-2: Layout resilience strategies ................................................................................. 154
Table 8-3: Structure resilience strategies. ............................................................................. 156
Table 8-4: envelope resilience strategies .............................................................................. 159
Table 8-5: System resilience strategies ................................................................................. 161
Table 8-6: Operation resilience strategies ............................................................................. 163
Table 9-1: The professional roles of respondents. ................................................................ 176
Table 9-2: Years of experience or respondets. ..................................................................... 176
Table 9-3: Reliability Statistics ............................................................................................ 176
Table 9-4: Site design resilience strategies. .......................................................................... 179
Table 9-5: Layout design resilience strategies. ..................................................................... 183
Table 9-6: Structure design resilience strategies ................................................................... 187
Table 9-7: Envelope design resilience strategies (part 1). ..................................................... 194
Table 9-8: Envelope design resilience strategies (part 2) ...................................................... 195
Table 99-: System design resilience strategies. .................................................................... 199
Table 9-10; Operation design resilience strategies. ............................................................... 201
Table 9-11: Operation design resilience strategies. ............................................................... 201
Table 10-1: Resilience building design strategies: resilience design site. ..................................... 206

Table 10-2: Resilience building design strategies: resilience design layout. 207
Table 10-3: Resilience building design strategies: resilience design structure. 208
Table 10-4: Resilience building design strategies: resilience design envelope. 210
Table 10-5: Resilience building design strategies: resilience design system. 212
Table 10-6: Resilience building design factors: resilience design operation. 213
Table 10-7: Most effective ranked resilience factors extracted for resilience building design. 214
Table 11-1: Respondents' classification based on their professional role 218
Table 11-2: The top resilience factors of Site based on the F-value. 219
Table 11-3: The top resilience factors of layout based on the F-value. 220
Table 11-4: The top resilience factors of structure based on the F-value. 221
Table 11-5: The top resilience factors of envelope-based on the F-value. 222
Table 11-6: The top resilience factors of system based on the F-value. 223
Table 11-7: The top resilience factors of operation based on the F-value. 224
Table 11-8: Respondents' classification based on their experience. 224
Table 11-9: The top resilience factors of site based on the F-value. 225
Table 11-10: The top resilience factors of layout based on the F-value. 226
Table 11-11: The top resilience factors of structure based on the F-value. 226
Table 11-12: The top resilience factors of envelope based on the F-value. 227
Table 11-13: The top resilience factors of system based on the F-value. 228
Table 11-14: The top resilience factors of operation based on the F-value. 228
Table 11-15: Summary of SFs rejected after ANOVA analysis of discrepancies between respondents' data based on professional capacity and level of experience. 229
Table 11-16: Summary of SFs rejected due to F-values of ANOVA analysis of discrepancies between respondents' data based on professional capacity and level of experience. 229
Table 12-1: Summary of previously proposed quantitative assessments of resilience (Serulle, 2010). 232
Table 12-2: BREEAM rating (Inbuilt, 2010). 235
Table 12-3: LEED rating (Inbuilt, 2010). 235
Table 12-4: Design resilience strategy rating. 238
Table 12-5: Present the designers' evaluations and the overall resilience scores of Queens Court project. 241
Table 12-6: Present the designers' evaluations and the overall resilience scores of New Office for Unit in Portsmouth 246
Table 12-7: Diagram for New Office for Unit Project. 247
Table 12-8: Present the designers' evaluations and the overall resilience scores of New Office for Unit in Stoke on Trent 250
Table 13-1: The highest ranked resilience factors (from Chapter 9). 258
Table 13-2: The highlighted resilience strategy rankings for site design resilience. 260
Table 13-3: The highlighted resilience strategy rankings for layout design resilience. 261
Table 13-4: The highlighted resilience strategy rankings for structure design resilience. 261
Table 13-5: The highlighted resilience strategic ranking in envelope design resilience. 263
Table 13-6: The highlighted resilience strategy ranking for system design resilience. 264
Table 13-7: The rejected resilience strategies. 265
Table 13-8: Research Question, the rejected hypothesis based on professional role: A2, A3, A4, A5 and A6 Result. 266
Table 13-9: Research question, the rejected hypothesis based on experience: $A_2$, and $A_5$ result. 266
Table 19-1: The F-value and significant value of the ANOVA analysis. 315

Table 19-2: The F-value and significant value of the ANOVA analysis. 317
Table 19-3: The F-value and significant value of the ANOVA analysis. 319
Table 19-4: The F-value and significant value of the ANOVA analysis. 323
Table 19-5: The F-value and significant value of the ANOVA analysis. 326
Table 19-6: The F-value and significant value of the ANOVA analysis. 327
Table 19-7: The F-value and significant value of the ANOVA analysis. 328
Table 19-8: The F-value and significant value of the ANOVA analysis. 329
Table 19-9: The F-value and significant value of the ANOVA analysis. 330
Table 19-10: The F-value and significant value of the ANOVA analysis. 332
Table 19-11: The F-value and significant value of the ANOVA analysis. 333
Table 19-12: The F-value and significant value of the ANOVA analysis. 333

## List of Abbreviations

| The Abbreviations | Meaning |
|---|---|
| CC | Climate Change |
| CCR | Climate Change Risks |
| PR | Physical Risks on Building |
| SR | Social Risks on Building |
| ER | Economic Risks on Building |
| MR | Management Risks on Building |
| SFs | Resilience strategies |
| SS | Site Resilience |
| SL | Layout Resilience |
| TS | Structure Resilience |
| SE | Envelope Resilience |
| YS | System Resilience |
| SO | Operation resilience |
| R | Redundancy |
| RO | Robustness |
| CA | Capacity for adaptation |
| ER | Environmental responsiveness |
| W | windstorm |
| PC | precipitation |
| T | Temperature |
| F | Flood |
| SLR | Sea-Level Rise |

# Chapter 1: Research Plan

## 1.1 Introduction

The increasing impact of industrialisation on climate in recent decades, caused mainly by the burning of fossil fuels and subsequent release of large amounts of carbon dioxide (a greenhouse gas) into the atmosphere, has focussed attention on issues to do with climate change. One of these issues, and the subject of this research, is the risks of climate change on the built environment and the need to develop resilience strategies that address the risks of climate change events to buildings. Specifically, with the threat from more frequent and severe hydro-meteorological events to buildings becoming greater, there is increased emphasis on (1) the designer’s role in establishing concepts necessary to achieving resilience in buildings, and (2) balancing climate change risks with the real needs of design resilient buildings.

Spelman (2011) has noted that not enough studies have been carried out on how climate change will affect the design of buildings and that this represents a major challenge for the future. Extensive studies and planning are needed in order to insure that buildings can cope with the dangers posed by climate change. Houghton (2002) has suggested that multidisciplinary approaches should be taken that consider not only building design impacts but also the wider implications of climate change for society, the economy, and human health. Bush et al. (2011) points out that more research is needed on forecasting possible impacts of climate change in general.

The design of buildings is a complex process made more complex when the design must involve resilience strategies (SFs) to address a range of resilience characteristics. A key aspect of the present work is the identification of specific SFs, to be discussed later, which are used to support the four resilience characteristics dealt with in this study: robustness, redundancy, capacity for adaptation, and environmental responsiveness.

A theoretical framework will be presented for resilience building and the key role of architects as building designers to establish resilience concepts in both the early stages of design and over the whole life cycle of designed assets. Climate change risks and anticipated events will be assessed in terms of how they will impact on buildings. Then resilience strategies will be evolved based on their effectiveness in enabling a building to continue functioning as designed when confronted with the challenges of climate change. The main objective of this research is to provide designers with a tool for implementing appropriate resilience in a building to climate change risks. The outcome is the identification of resilience indicators that are ranked, grouped and processed to provide a qualitative model for assessing the various aspects of resilience building design.

## 1.2 Rationale of this study and problem statement

Designing for resilience against climate change is becoming a matter of pressing concern as the effects of global warming become increasing apparent. In regard to resilience design, it is important for architects working in this area to be aware of and understand the resilience design strategies available for each aspect of a building.

The need to incorporate SFs into building design has been highlighted by several authors. For example, Dickson (2003) mentions the problems that might ensue unless a design team considers future and current climate change risks, and well as solutions to them, in the design process. Other studies have primarily emphasised specific measures for responding to identifiable future climate risks in terms of the designer meeting the building resilience before completing the design. Lim at al. (2004) are among those who have advocated the integration of building resilience specifications into the early stages of the design process, in part because retrofitting the design post-construction to meet design resilient building against CCR will be expensive. Birkmann et al. (2010) indicate the limited practical experience there has been to date in planning for such adaptation. A number of authors (e.g., Chang, 2009) have raised the question of exactly how a building system should be designed to resist climate change events, while stressing the importance of research into resilience factors. (Satterthwaite et al., 2007; Wilbanks et al., 2007; Balk et al., 2009; UN-HABITAT, 2011). De Wilde and Coley (2012) have argued that rethinking resilience design for the challenges of climate change is one of the greatest challenges confronting architects today.

This study maintains that SFs should be incorporated into the architect's agenda at the earliest design stage. SFs should ideally be incorporated during the development of the conceptual model and certainly before preparation of the final design. De Wilde and Coley (2012) maintain that the ability of a building to face climate change risks is becoming one of the main pillars of design and that there is a need for "more expertise in development of approaches to rank various mitigation and adaptation strategies as well as exploration of the concepts of flexible, robust and resilient building design, integrating concepts for a long lifetime with concepts that allow for adaptation". Waskett (2003), too, refers to the pivotal role of the designer in integrating SFs into the design and the increasing demand to conceive of systemic processes that enable resilience strategies to interact with the design process.

This research aims to bridge the gap between the CCRs to building and resilience design by determining SFs that play an important part in resilience design. It involves an extensive literature review to examine previous studies of architectural design that bear on resilience strategies and finds that little has been done thus far to model the interaction between SFs and CCRs in the domain of building design.

The problem set for this study is to identify the SFs that, when incorporated into a building design, have a clear impact on resilience to CCRs. Additionally, the research here will consider the way in which SFs can be integrated into the design process to enhance the architects' role to face CCRs on buildings.

## 1.3 Research questions

In order to address the problem statement, the study will focus on the following questions:

- What are suitable methods for modelling, capturing and integrating CCRs into SFs?
- What are the risks of climate change on buildings and how the buildings will be resilience?
- What are the key factors for operating and designing buildings that are resilient to future climate change risks?
- What are the most effective SFs for a resilience design?
- How can these determinants be used to evaluate the resilience of designed buildings to emerging climate change risks?
- What is the best way to map SFs to CCRs, and to show the most relevant connections between these?
- What is a conceptual model that can help the designer to meet building needs during resilience design for CCRs?
- What is the most appropriate tool for integrating SFs into resilience design?

## 1.4 Research hypotheses

The main hypothesis to be tested whether there is a significant difference between architects' assessments of resilience strategies to be face CCRs. These assessments will be used to score resilience factors and determine their inclusion in the final resilience model. The main hypothesis is divided into two hypotheses as follows:

$A_x$ : There is no statistically significant difference between the respondents' perceptions on the effectiveness of resilience factors.

$A_{0x}$: There is a statistically significant difference between the respondents' perceptions on the effectiveness of resilience factors.

## 1.5 Aim and objectives of this study

### 1.5.1 Aim of the research

The overarching aim of this research is to investigate resilience strategies that are significant in the design of buildings in a world of climate change, and to construct a model for designers to use in architectural design to address climate change risks. In order to achieve this aim, the study has the objectives identified below.

### 1.5.2 Objectives of the research

The objectives are as follows:

- To identify the climate change risks that facing a buildings.
- To identify key resilience design indicators
- To determine suitable methods for modelling and integrating SFs into resilience designs.
- To identify the most effective SFs for resilience building design and build a conceptual model based on the results of a questionnaire and statistical analysis.
- To analyse and extract the most significant SFs, discuss the results, and propose an assessment tool aimed at helping designers achieve the design resilient buildings.

### 1.6 Scope of the study

The scope of this study extends to architects who practice resilience design, so that, to this end, a resilience design conceptual model is suggested to confirm whether or not designers are considering the strategies of design resilience building in the face of climate change risks. Three steps will been undertaken.

The first step is to arrange CCRs into physical, social, economic and management categories, which will form one of the main aspects of the model. The second step involves grouping the resilience design strategies into six main classes – site, layout, structure, envelope, system and operation. Finally comes the development of a process for the designer to follow to ensure that all aspects of the resilience design model are validated systemically.

During these steps, an evaluation of the resilience design strategies, which address the requirements for robustness, redundancy, capacity for adaptation, and environmental responsiveness, is conducted to see if the SFs are integrated or not, because one of the study aims is to bridge the gap between the SFs and CCR. In this regard, this study contributes a novel step in advancing the use of the SFs in resilience design.

A number of academics, who specialise in resilience building design, were asked to examine the questionnaire in order to check its validity, before the questionnaire was sent to a large sample of architects with experience in resilience design to gather data. The responses of the architects were used then used to further develop and refine the resilience building design model.

### 1.7 Significance of the study

The significance of this research is in its practical application in helping architectural designers incorporate building resilience that can effectively counter foreseeable climate change risks. A specific challenge connected to this study is arriving at a detailed understanding of how different resilient strategies can be applied in addressing CCRs. Little work has been done in this area to date so that the research here will, hopefully, make a valuable addition to the literature on resilience building design.

## 1.8 Definition of terms

**Resilience building design**: A design that places both CCR and resilience design strategies at the heart of the design process. It deploys SFs throughout the planning, design, development and operation of building assets.

**Resilience building design aspects**: Strategies that capture the requirements and limitation of buildings with regard to resilience in relation to site, layout, structure, envelope, system and operation.

**Resilience design site**: A set of design determinants that relate to the existence of set of resilience design site (i.e., site analysis, orientation and landscape) that fulfil design resilient building.

**Resilience design layout**: A set of design determinants that relate to the existence of set of resilience design layout such as: spaces and entrances that fulfil design resilient building.

**Resilience design structure**: A set of strategies that relate to foundation and materials of resilience design structure to regulation standards and building efficiency.

**Resilience design envelope**: A set of strategies that relate to the ability of resilience design envelope to be remodelled to satisfy new use conditions.

**Resilience design system**: A set of determinants that relate to the capability of resilience design system such as: (HVAC and lighting) to maintain their level of Service performance under building stated conditions within the design service life period.

**Resilience design operation**: A set of determinants that relate to the ease of inspecting and maintaining to continuous operation of building.

## 1.9 Methodology

The details of the methodology used in this research are illustrated in Fig 1-1 and summarised below.

The methodology involves firstly a literature review about climate change risks and resilience building design (see Chapters 3, 4, 5 and 6). Based on the literature review and prior studies a theoretical model for resilience design is developed (see Chapter 6); how the CCRs and SFs are interconnected is explained an mapped in Chapter 7. Also based on the literature review and earlier experience in architectural design, an inclusive series of indicators were identified and used to formulate as a questionnaire (see Chapter 2). This questionnaire was sent to a broad sample of architects to obtain their opinion on resilience design strategies. Potential respondents were requested to assess the indicators using a ranking scale from 1 to 5. Completed questionnaires were collected and the data on them entered into computer. To analyse and process the data, SPSS and Excel software were employed (see Chapter 9). Indicators were subsequently extracted for further analysis and used as resilience design strategies for assessing building design (see Chapter 10). The extracted strategies were used to develop a resilience design assessment tool (see Chapter 12). This tool has the capability to distinguish between buildings that have resilience characteristics and those that are deficient in this respect, and to identify where weaknesses in the design exist and what indicators need to be improved.

## 1.10 Outline of the thesis

The arrangement of the thesis is shown in Fig 1.1. The content of each of the chapters is as follows:

**Chapter 1:** An overview of, and introduction to, the research, including its overall content, scope, and limitations, and a definition of terms.

**Chapter 2:** Review of the research methods and development of the questionnaire through various stages. In addition, there is a discussion of the advantages of using questionnaires, and of quantitative and qualitative methods.

**Chapter 3:** This chapter provides an overview climate change from the events of CC (Temperature, Precipitation, Wind storms, Sea-level rise and Flood)

**Chapter 4:** This chapter provides the risks of climate change poses to the built environment (physical, economic, social and management)

**Chapter 5:** A review of the concepts and nature of resilience design, resilience characteristics, and resilience design aspects.

**Chapter 6:** Extraction of the SFs of resilience design aspects (site, layout, structure, envelope, system and operation).

**Chapter 7:** Mapping of CCR to SFs using Gephi software to draw the maps, show the various factors interact with each others.

**Chapter 8:** Proposal of a resilience building design conceptual model. This is achieved through merging three components, namely the resilience design aspects of site, layout, structure, envelope, system and operation, as the core of the model; the second component is the process; and the third component is the four resilience evaluations.

**Chapter 9:** Findings of the data collection, including a description of the highest and the lowest effective SFs for each aspect. For this the SPSS program was employed using mean value and standard deviation methods.

**Chapter 10:** Ranking of aspects of the design using data from the questionnaire. The rankings were based on the architects' experience level.

**Chapter 11:** Testing of the hypothesis of the resilience design based on both the architects' experience and one-way ANOVA analysis.

**Chapter 12:** The SFs, extracted in chapter 9, are used to develop an assessment tool. Then this tool is tested using 3 projects – that of the Queens Court Project, the New Office for Unit in Portsmouth, and the New Office for Unit in Stoke on Trent.

**Chapter 13:** Presentation of the discussion of thesis.

**Chapter 14:** Presentation of the conclusion, contribution and future research work to be done.

**Thesis outline**

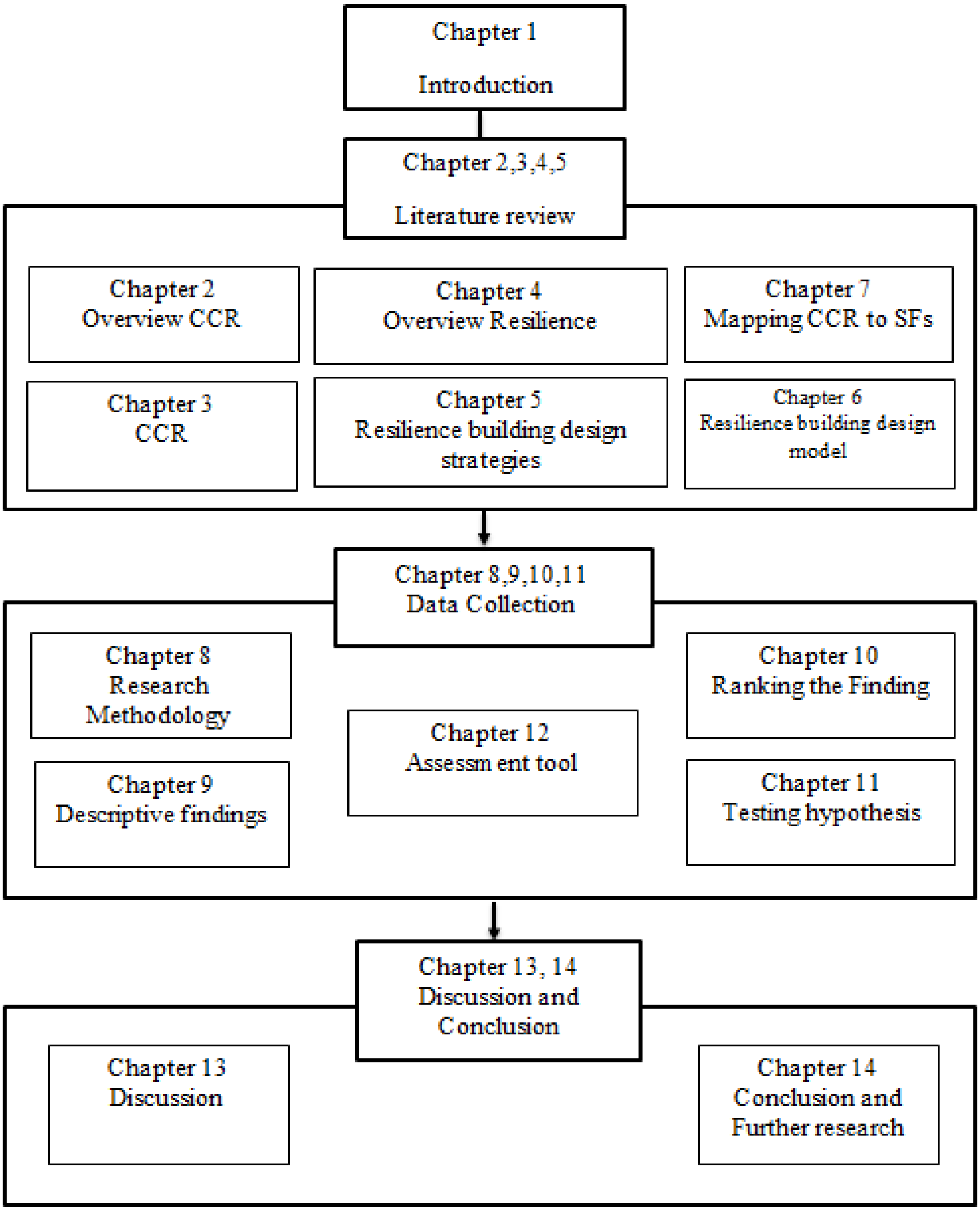


Figure 1.1: Thesis outline

## 1.11 Summary

In this chapter the study has been introduced by explaining the rationale behind the research and providing the problem statement, before moving on to state the research problem, research hypothesis and aims and objectives. This chapter also discussed the scope, limitations, and assumptions of the study, together with its significance, before ending with reference to the definition of terms that will be used.

# Chapter 2: Research Methodology

## 2.1 Introduction

Research methods are categorised as being quantitative, qualitative or both. Quantitative methods deal with measurements and typically involve numerical data, whereas qualitative methods are concerned with descriptions and observations that do not involve measurements. The purpose of a quantitative approach is usually to test a model or hypothesis that has been put forward based on some theory or theories (Russell, 2000). By contrast, a qualitative method is normally chosen if a study uses observations made in a natural setting (Leedy and Ormrod, 2005).

The present research develops and proposes strategies for the design of buildings intended to provide resilience to the effects of climate change. It employs both qualitative and quantitative approaches. Yao (2004) has indicated that such a hybrid of approaches can strengthen the overall methodology and help eliminate weak points in the research.

The researcher started by using qualitative data obtained by way of a critical literature review. This review dealt with the investigation of appropriate methods for bridging the gap between climate change risks (CCR) and resilience building design strategies. Based on the critical literature review, a quantitative method was developed that involved a questionnaire being sent to a sample of architects. The purpose of the questionnaire-centred survey was to gather the architects' perceptions about SFs from a conceptual point of view. From the results of the survey, an assessment was made of the most effective resilience factors and the designers' opinions on the best way to integrate resilience building design strategies within the building design process.

## 2.2 Research methodology theory

Details of the methodology adopted in the present research will now be discussed along with the strengths and weaknesses of the techniques used.

## 2.3 Qualitative: critical literature review

A literature review serves to find out what is already known about a particular area of research, in order to avoid 'reinventing the wheel'. It establishes a theoretical framework for a particular topic, and includes a definition of key terms and identification of previous studies and models. It also identifies any significant controversies or inconsistencies arising from research in the area, as well as unanswered research questions (Bryman, 2008). By thus bringing to attention gaps in what is known and to specific weaknesses and the strengths of research to date, the literature review helps to shape and refine the goals of new research. Next, the detailed methodology of the present research will be considered.

## 2.4 Quantitative: questionnaire design

This section reviews the qualitative research methods and the process that has been followed to design and develop the final version of the questionnaire. Employing a questionnaire has both advantages and disadvantages.

Among the advantages of using a questionnaire (Powell, 1997, as cited by Grover et al., 2010):

- It prevents interviewers from distracting respondents.
- If its format is carefully prepared, it helps eliminate differences in the way questions are framed during the questioning process.
- By giving respondents plenty of time to respond, it encourages thoughtful answers.
- The questionnaire format can be designed to facilitate both data collection and analysis.
- It is a technique that allows a large amount of data to be collected in a relatively short time.
- Questionnaires sent via emails involve little or no cost.

Disadvantages of a questionnaire conduced via email include the following (Powell, 1997, as cited by Grover et al., 2010):

- The lack of face-to-face contact between the researcher and respondent.
- The difficulty of getting a quick clarification if the respondent needs one. Any queries could, however, be handled via email. This problem is, in any case, reduced or eliminated if the questionnaire is kept simple.
- There is the possibility of bias. For example, highly opinionated people are more likely to respond to a questionnaire.
- There is likely to be a fairly low percentage of respondents. This can be attributed to various factors, e.g., unavailability or time constraints of potential respondents and difficulties in understanding or being able to reply to what is asked on the questionnaire.

The questionnaire for this research was constructed with the aim of determining SFs and their effect on building design. The data collected from responses were extracted and analysed prior to developing a design model for building resilience to climate change events. The ultimate goal of the research is to help designers (architects) ensure that their designs meet building resilience requirements to CCR.

In what follows, the methodologies that have been used to develop the questionnaire will be described, along with the process in going from initial concept to final version. The responses of architects to the survey were analysed using SPSS and Excel. Then the results of the analysis were used in developing the building resilience design model and measuring its effectiveness in the design of resilient buildings.

## 2.5 Rational for designing the survey

Various research strategies may be used depending on the situation. Yin (2003) classifies research strategies into three types, namely: the form of the research question, the control of the researcher, and the focus on contemporary events (see Table 2-1).

The present research is focussed on three questions – What? How? Who? From Table 1 it can be seen that compatible strategies are archival analysis and survey. Of these two options, the researcher selected a two-part approach involving a survey. The first part involved designing the survey and validating it to ensure that its contents covered the main aim of the research topic and, moreover, to confirm that all of the selected factors would be relevant in answering the research question and problem. The second part was to collect the data through use of an online survey. The following section explains the process and tasks that were followed to develop the questionnaire.

Table 2-1: Research strategies in different of Relevant situations (Yin, 2003, p.5).

| **Strategy** | **Form of research question** | **Requires control over behavioural events?** | **Focuses on contemporary events?** |
|---|---|---|---|
| Experiments | 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 |

## 2.6 Research method process

To summarise, the methodology of the present research incorporates six main tasks. The first was to determine the main aim, objectives, problem statement and hypothesis. The second task was to conduct a literature review, in order to identify the climate change risks and building resilience design strategies that have been described by other researchers to address CCR. The third task was to develop and validate a questionnaire with academics who are experts in the relevant field, before delivering the final questionnaire to respondents. Fourth came data collection and analysis, and a progression from descriptive results to hypothesis testing. The fifth task was to develop an assessment tool. Finally came the discussion and conclusion of the results. Each of these tasks will now be explained in detail.

### 2.6.1 Task 1: Initial research

The first part of the methodology consisted of identifying the research aim and problem and ensuring that no other studies had already been carried out that tackled the same problem. This initial phase was also used as the springboard for obtaining the necessary knowledge for forming the building resilience design constructs.

### 2.6.2 Task 2: Literature review

This task consisted of performing the critical literature review and was broken down into four main stages as follows.

#### *2.6.2.1 Climate change review*

This section of the review (see Chapters 3 and 4) investigated various aspects of climate change. The primary purpose was to ensure all aspects of climate change events and forecasts as they pertain to the built environment were covered

#### *2.6.2.2 Building resilience design review*

As a result of this section of the review, building resilience design was divided into six dimensions: site, layout, structure, envelope, system and operation. Then the resilience characteristics of each of these dimensions were extracted. The design resilience strategies were revised and classified before being included in resilience characteristics, in order to avoid repetition in the various groupings; additionally, some strategies have dual functions. These design strategies are identified and listed in relation to the design aspects in Chapter 5. In this section of the review, too, some of the definitions of building resilience design were assessed to see whether they were appropriate for design resilience specific to CCR or not.

The previous steps describe the process used to develop the conceptual model used in this research. The process consisted of several iterative steps, as shown in Figure 2-2. It began by classifying resilience characteristics into four dimensions: robustness, redundancy, capacity for adaptation, and environmental responsiveness. Then, the resilience building design strategies were reviewed to ensure that their functionality is applicable specifically to the resilience design with respect to CCR. Then, these were further investigated to ascertain their suitability to be included in building resilience design processes (see Chapter 5).

#### *2.6.2.3 Mapping CCRs To SFs*

The various resilience strategies were mapped to the climate change risks to reveal all the interconnections between the two categories of factors. This process, as described in Chapter 6, resulted in a series of network diagrams, generated using the Gephi software package, showing the CCR–SF links for the four different aspects of CCRs under consideration.

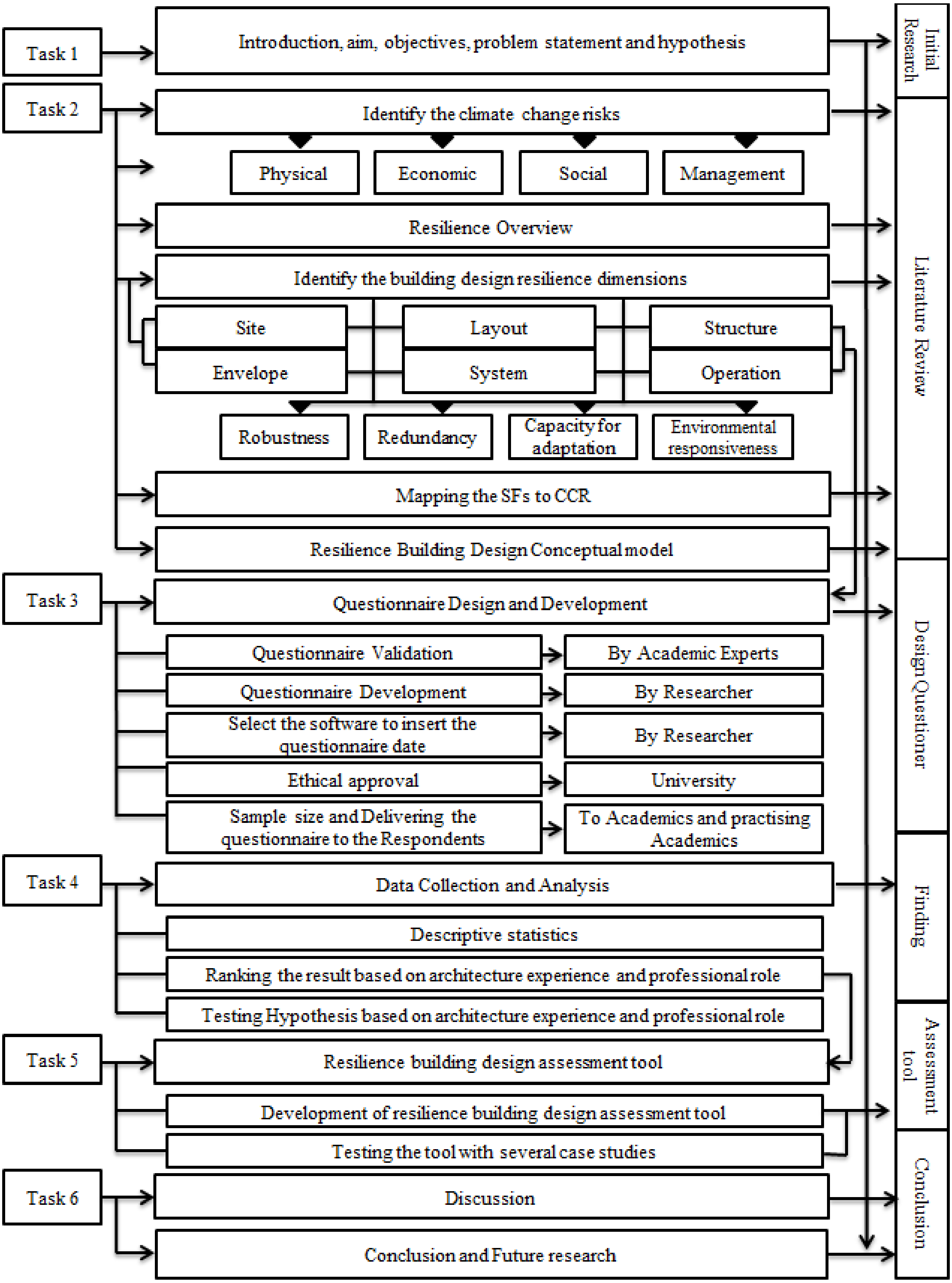


Figure 2-1: Research process.

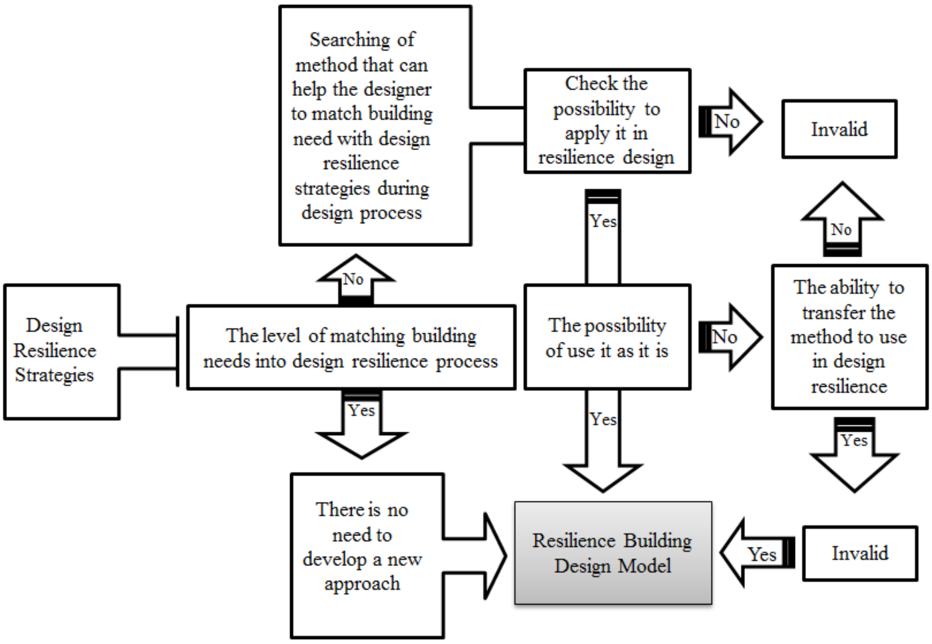


Figure 2-2: The process of the research methods to develop a building resilience design conceptual model.

### *2.6.2.4 Conceptual model*

In this stage of the review, the conceptual model, which comprises the resilience characteristics, the design process, and the building resilience design aspects, was identified. The methodology that was followed in order to develop the conceptual model was based on a critical analysis of the literature and prototype modelling. The analysis followed by this research was based on system development methods.

The researcher carried out an intensive literature review into design methods and resilience strategies in the built environment, taking in sources from 1980 to the present date. The literature review turned up no existing coherent models in the building industry that captured the totality of climate change risks along with resilience strategies as shown in figure 2-3. However, the information extracted from the literature was classified and, in addition, a systematic process developed for integrating SFs into design resilience. In all, 85 SF strategies were extracted. The selected SFs were assessed for their effectiveness in addressing building resilience needs with regard to climate change risks (see Chapter 6).

#### *2.6.2.5 Building resilience design aspects*

For the purposes of this research, building resilience design aspects are considered to fall into six main categories, each of which is associated with a number of resilience strategies. These aspects, together with the associated categories are shown in Figure 8-3 and are as follows: (1) site, including 7 strategies; (2) layout, including 14 strategies; (3) structure, including 12 strategies; (4) envelope, including 32 strategies; (5) system, including 16 strategies; and (6) operation, including 4 strategies. The SFs were determined and extracted following the literature review. The six aspects of building design resilience and SFs form the subject of Chapter 5, as shown in Figure 2-4.

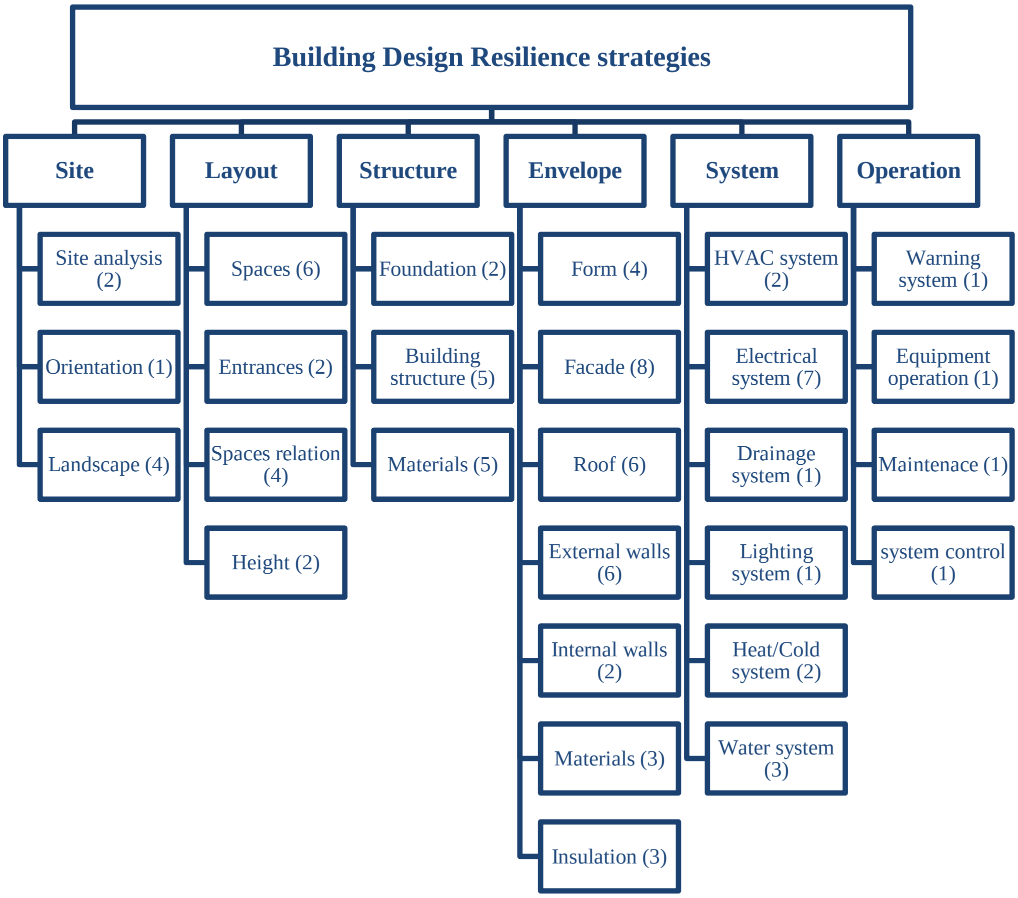


Figure 2-3: The total number of SFs.

### 2.6.3 Task 3: Questionnaire design and development

The researcher selected this method because of the advantages it offers, identified earlier, and because it was an appropriate way of presenting and receiving feedback on the long list of selected SFs. These factors were chosen based on the literature reviewed on building resilience design strategies, the researcher's personal knowledge, and discussion with the supervisor. The literature review stage provided the foundation for creating the contents of the survey.

The questionnaire was divided into seven parts. The first of these gave an overview of the research and the idea behind it. The remaining six parts dealt with the six aspects of buildings considered in this study and the corresponding SFs that had been identified from the literature review. Architects, to whom the questionnaire was sent, were asked to rank these SFs in order of importance. Additionally, the views of respondents were sought on the main research question: namely, about the SFs and their effect on building resilience with respect to climate change risks.

Respondents were requested to give a score to each SF based on the estimated level of its effectiveness. In Table 2-3, the five-degree scale that was used in the questionnaire is illustrated. Effectiveness could be characterised by respondents as ‘very ineffective’, ‘ineffective’, ‘neutral, ‘effective’, or 'very effective'. A scoring system was then used to quantify the replies: 1 point for ‘very ineffective’, 2 for ‘ineffective’, ‘3’ for neutral, ‘4’ for effective and 5 ‘very effective’ as shown in Figure 2-5. In this way, the various proposed strategies could be ranked in terms of their importance, based on the respondent’s evaluations, to the study's conceptual model.

A sample of the first part of the questionnaire is illustrated in Figure 2-5.

Table 2-2: Scale based on SF’s effectiveness.

| Very ineffective | Ineffective | Neutral | Effective | Very effective |
|---|---|---|---|---|
| | | | | |

How effective are the following site design strategies for the design of resilient housing to climate change risks?

Please check one box from the effects:

| | Very ineffective | Ineffective | Neutral | Effective | Very effective |
|---|---|---|---|---|---|
| Use site stabilisation techniques to prevent erosion | | | | | |
| Direct runoff of water to a catch basin or holding area to reduce erosion | | | | | |
| Plant mature trees to assist in dissipation of the wind force | | | | | |
| Use water catchment systems/cistern to reduce flooding | | | | | |
| Prepare site landscape and landforms for high wind conditions as well as to reduce the noise, pollution, energy consumption, temperature degree and relative humidity | | | | | |
| Use optimum building orientation to improve resilience to high/low temperature | | | | | |
| Use permeable surfaces in landscaping against vulnerability to flooding | | | | | |

Figure 2-4: Sample of the first part of the design questionnaire.

The hypotheses used in this task are:

$A_x$: ($p > 0.05$): There is no statistically significant difference between the respondents' perceptions on the effectiveness of resilience factors, based on their professional role.

$A_y$: ($p < 0.05$): There is a statistically significant difference between the respondents' perceptions on the effectiveness of resilience factors, based on their professional role.

In the second part of the questionnaire, respondents were asked to supply general information such as name, contact details, and professional capacity and level experience (see Figure 2-6).

#### 2.6.3.1 Personal information

| | |
|---|---|
| 1- Respondent's name (optional) | |
| 2- Contact details if you wish to receive a £10 voucher from Amazon (optional) | Email: |
| 3- Company name (optional) | |
| What is your professional role?<br>□ Architect practicing □ Academic and architect practicing □ Academic | |
| How many years of experience do you have?<br>□ 0-5 years □ 5-10 years □ More than 10 years | |

Figure 2-5: The second part of the design questionnaire collected personal information.

#### 2.6.3.2 Questionnaire validation

Before the questionnaire was sent out to potential respondents, an early draft of it was provided to the researcher's colleagues and supervisor to obtain their comments about its contents and how it was worded and laid out. This feedback was used to improve the clarity and substance of the questionnaire, which was then further tested with the help of a group of specialists in the field of resilience design. Four individuals – from the respondents – offered suggestions that were used in the preparation the final version of questionnaire (see Appendix: A).

The reason for this lengthy validation process was to ensure that all relevant factors were included, and that the presentation was clear and comprehensible for those participating. The process of designing the questionnaire is shown in Figure 2-7.

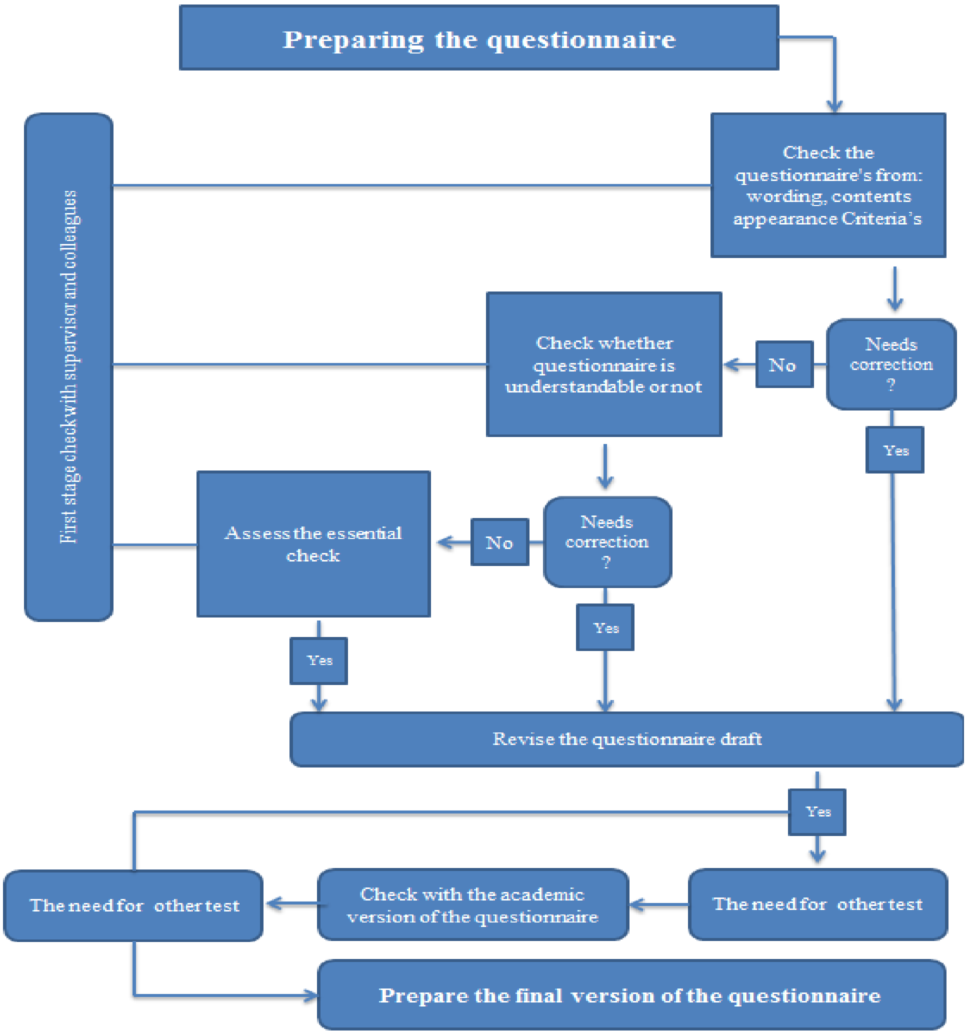


Figure 2-6: Questionnaire design process.

### 2.6.3.3 *Questionnaire development*

The pre-testing revealed that some modifications were needed to the survey and the feedback of the expert respondents was included when developing the questionnaire. The entire process of designing the questionnaire is illustrated in Figure 2-7.

### 2.6.3.4 *Selecting the survey software*

The main criterion in the selection of the survey software was its ease of use by respondents and, in particular, the ease with which it allows data to be inserted. Various survey programs were considered, such as 2ask, Survey Monkey, Survey Galaxy and online surveys. In the end, it was decided to use Create Survey for this research, as it was available on the university website and has a user-friendly interface that makes it easy to insert data.

#### *2.6.3.5 Ethical approval*

Ethical approval to involve human participants in the study was sought from the University of Liverpool via a form submitted on 27 March 2014. Approval to go ahead with the data collection was received on 14 May 2014. A copy of the approval is supplied in the Appendix A.

#### *2.6.3.6 Sample size and delivery of the questionnaire to respondents*

The questionnaire used in this research was distributed to three categories of professionals: practicing architects, architects in academia, and those who are both practicing and academic. Potential respondents from around the world were identified based on their expertise and interest in the combined fields of resilience design and the climate change risks to the built environment. Their information and contact details were obtained from the RIBA website and universities' websites. 85 questions were sent to 270 architects from both sectors, practicing and academic. To motivate potential respondents to fill in the questionnaire, they were offered a £10 voucher from Amazon (See Appendix: A).

77 respondents completed the survey, which equates to a response rate of 30.1%. This was a satisfactory number, especially given that many respondents indicated that the questionnaire was too long. Akintoye (2000) refers to the norm rate for survey responses as being between 20% and 30%, a percentage considered as an acceptable in cases where the author has no formal relationship with the respondents (Zoomerang, 2010). The rate can be increased in situations where the method of delivering the questionnaire is different, such through interviewing the respondents, or when the researcher knows the respondents. Other researchers have also indicated that 20–30% is a typical response rate for the type of survey

used in this study, for example Sherrie (2010), Couper (2000), and Prahalad and Hamel (1990).

### 2.6.4 Task 4: Data collection and analysis

Detailed analysis of the data involved three sub-tasks: the descriptive analysis, ranking the findings and testing the hypotheses. These are explained in detail below.

#### *2.6.4.1 Sub-task: Descriptive finding*

Two techniques were applied in the analysis of responses received to the questionnaire. The first used the mean values and standard deviations to rank the resilience factors from highest to lowest (as shown in Chapter 8). The researcher found the mean values and standard deviations using SPSS.

#### *2.6.4.2 Sub-task: Ranking findings*

SPSS was also used to analyse the data and rank the results with regard to the respondents' level of experience (0-5 years' experience, 5-10 years' experience, and more than 10 years' experience) and their professional capacity (academic, practicing, or both). The findings are presented in Chapter 9. For this part of the analysis, two statistical quantities were calculated: the coefficient of variation, a measurement useful for comparing the variability in replies of different respondents, and the severity index (S.I.), which indicates the significance of each SF.

#### *2.6.4.3 Sub-task: Testing hypotheses*

The third stage of data analysis involved putting the hypotheses to the test through analysis of variance (ANOVA) and calculating the P values. This method also helped to flag any significant differences between the replies of the respondents. The criterion used on the hypothesis was as follows: if $P < 0.05$ the hypothesis was rejected, otherwise it was accepted. Additionally, the Tukey HSD Post Hoc Multiple Comparison Test was applied to check each value that scored less than 0.05. The rankings of the resilience factors as derived by the statistical analyses are presented in Chapter 10.

### 2.6.5 Task 5: Design Resilience Strategy Assessment tool

A central part of this research involved the implementation of a Design Resilience Strategy Assessment tool. This involved two sub-tasks: the development of the tool and its testing. These sub-tasks will now be explained further.

### 2.6.6 Sub-task: Development of the Design Resilience Strategy Assessment tool

In building this new tool, assessment tools already in existence, including AECOM, SCEAM, CABE and EVOLVE, were examined. In particular, their criteria were compared with those of the Design Resilience Strategic Assessment Tool. The scoring systems and certification methods used in CASBEE, DGNB Label, BREEAM and LEED were reviewed, along with the formula applied to evaluate the resilience of the design. After all these comparisons and reviews had been conducted, the method of scoring the Design Resilience Strategic Assessment Tool was developed, as described in Chapter 11.

### 2.6.7 Sub-task: Testing the tool

The second part of the process involved testing the tool. This was carried out based on the work of three projects, namely those of Queens Court, the New Office for Unit Project in Portsmouth, and the New Office for Unit Project in Stoke on Trent. Each of these projects was scored by the designer, the calculations carried out and percentages evaluated, as shown in the bottom of each assessment sheet in Chapter 11.

### 2.6.8 Task 6: Discussion and conclusion chapter

Chapter 12 discusses the research questions and their relationship and relevance to objectives of the study. Each question is dealt with in terms of the following topics:

architectural design, the conceptual model, the building resilience design conceptual model, the resilience strategies, tdata analysis, and the assessment tool. Chapter 13 contains the conclusion of the research, its main contribution, suggestions for future work and the limitations of the study.

## 2.7 Summary

The methodology used in this research is a hybrid of qualitative and quantitative methods. Quantitative data from the literature review formed the basis for the development of a qualitative questionnaire. This questionnaire was then sent to a sample of several hundred architects, who are experts in the relevant field. The data collected from the respondents, and the results that follow from them, will be discussed in the following chapters.

# Chapter 3: Climate Change Overview

## 3.1 Introduction

Climate is the weather prevailing in a region over a long period of time. Natural changes in the global climate may be caused by various factors, including major volcanic eruptions, minor rises and falls in solar irradiance, the so-called El Nino effect, and periodic shifts in the Earth's axial and orbital motion (UK Met Office).

Compelling scientific evidence now exists that global climate change is occurring at the present time due primarily to human activity (Pethica et al., 2010). The main cause of this anthropogenic climate change is believed to be the burning of fossil fuels and the consequent release into the atmosphere of large amounts of carbon dioxide (CO2), which functions as a greenhouse gas (UK Met Office).

## 3.2 Evidence for anthropogenic climate change

The science of climate change is complicated by the fact that both natural and human factors are involved. However, data suggesting that the primary influence behind recent decades of global warming is human-centred has becoming increasingly incontrovertible (IPCC, 2007).

In the middle of the 19$^{th}$ century, the level of CO2 in the atmosphere, as later measured from Antarctic ice cores, was about 290 ppm (parts per million), and the mean global temperature during the period 1850–1870 was about 13.6°C. By 2009, the CO2 level had climbed to 385 ppm (higher than at any time in the past 650,000 years) and the mean global temperature had risen by almost one degree to 14.5°C. In the intervening years, the rise in CO2 level, corresponding to increased industrial activity and burning of coal, oil and natural gas, has been matched closely by a gradual rise in mean global temperature. In its 2007 report to the United Nations, the Intergovernmental Panel on Climate Change (IPCC) stated that it was now 90% certain that the last 50–60 years of climate change was human-caused and that the elevated levels of carbon dioxide would result in the mean global temperature rising even further (IPCC, 2007). At a global level, as of 2013, 12 of the last 14 years had been the hottest since accurate records began 1850, with 2010 being the hottest of all at 0.66°C above the global mean for the period 1911–2000.

Ice sheets in regions like Antarctica and Greenland are now melting rapidly. This melting, in combination with an increase in the volume of ocean water due to thermal expansion, is causing sea levels to rise around the world (Bindoff et al., 2007). Mean global sea levels increased by 195 mm between 1870 and 2004 (Church and White, 2006). However, over the past few decades the rate of sea-level rise has accelerated. In the period 1950 to 2009, measurements show an the measured average annual rise of in sea-level was 1.7 ± 0.3 mm per year, while from 1993 to 2009, according to satellite data, it has been 3.3 ± 0.4 mm per year. Moreover, sea-level rise is expected to continue; according to one projection, global sea levels will increase on average by another 180–590 mm during the 21$^{st}$ century (IPCC, 2007).

As the mean global temperature rises, climate models suggest that more extreme hydro-meteorological events are likely to be increasingly common (Cruz et al., 2007). Indeed, there is evidence to suggest that global warming has already resulted in the occurrence of additional natural disasters through phenomena such as powerful hurricanes, floods, drought, and heavy precipitation (Meehl et al., 2007). At a regional level, both an increase and decrease in the rates of precipitation are expected, depending on local circumstances. Heavier rainfall poses many risks, with the most significant being flooding (Brooks et al., 2000). In addition, rising sea levels pose a special threat of flooding to low-lying coastal areas are at risk of flooding from rising sea levels (Wassmann et al., 2004).

High temperatures also increase the likelihood of other events, such as forest fires and windstorms (Haines and Patz, 2004).

A higher frequency of phenomena such as hurricanes, drought, heavy rains, and high temperatures are forecast to accompany global warming and have a significantly negative impact upon the environment (Christensen, 2007). The effect of climate change also has marked implications for the built environment and on the strategies that designers need to adopt to make buildings more resilient to this growing challenge.

## 3.3 Events associated with climate

Hydro-meteorological events associated with climate may be classified as follows: storms, rain, heavy snow, waves, hurricanes, drought, flood, drifts, forest fires, fog, frost, volcanoes and sea level rise. These events may then be grouped so that associated events fall within the same group. The first group is **storms,** including ice storms, blizzards, snowstorms, ocean storms, firestorms, dust storms, windstorms, thunderstorms and hailstorms. The second group is **rain,** incorporating heavy rain and more moderate forms of rain. The third group is **snow,** including heavy snow, the fall of snowy blocks and the melting of snow. Other groups include **waves** (incorporating cold waves and heat waves), **hurricanes**, **drought**, **floods**, **drifts** (including mud and soil drifts), **forest fires**; **fog**, **frost**, **volcanoes** and **sea-level rise**. (See Figure 3-1 below.)

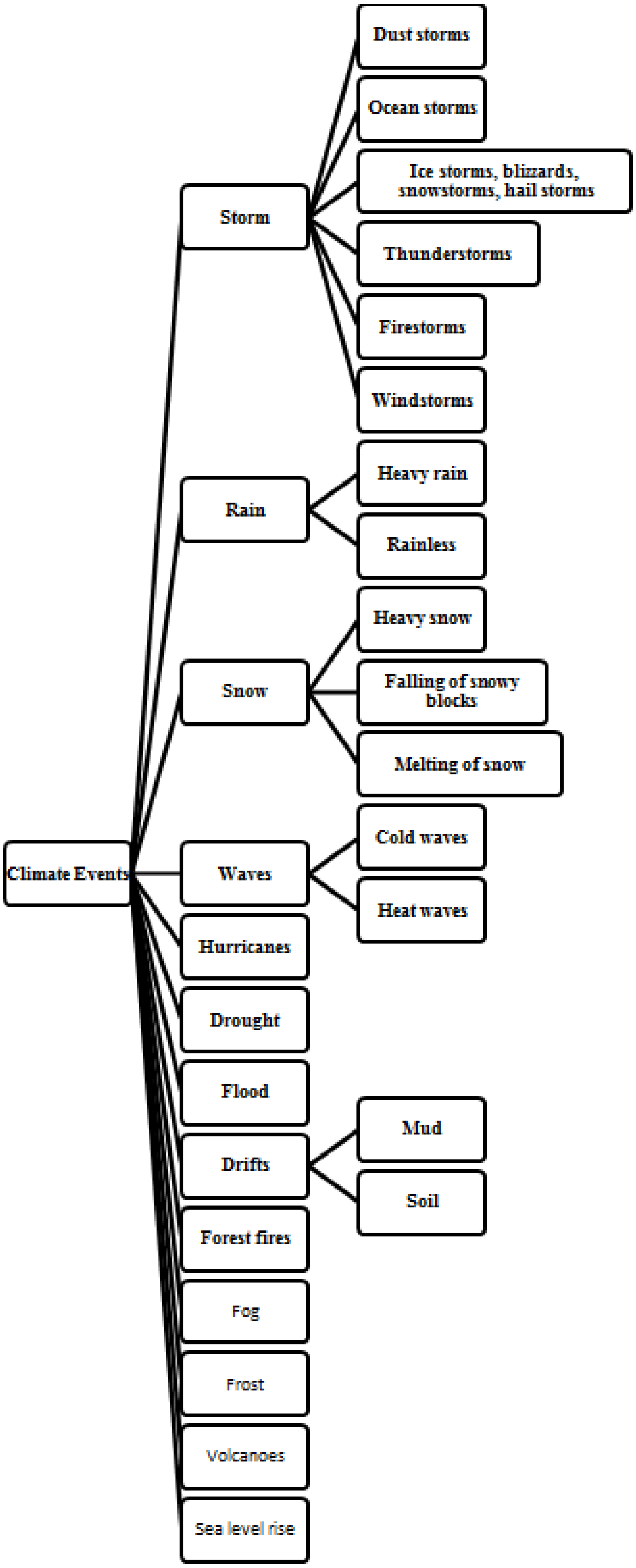


Figure 3-1: Climate events.

## 3.4 Events associated with climate change

Figure 3-1 identifies all severe events that may be associated with climate in general. However, this research will focus only on climate change events related to buildings. For the purposes of the present study, five types of climate change event and their impact on the built environment will be considered. These events are: temperature extremes, precipitation, windstorms, sea-level rise, and floods (as shown in Table 3-1).

### 3.4.1 Temperature extremes

Projections suggest a probable increase in the frequency and severity of heat waves, as well as warmer summers and milder winters (IPCC SREX, 2012). Studies of recent exceptional heat waves, which occurred in Russia (2010), Texas (2011), and Australia (2012), have indicated that climate change was a factor in triggering these events. Even during the recent brief hiatus in global warming, the highest temperatures over land continued to become more extreme.

### 3.4.2 Precipitation

Research indicates that there will be major changes in the patterns of rainfall and other types of precipitation – more frequent and intense in some places, less frequent leading to drought conditions in others. As the atmosphere heats up it will be able to retain more moisture – 7% for every additional degree Celsius in mean global temperature. Although estimates vary as to how much additional precipitation this will lead to, climate models suggest that places that are already wet will become wetter, but it has yet to be determined to what extent precipitation will rise or what local impacts will ensue. Significant increases in rainfall may result in flooding, an acceleration in the loss of topsoil, and a threat of damage to property (Brooks et al., 2000).

When soils in areas of high rainfall become saturated with water, they may slide downwards in a semi-liquid state. These mild landslides are referred to as mud or soil drifts (Smith and Mendelson, 2006) and occur in areas with extremely high levels of rainfall, resulting in the over-saturation of soil, causing it to slide downwards, especially on sloping ground (Lydolph, 1985).

### 3.4.3 Wind storms

Differential heating of the atmosphere gives rise to pressure differences that cause wind. Climate change is expected to give rise to more powerful and frequent storms involving higher wind velocities. Of particular concern as a threat to lives and property are hurricanes, the number and intensity of which many researchers believe will increase as a consequence of global warming (Mimura et al., 2007). A hurricane forms as a result of a deep low pressure over warm water near the equator, between latitudes roughly 5° and 20° north and south of the equator. This causes strong winds that can reach speeds of 200 km/h or more, accompanied by very heavy rain and thunderstorms. In the Indian Ocean and the South Pacific, hurricanes are referred to as tropical cyclones. Meteorologists believe that one of the effects of climate change will be the spawning of larger and more frequent hurricanes with more intense winds (Knutson et al., 2004).

### 3.4.4 Sea-level rise

The graph below (see Figure 3-2), formulated by Church et al. (2004), shows the mean global sea level for the period 1900–2000 (as shown in Figure 3-2). The Intergovernmental Panel on Climate Change (IPCC, 2007) stated that the rise in sea level is a concern, particularly in coastal zones. Moreover, it is expected that the rise in sea level may eventually submerge low-lying areas that are currently home to many millions of people around the world (Wassmann, 2004).

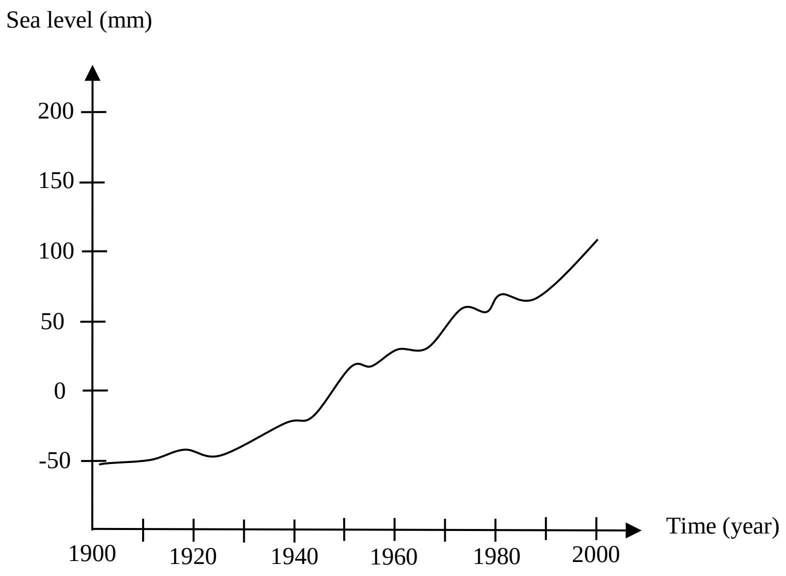


Figure 3-2: Global mean sea level between 1900 and 2001 (Church et al., 2004).

### 3.4.5 Floods

Floods may occur anywhere as a result of intense precipitation and may arise after a period of drought, when heavy rain falls onto ground that is dry and hard, thus making it difficult for water to penetrate the surface. Floods may be caused by thunderstorms, tropical cyclones, deep, low pressure, melting snow or atmospheric instability. However, The National Sea Grant Network says that floods occur when water draining from a watershed exceeds the capacity of the river or stream channel, which would usually contain the normal flow. This increase in flow is typically caused by heavy rainfall from a large storm or may even be caused by the melting of snow. Some river flooding occurs naturally and seasonally and is thus incorporated into the way of life where it happens. Other river flooding takes place in conjunction with the melting of ice, where a river is filled with water very quickly as a result of very heavy rain, leading to flooding of the river (McCluskey, 2001). *Coastal flooding* is often the result of earthquakes or volcanic activity, the wind generated from tropical storms and hurricanes, intense or low-pressure systems or, sometimes, a result of the tides. All of these conditions can occur and cause significant coastal flooding (McCluskey, 2001). *Urban floods*: Urbanisation has reduced the capacity of water absorption to 2 to 6 times less than that seen in natural terrain. In urban areas, flooding can quickly escalate, leading to streets becoming fast-flowing rivers. *Flash floods* tend to be the result of heavy rain within a small area, free of dams and often in dry or desert areas (McCluskey, 2001).

Table 3-1: Phenomena linked to climate change.

| | Temperature | Precipitation | Windstorms | Sea-level rise | Flood | References |
|---|---|---|---|---|---|---|
| 1 | x | | x | | x | Jollands et al., 2005 |
| 2 | x | x | x | x | | Hulme et al., 2002 |
| 3 | x | x | x | x | | Gill, 2004 |
| 4 | x | | x | x | x | The Council of Australian Governments, 2007 |
| 5 | x | x | x | x | | Austin, Rydin and Maslin |
| 6 | x | x | x | x | x | Garvin, Phillipson, Sanders, Hayles and Dow, 1998 |
| 7 | X | X | | x | | Nickson et al., 2011 |
| 8 | X | X | X | | x | Principal Sustainability and Climate Change Coordinator, 2012 |
| 9 | X | X | | x | | Jenkins et al., UK Met Office, 2007 |
| 10 | X | X | X | | x | Snow and Prasad, 2011 |
| 11 | X | X | | x | | Commercial Building Stock and Climate Change Adaptation: Costs, Value and Legal Implications, 2009 |
| 12 | x | x | | x | | The SCCIP programme, 2011 |

## 3.5 Summary

Human-caused climate change is now a scientifically recognised fact, although uncertainty still exists over the speed, severity and detailed nature of future changes. The risks of climate change (CCRs) to the built environment can be grouped into five main categories: temperature extremes, precipitation, windstorms, sea-level rise, and floods. Each of these categories are discussed.

# Chapter 4: Climate Change Risks

### 4.1.1 Introduction

Climate change is a significant new risk factor that will influence the design, construction and operation of buildings (De Wilde and Coley, 2012). However, In recent years, researchers have begun to focus more attention on the likely impacts of climate change on the built environment (Booth, Hammond, and Lamond, 2012), so that there is a pressing need for further research in this field. The present chapter will review the risks emerging as a result of climate change and examine how they are likely to affect building assets. These risks will then be clustered into physical, social, economic and management categories, in order to facilitate the development of resilience strategies.

Next will be considered what is meant by "built environment", what this term will be taken to mean for the purposes of this study, and aspects of the built environment that are at risk from climate change.

## 4.2 Built environment

The term "built environment" has been defined in many different ways, with varying degrees of generality. The Oxford English Dictionary states: "*the built environment consists of buildings and all other things that have been constructed by human beings*". Other definitions see it as the outcome of human needs and actions, inclusive not only of the buildings in which we live, work, go to school, and play, etc., but of the support system we have created around us including farms and plantations (Glanz et al. 2008). McClure and Bartuska (2007) concur, arguing that the built environment consists of not only human-made structures and spaces (e.g. parks) but also infrastructure elements such as streets, walkways, and mains supplies of power and water.

In a broad sense, the built environment can be considered to be an entity, both physical and cultural, in which material elements and energy are made to work in various ways to support our lives, work, and recreation. It is "*the human-made space in which people live, work, and recreate on a day-to-day basis*" (Roaf and Oleru, 2008). In another study (Washington, D.C., 2005) the built environment is seen to encompass the way humans use land, their systems of transport, and designed aspects of their environment that enhance a varieties of activities from travel to aesthetic.

For the purposes of this study, the built environment will be taken to include all structures created by humans but will focus in particular on buildings of which the key elements will be taken to be the structure, materials, system, roof, ground floor and façade. Furthermore, this study will be concerned with the impact of climate change on these elements of the built environment.

The overwhelming scientific consensus is that rapid change, human-caused climate change (over a timescale of decades) is now happening and will lead to a range of increasingly severe environmental conditions around the globe. These conditions, and their impact on human and other life, will vary from one location to another, but will include rising sea-levels, disruption of oceanic and atmospheric currents, flooding, drought, increasingly severe weather (for example, more powerful storms), and greater extremes of temperature. Multiple effects will follow from these changing meteorological and oceanic conditions, including loss of agricultural land, health risks (especially to the young and elderly) from intense and sustained heat waves, coastal erosion and inundation of low-lying coastal areas by the sea, potable water shortages, and degradation of the natural environment (World Meteorological Organization, 2013).

The present study focuses specifically on the effects and risks of climate change as they pertain to occupied buildings.

## 4.3 Climate change and the risks to buildings

Buildings are both extremely important to human life and vulnerable to climate change, and for these reasons more research is urgently needed into the impact of climate change on the building sector (Waskett, 2003). Among the more significant challenges facing the integrity of buildings, due to climate change, are increasing average temperatures, stronger winds, and changing precipitation patterns (Capon and Oakley, 2012).

Future events, stemming from climate change, may serve to weaken the structure of buildings, increasing the risk of collapse in some, and generally lowering the average lifespan of buildings, thus not only putting their occupants at risk but reducing their value (De Wilde and Coley, 2012). The effects of climate change on buildings are expected to be incremental, with the risks and impact mounting over time (Hacker et al., 2005). In addition, the probability of complete destruction of some buildings will also increase due, for example, to the increasing severity of storms and, in low-lying coastal regions, the threat of erosion and saltwater intrusion (Vivian et al., 2005).

## 4.4 Classification of types of risks of climate change on buildings

### 4.4.1 Classifications used in earlier studies

The purpose of this section is to review how recent studies have classified the various types of impact that climate change is expected to have on the built environment and the risks associated with these. Different authors have identified, or focused on, different aspects of the effect of climate change on buildings. These aspects include: physical, environmental, economical, social (or socio-economic), cultural, and management. Lienert and Kropac (2012), for example, discuss social, physical, economic and management factors (see Figure

4-1), whereas Chantry (2012) focuses on social, physical, environmental and economic (see Figure 4-2). Comley (2007) breaks down the climate change risks into the three dimensions of economic, social and environmental. For both Midgley et al. (2005) and Williamson et al. (2009) the emphasis is on physical, social and economic factors (see Figure 4-3).

Other reports, in classifying risks, have been concerned with specific geographical regions or cultures. For example, a study by the Centre for Indigenous Environmental Resources (2006) addressed physical, social and cultural impacts of climate change. In a paper specific to South Africa, Turpie et al. (2002) dealt with only economic issues, whereas Bartlett et al. (2010) restricted themselves to social and economic factors insofar as climate change would affect the living conditions of people in Nepal. By contrast, Coughlin and Goldman (2008), reporting on the impact of climate change on the Western US electricity system addressing mainly the physical aspect. Socio-economic impacts formed the central focus of a study by the UK Climate Impacts Programme (2000).

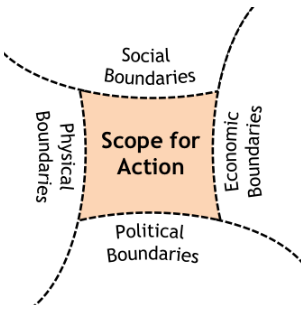


Figure 4-1: Main aspects of sustainability in the built environment
(Lienert and Kropac, 2012).

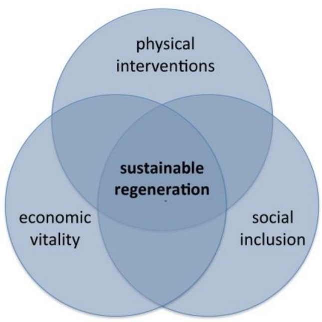


Figure 4-2: Main aspects of sustainability in the built environment
(Design principles 2015)

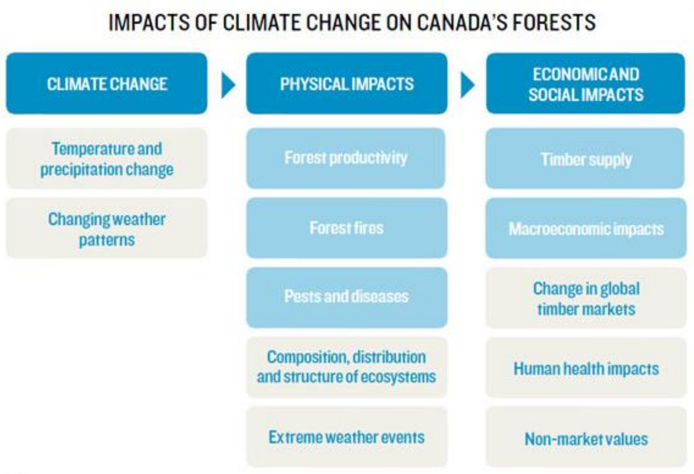


Figure 4-3: Impact of climate change on Canada's forests (Williamson et al., 2009).

### 4.4.2 Classification of climate change risks for buildings used in this research

For the purposes of the present research, which is concerned with the risks of climate change on the built environment, the risks due to climate change will be broken down into the following categories: physical, social, economic and management (see Figure 4-4). In the next section of this chapter, each of these categories of risk will be dealt with in turn, and discussed in relation to some of the main phenomena that will be associated with climate change and how these will affect different elements of buildings. This categorisation will then be used as the basis from which to develop resilience strategies.

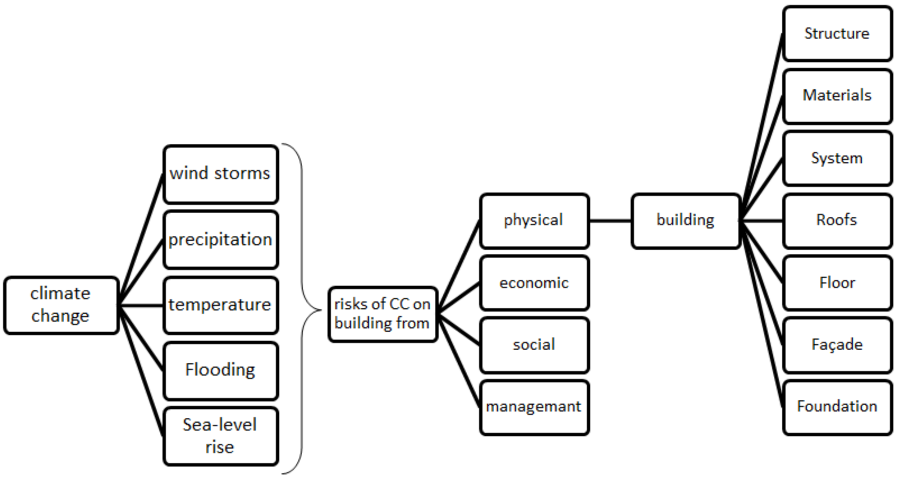


Figure 4-4: Classification of risks of climate change on aspects of buildings used in this research.

## 4.5 Risks of climate change on buildings

### 4.5.1 Physical risks

#### *4.5.1.1 Introduction*

In the context of the present study, ‘physical environment’ is taken to mean the physical environment of a building. The physical built environment includes any measurable property such as temperature, humidity, illuminance, and thermal conductivity. Phenomena associated with climate change are anticipated to have a direct effect on the physical environment of buildings (De Wilde and Coley, 2012 and Rickaby et al., 2009), which in turn will affect the wellbeing of its inhabitants. The severity and nature of these effects will vary from one location to another. Among places where the impact will be particularly acute are low-lying coastal regions, which will suffer because of sea-level rise. Such regions account for only about two per cent of the world’s land area but are home to about 13 per cent of the total global urban population. In the next section, the physical risks of climate change on buildings will be considered. In addition, List of physical risks on building are placed on the end of this section (see table 4-1).

With regard to the parts of a building, there are various ways to consider and analyse these. Figure 4-5, for example, illustrates the main components as identified by TURK Structure (2013); these include floors, walls, openings (e.g. doors and windows), and the overall structure. McMichael et al. (2006), in their study, emphasise the building’s systems (electric system, sanitation, etc.), infill, content and structure. Straubein (2006), as shown in Figure 4-7, takes as the component parts: floors, overall structure, walls, openings and roofs. Newman et al. (2013) single out floor, foundations, structure, surface and drainage system, whereas the National Institute of Building Sciences (2011) treats the main parts of a building as being the walls, structure, façade, roof, system and foundation For the purposes of the present study the main physical elements of building will be taken to be: (1) structure, (2) materials, (3) system, (4) roofs, (5) ground floor, and (6) façade (see Fig 4-6).


Figure 4-5: Main parts of a building as indicated by TURK Structure (2013).

Figure 4-7: Main parts of a building according to Straube (2006).

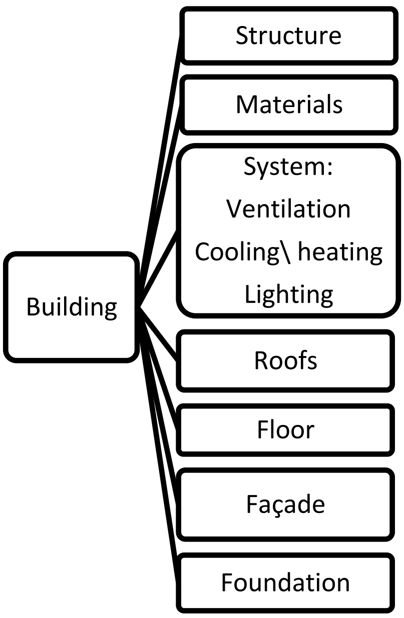


Figure 4-6: The components of a building considered in the present study.

#### *4.5.1.2 Physical risks from windstorms*

With regard to enhanced windstorm risks resulting from climate change, the very few studies have been published that show the resulting effects on buildings as the storm gets progressively stronger. Some research is available, based on past experience and theoretical modelling, such as that by Needham and Keim (2011), on the effects of tropical cyclones on coastal regions (see Figure 4-7). There are also studies that investigate the extent to which areas of low-lying coastal land may be flooded and submerged at times of surge, especially when the surge comes obliquely to the coast (Berg, 2009). Local differences in topography, in addition to the whether flood control features, such as levees, are in place,  influence the outcome of surges (Needham and Keim, 2011).

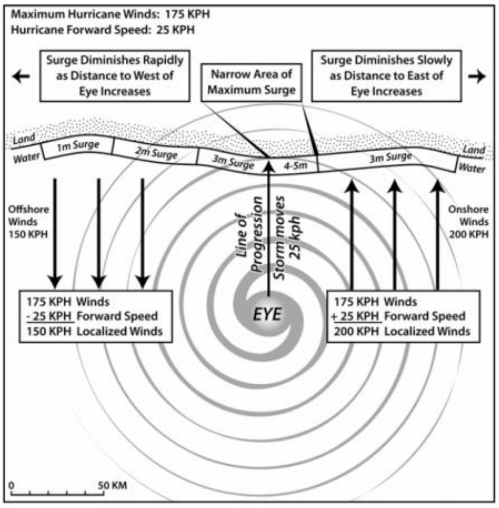


Figure 4-7: Generalized schematic of storm surge heights relative to position, path and wind speeds of a tropical cyclone (Needham and Keim, 2011).

Non-elevated structures in coastal zones not protected by levees or seawalls are most at risk from flooding when surges occur. Marine infrastructure, such as docks and other structures adjacent to the water, may sustain substantial damage or be washed away, especially where there is also powerful wave action (Needham and Keim, 2011).

Storm winds have a particularly pronounced effect on high-rise buildings, which are subject to a variety of strong linear, shear, and twisting forces. Rapid changes in wind strength can create large pressure differentials between the interior and exterior faces of a building, posing the risk of damage to the façade and external walls. In addition, strong winds can act as a weight on flat roofs and cause neighbouring structures, such as trees, to collapse on the roof and walls (Principal Sustainability and Climate Change Coordinator, 2011). The effects depend to a large extent on the materials and techniques used in construction, and upon how well the building is designed to resist the effects of wind and water.

In the UK in 2003 it was estimated that there were approximately 200,000 wind damage events, which resulted in destruction costing around £70 million (Sanders and Phillipson, 2003). Major disasters, such as the storm of 1987, which affected 1.3 million houses (6%) of the UK domestic housing stock and are expected to increase in frequency due to climate change, can dramatically affect annual statistics (Sanders and Phillipson, 2003). There is also some evidence that even a slight increase in average wind speed over time may lead to significantly more incidences of damage to property (Graves and Phillipson, 2000).

Another factor to be considered is the effect of more frequent and powerful storm surges, as a result of climate change, on the strength of buildings due to increasing levels of humidity and saltwater incursion. Coastal buildings exposed to storms are at risk from corrosion of steel in structural members from saltwater, leading to cracks and a loss of structural integrity or a weakening of foundations (Moncmanova, 2007). Increased humidity and salting can also adversely affect other building materials, especially wood, which is made to warp and split (Richardson, 2001).

Figures 4-8 to 4–13 illustrate some effects of a powerful storm surge on a coastal community in the United States in 2004. The photos were taken before and after the storm.

Figure 4-8 Before storm, 2004 (USGS)

Figure 4-9 Before storm, 2004 (USGS)

Figure 4-10 Before storm, 2004 (USGS)

Figure 4-11 After storm, 2004 (USGS)

Figure 4-12 After storm, 2004 (USGS)

Figure 4-13 After storm 2004 (USGS)

#### *4.5.1.3 Physical risks from precipitation*

Erkal, D'Ayala and Sequeira (2012) state that heavy rain, more occurrences of which in some regions will be another consequence of climate change, is one of the key factors responsible for the erosion of roofs and walls. By erosion in this context is meant the separation of building materials from the interface due to the impact of raindrops on the wall surface. This process happens continuously and, over long periods, rainwater can penetrate a building's façade, reaching deep into walls and causing their inner parts to decay (Smith et al., 2010).

With increasing levels of precipitation due to climate change, combined with rising levels of atmospheric pollution, comes a heightened risk of acid rain attack on buildings. Acid rain is caused when gases such as sulphur dioxide and nitrogen oxides dissolve in water droplets. Berg (2009) has investigated how changing levels of acid rain and other factors affect the rate of erosion of building materials such as stonework and metals. The risk of walls and other parts of buildings disintegrating is particularly great when there is frequent alternation of saturation of walls by rainwater and drying by solar radiation. As the outer surfaces of the wall expand and contract, fissures open up in them allowing moisture to penetrate the structure (as shown in figure 4-14). Driving rain, accompanying more intense precipitation events, also enables water to penetrate exterior walls and, especially when combined with expansion damage when the water freezes and melts, can compromise the surface of a building. The detrimental effect is greater in the case of walls that have been rendered than those with cladding (Lisø et al, 2003), and penetration by intense rain can also be a problem in walls with cavity insulation unless the cavities and gaps are made wide enough (Sanders and Phillipson, 2003).

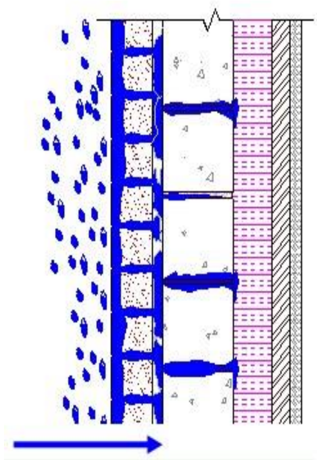

Figure 4-14: Water incursion in a wall. Daniel et al. (2010).

With more frequent rain due to climate change, there is the increased likelihood of fog, which can also contribute to the corrosion of buildings whose structural components contain steel or iron (McCauley, 2004). Acidic fog is a particular problem in this respect because it accelerates the corrosion of building materials, especially those that are galvanised, rendering them flakier and less structurally sound (EPA, 2012). Fog may also cause the settling of moisture in small gaps, resulting in the degradation of building materials by various processes including the formation of moss (Shultz, Russell and Espinel, 2005).

#### *4.5.1.4 Physical risks from temperature change*

Temperature changes due to climate change will affect the physical integrity of buildings both internally and externally. Greater extremes of temperature and, in some locations, greater variations in the amount of solar radiation falling on different external surfaces of buildings are anticipated consequences of climate change. The latter effect, for example, results in the walls of a building expanding (or contracting) differentially with the result that a wall exposed to harsh sunlight may curve convexly, while a sheltered wall will tend to have its structural units deformed concavely (Grøntoft, 2012).

Thermal movement between adjacent materials and components is an increasingly important area of concern in connection with the impact of climate change on buildings. Whenever there is a significant difference in expansion coefficient between adjacent materials and there are large changes in temperature then problems are likely to arise. Thermal movement can also occur between materials of different colour and absorptivity when exposed to sunlight (Grøntoft, 2012).

Increasing amounts of ultraviolet radiation have been predicted in the summer months due to reduced cloud cover, which is another consequence of climate change. According to one projection, global cloud cover will be about 15% less by the 2080s than it is now. This increased UV, together with rising average temperatures, will degrade paintwork, other exterior finishes, and plastic- and rubber-based materials faster, so that properties need maintenance work on a more regular basis. Sealants and jointing materials will be especially vulnerable and their failure would exacerbate the problem of rain penetration through a structure (Garvin et al., 1998).

As drought becomes more prevalent in some places, due to climate change, so many buildings will start to experience fatigue faster. One way this could happen is as a result of tree roots forcing themselves under buildings, away from the dry soil around the building's edges and thereby forming cracks in the floor and walls (Waugh and Bushell, 2002). Sometimes such damage may be irreparable and require the entire dismantling of the structure (Campbell and Corley, 2012).

Additional heating of buildings, due to climate change, may also lead to extra stress on roofing materials so holes appear in them through which water can gain access in the rainy season. Worsening droughts will also lead to more wildfires, and an increase in the threat these pose to homes and other properties (Parker and Shapiro, 2008). Rising temperatures also heighten the risk of aggressive insect infestations, such as those of wood-boring and other invasive insects (Austin, 2013).

#### *4.5.1.5 Physical risks from flooding*

In most years, flooding causes more deaths and damage than any other hydro meteorological phenomenon (McMichael et al., 2006). In the US, three-quarters of all federally declared disaster declarations are typically due, at least in part, to flooding. The amount of damage to buildings from flooding depends largely on the height to which water rises inside the buildings (Ross et al., 2007). Not surprisingly, material damage from floods tends to be less serious in the case of buildings with masonry construction than those of weaker structure (Sanders and Phillipson, 2003).

With heavier precipitation and rising sea levels, as consequences of climate change, more flooding is expected, especially in buildings on the coast or on flood plains. Differences in elevation between the water inside and outside a structure (see Figure 4-15) put pressure on the walls and can also cause uplift on slabs and floor systems (Munach, 2010). The physical effects of flooding may involve the buildings structure, systems, infill and contents (McMichael et al., 2006).

Figure 4-15: Difference in elevation between the water inside and outside of a structure (Munach, 2010).

In some cases floods may cause landslides, which may, depending on the underlying geology, trigger ground movement, or drift, and subsidence under buildings (see Figures 4-16 and 4-17). The risk to a building, if subsidence occurs, depends largely on its construction and, in particular, the strength of its foundations (Munach, 2010). If the foundations move because of drift then the building might collapse (Oreskes, 2002). Residual drifts, too, may affect a building's structural performance (Ramirez, 2012). There is also the danger that adjacent structures might be destabilised, leaving cracks over the entire building, and that a building's electrical installations are put at risk (Philips, 2001). In the UK in 2003 insurance claims totaled around £400 million for domestic residences that had suffered from subsidence (Not all of the claim are related to subsidence risk) (Sanders and Phillipson, 2003).

Figure 4-16: Muncah (2010)

Figure 4-17: Munach (2010)

#### 4.3.1.4 Physical risks from sea-level rise

Over the past 100 years, the average level of seas around the world has increased by about 170 mm (Solomon et al., 2007). By 2050, studies suggest that this rise will have reached approximately 1 metre, depending on the assumptions made about the extent of global warming. This effect will pose a challenge to the erection of any buildings in coastal regions due to more frequent incidences of floods and storm surges (Leatherman et al 1997).

Physical risks caused by sea-level rise due to climate change will in many cases affect buildings indirectly or slowly, due, in the first place, to various environmental degradation processes (SMH, 2012). In other instances, inundation may come quickly in the form of destructive wave over-topping or severe storms, such as hurricanes, that result in the immediate and extensive loss of infrastructures and both residential and commercial buildings (Vafaee, Harati and Sabbaghian, 2012). Some studies have cited disruption of drainage systems due to sea-level rise, especially in coastal regions, which will make it difficult to erect new properties in those areas (Houghton, 2004).

Table 4-1: Physical Risks of CC on Building. W = windstorm, PC = precipitation, T = Temperature, F = Flood, SLR = Sea-Level Rise.

| Building parts | code | Risks | Category | References |
|---|---|---|---|---|
| Structure | PR1 | Reduce the structure strength | W | Moncmanova, 2007; Richardson, 2001; Principal Sustainability and Climate Change Coordinator, 2011 |
| | | | T | Baum, 2011; Llanos, 2012; Hertfordshire County Council, 2013 |
| | | | PC | Hobson and Wassenaar, 2008 |
| | | | F | Ramirez et al., 2012; Munach, 2010; Benton, 2005; Sanders and Phillipson, 2003 |
| | | | SLR | Almås et al., 2012 |
| | PR2 | Structure's corrosion | PC | Berg, 2009; McCauley, 2004 |
| Facade | PR3 | Blockage entrance to building | W | Needham and Keim, 2011 |
| | PR4 | Appearance of fungus and mould on parts of the building | W | Beall, 1998 |
| | PR5 | Damage to the exterior walls result from erosion | W | Richardson, 2001 |
| | | | PC | Erkal, D' Ayala and Sequeira, 2012 |
| | PR6 | Damage to the exterior walls result from cracking | W | Richardson 2001 |
| | | | T | Campbell and Corley, 2012 |
| | | | F | Philips, 2001; Sanders and Phillipson, 2003 |
| | PR7 | Change colours of the exterior walls | W | Richardson, 2001 |
| | | | PC | Human Settlements, 2011 |
| | PR8 | Reduce the performance of the windows | PC | Noble, 2004 |
| | PR9 | leaks | PC | Sanders and Phillipson, 2003; Lisø et al., 2003 |
| System | PR10 | Reduce the efficiency of ventilation system | W | Richardson, 2001 |
| | PR11 | Reduce the efficiency of lighting System | W | Richardson, 2001 |
| | PR12 | Damage to overhead power lines in buildings. | W | The Secretary of State for Environment, Food and Rural Affairs, 2011 |
| | PR13 | Sanitation system capacity efficiency | W | Richardson, 2001 |
| | | | F | Sanders and Phillipson, 2003; Hertfordshire County Council, 2013 |
| | | | SLR | Houghton, 2004 |
| | PR14 | Reduce the efficiency of the power generators | PC | Principal Sustainability and Climate Change Coordinator, 2011 |
| | | | T | Gregory, 2011 |
| | | | F | Philips, 2001 |
| Roof | PR15 | Reduce the efficiency of the roof | W | Graves and Phillipson, 2000; Richardson, 2001 |
| | | | PC | Erkal, D' Ayala and Sequeira, 2012 |
| | PR16 | Leaks | W | Principal Sustainability and Climate Change Coordinator, 2011 |
| | | | PC | Sanders and Phillipson, 2003; Lisø et al, 2003 |
| Ground floor | PR17 | Reduce the foundation's strength | W | Needham and Keim, 2011; Barnes, 2007 |
| | | | F | Oreskes, 2002 |
| | | | SLR | Almås et al., 2012 |
| | PR18 | Loss the ground floor usage | W | Berg 2009; Lawrence and Cobb, 2005; Richardson 2001 |
| | | | T | Waugh and Bushell, 2002 |
| | | | F | Munach, 2010 |
| Material | PR19 | Dilation the construction materials | PC | Erkal, D' Ayala and Sequeira, 2012 |
| | | | T | Garvin, et al., 1998 |
| | PR20 | Materials erosion | PC | Berg, 2009 |
| | PR21 | Damage to materials due to the stability of moisture in small gaps | PC | Shultz, Russell and Espinel, 2005 |
| | PR22 | Appearance of fungus and mould on material | PC | Shultz, Russell and Espinel, 2005 |

### 4.5.2 Economic risks from climate change

#### *4.5.2.1 Introduction*

Climate change has serious economic implications from the individual to the international level, and for both the public sector, including governments, and the private sector, not least for insurance companies (Wallingford, 2012). In this section the economic effects of climate change will be considered as they pertain to buildings. In addition, List of economic risks on building are placed on the end of this section (see table 4-2).

#### *4.5.2.2 Economic risks from windstorms*

Strong winds and storms or various kinds, the prevalence of which is expected to increase due to climate change, will cause property damage and even the complete loss of many buildings in the future. The negative economic effect is exacerbated by the fact that storms strike unpredictably and often with little warning (Benders-Hyde, 2003). Affected buildings may include essential commercial centers, factories, hotels, restaurants, and retail properties, as well as homes. When buildings are damaged or destroyed, or when they are unable to operate properly, businesses suffer a setback (Doesken, 1994).

Even seemingly minor increases in the average wind speed of storms may have major economic consequences. Graves and Phillipson (2000) reported that a rise of just 6% in wind speed could cause damage to up to one million buildings, costing £1-2 billion (Graves and Phillipson, 2000). Individual large-scale events can prove extremely costly, and such events are anticipated to increase both in frequency and severity over the coming decades. The losses due to Hurricane Rosa in 2002, for example, totalled about $4.5 billion (Nott, 2003).

#### *4.5.2.3 Economic risks from precipitation*

Economic risks accompany both increases and decreases in precipitation. Extended droughts damage crops (Oxfam America, 2012) and pose a threat to stocks of potable water.

Over the next half-century the number of people suffering from a shortage of drinking water is expected to rise from 5 billion to 8 billion with a consequent shortage of water deliverable to many buildings (Ali, 2013).

Increased precipitation, in some areas and at certain types of year, also adds an economic burden in the form of damage to buildings, for example by acid rain (Wallace, 1989), which then requires additional maintenance (Oguntoyinbo and Akintola, 1983). Acid rain degradation is a particular problem in highly industrialied regions (Selders, 2011). To protect the buildings different paints are applied which is costly in terms of materials and labour (Lackey, 1997).

#### *4.5.2.4 Economic risks from temperature change*

Rising temperatures, due to climate change, will increase the need for artificial cooling of both domestic and commercial buildings, and therefore the cost of running them (Lomas and Giridharan, 2012). This will be the case particularly in urban areas where temperatures will increase disproportionately due to the urban ‘heat island’ effect. On the other hand, in dwellings where there is inadequate cooling, the greater frequency of heat waves will prove hazardous to health, especially among the elderly and very young, which is costly both in lives and health care. Commercial buildings in which temperatures become excessive will have economic effects through loss of working days. How much a building is vulnerable to more severe heat waves, stemming from climate change, depends on how it is constructed and, especially, on its thermal mass. Masonry and concrete buildings, for example, have a greater thermal mass than timber-framed ones and therefore have less need to be artificially cooled in summer and heated in winter (Arup Research and Development, 2007). Certain types of building design, for example where there is a central mass of masonry with a curtain wall of glass, are not as effective getting rid of heat than in cases most of the thermal mass is located in the roof and ceilings (Arup Research and Development, 2007).

Increased energy demand for electricity due to the need for more artificial cooling will put extra stress on power companies, which in turn will have economic consequences. Incidences such as that in which the electric power company Constellation Energy had its quarterly earnings cut due to an unprecedented heat wave in Texas in 2011, when it was forced it to buy additional power during peak demand, will become more common (Oxfam America, 2012).

As mentioned earlier, climate change brings with it too an increased risk of bush and forest fires and a consequent threat to buildings in the vicinity of such events (Alexander, 2002). The increasing threat to property and lives thus arising also has economic consequences, through the increased cost to government emergency services and disaster relief agencies, insurance companies, businesses, and individuals (Stephens and Lawrence, 2005).

#### *4.5.2.5 Economic risks from flooding*

Floods have increased in magnitude in recent years due to climate change (Wisner, Blaikie, Cannon and Davis, 2004). This is a problem most common in coastal areas and other areas that lie at, close to, or below sea level (Bankoff, Frerks and Hilhorst, 2003).

As in the case of rising average temperature, the economic risks of climate change from flooding of buildings may be both direct and indirect. Into the latter category fall insurance losses and increased costs to owners of property from flood damage and destruction (Third Assessment Report of IPCC. 2001). Costs are incurred not only through damage, however, but also through at least temporary loss of the building’s function (Kirshen et al., 2006). The economic effects also spill over into the transport sector, for example through delays or cancellations of flights due to flooding.

In the aftermath of major floods there may also be a shortage of construction materials, which puts the businesses of building companies at risk (Ruth et al., 2004). Water damage to properties is costly in terms of repair and loss of performance of buildings; moreover, maintenance costs in areas prone to flooding can be high (Rappaport, 2006). Negative economic consequences follow from both the impact on buildings and, in many cases, the loss of use of land during the time it takes the water to recede (Benton, 2005).

#### *4.5.2.6 Economic risks from sea-level rise*

The economic risks associated with rising sea levels are significant because of the large numbers of people living, and the amount of commercial development, in low-lying coastal areas around the world. Among the biggest negative impacts are the potential massive damage to properties and loss of land to erosion and fertile soil because of increased soil salinity (Davis, 2008). The economic loss can be quantified; for example, the cost of land erosion can be estimated from knowledge of the value of land in coastal communities, and, in particular, to what extent it decreases with increasing distance from the shore.

Even though sea levels are rising continuously due to climate change, economic problems that will ensue because of this have been given little attention (Davis, 2008). The economic impact will be especially severe where major ports and population centres are affected (San Francisco Chronicle, 2007).

Table 4-2: Economic Risks of CC on Building.

| Code | Risks | Category | Reference |
|---|---|---|---|
| ER1 | Increase in construction costs. | W | Sanders and Phillipson, 2003 |
| | | SLR | San Francisco Chronicle, 2007 |
| ER2 | Materials replacement due to damage | W | Nott, 2003 |
| ER3 | Shutdown of buildings to business | W | Oguntoyinbo and Akintola, 1983 |
| | | T | Pearce, 2002 |
| | | F | Hertfordshire County Council, 2013 |
| ER4 | Loss water storage usage | PC | Ilham, 2013 |
| ER5 | Increased demand for maintenance work for buildings | PC | Oguntoyinbo and Akintola, 1983 |
| ER6 | Increased manpower cost for buildings | PC | Selders, 2011 |
| | | F | Rappaport, 2006 |
| ER7 | Increased construction duration | PC | Lackey, 1997 |
| ER8 | Increase energy cost for cooling/heating | T | Arup R&D, 2007; Oxfam America, 2012; Hertfordshire County Council, 2013 |
| ER9 | Increases in maintenance costs of the building | T | Hertfordshire County Council, 2013 |
| | | F | Rappaport, 2006 |
| ER10 | Insurance losses for the building | F | Third Assessment Report of IPCC |
| ER11 | Reduce the efficiency of the building | F | Kirshen, at al., 2006; Rappaport, 2006 |
| ER12 | Increase materials prices. | F | Ruth, et al., 2004 |
| ER13 | increase prices of buildings | SLR | Davis, 2008 |

### 4.5.3 Social risks from climate change

#### *4.5.3.1 Introduction*

Scientists have begun to realise increasingly that climate change is an emerging risk factor in connection with the social aspects of buildings (International Association for Impact Assessment, 2003). These aspects have to do with the health and lives of occupants, and the well-being of communities and cultures. For example, rising temperatures and water infiltration into buildings due to flooding and more intense precipitation, may be detrimental to the health of the buildings' occupants (Benton and Ferry, 2010). A significant factor is the thermal comfort of those living or working in a building. Indeed, according to Nicol and Roaf (2007) thermal comfort is the single most important social factor in the context of climate change and energy conservation. The projected changes in climatic conditions will detrimentally affect human thermal comfort and the thermal performance of buildings (De Wilde et al. (2008). However, List of social risks on building are placed on the end of this section (see table 4-3).

The World Health Organization has estimated that 160,000 deaths since 1950 can be attributed directly to the effect of climate change, while others believe this may be a very conservative estimate (McMichael, Woodruff and Hales 2006). Social impacts will vary depending on the places, environment, community and social groups that are affected (Vanclay, 2002).

There is a great unevenness in the potential social consequences of climate change depending on factors such as income, age, ethnicity, and location. Differences within and between communities with regards to these factors result in some individuals and groups being far more vulnerable, and less able to adapt, to the effects of climate change than others (Confalonieri, 2007).

#### *4.5.3.2 Social risks from windstorms*

Powerful storms, such as hurricanes, the size and frequency of which are predicted to increase due to climate change, may devastate communities, and lead to the separation of family members after homes are destroyed and even the dispersion of whole communities (Penner, 2010). Another possible social implication is heighted crime, such as looting, after storm damage to buildings (Peek, 2006).

More subtle, yet still harmful psychological effects on people may follow after an important building in the lives of people, such as a home or school, is damaged by an event such as a severe storm. Children, for example, may be unsettled and find it hard to return to their previous routine. Peek (2006) found that displaced children who were put into different schools struggled to re-establish a stable pattern in their lives and to adjust possibly to a different racial, ethnic or socioeconomic environment, as well as trying to cope with disaster-related anxiety. In some cases, where hospitals or infrastructure is storm-damaged, people affected by a powerful event may find themselves without adequate medical care (Stephens, 2008).

#### *4.5.3.3 Social risks from precipitation*

In places that experience less overall rainfall because of climate change, social effects may stem from a shortage of water supplies and deterioration in the quality of water, for buildings and their occupants (Catford, 2008). An increase in frequency and intensity of rain and other forms of precipitation may also have a negative impact on social life. Open parts of a building, and its surroundings, become less usable, some outdoor activities may have to be cancelled (Bruce Arthur 2004), and, as Connolly (2008) has noted, more rainy days result in overall lesser enjoyment of leisure time.

#### *4.5.3.4 Social risks from temperature change*

It has been observed that there is a link between the psychological state of the occupants of a building and temperature. Hot weather appears to correlate with increased levels of violence, rioting and unrest in cities. Most significant riots in the USA, for example, have broken out when the temperature has been between 27$^{o}$C and 34$^{o}$C. (Rotton and Cohn, 2000a, 2000b).

An increase in average global temperatures due to climate change has the potential to adversely affect the health of building occupants, and even threaten the lives of vulnerable people, such as the elderly, in buildings without adequate cooling or ventilation (McMichael, Woodruff and Hales, 2006). The summer heat wave of 2003 in the UK, for example, resulted in some 2,100 additional deaths (Johnson et al., 2005).

Rising temperatures may also result in the loss of functionality of some parts of buildings, such as open spaces in schools or sports facilities, with a consequent social impact (Grimmer et al., 2006). Additionally, in areas that suffer elevated levels of air pollutants and periods of extreme cold in winter these will constitute health risks especially in buildings that have poor ventilation (Hajat, 2010 and Vandentorren et al., 2003).

#### *4.5.3.5 Social risks from flooding*

Occurrences of widespread and severe flooding, which are expected to accompany climate change, have the potential to affect large numbers of people at the same time. Especially in highly populated, low-lying regions that have a limited ability to absorb increased annual rainfall and that may lack efficient drainage systems, the social cost, in terms of lives disrupted or lost through flood damage to buildings will be high (Cooper, 2013). Among the social problems facing people who are the victims of more severe and recurrent episodes of flooding due to climate change are displacement from their homes and loss of belongings, with accompanying physical and emotional trauma, insecurity, deteriorating health conditions (especially in third world or developing nations where there may be inadequate medical and social services), and breakdown of communication within a community (Hussein, 2013).

Repeated episodes of flooding will also reduce the sense of security of residents of buildings in affected areas, causing them to feel as if to feel they are in danger at any moment (Ramirez and Miranda, 2012). Floods due to climate change also have the potential to increase social tensions or create new tensions, perhaps even serving a catalyst for violent conflict and a threat to security (United Nations News Centre, 2013).

#### *4.5.3.6 Social risks from sea-level rise*

Among the most notable social outcomes of sea level rise will be the displacement of millions of people whose homes and communities have become uninhabitable as the ocean encroached upon their coastal buildings. In some cases, individuals will be forced to give up their traditional dwellings, lifestyles and livelihoods. As large numbers become migrants because of sea level rise, either within their own countries or across national boundaries, there is the risk of cultural values being lost, psychological instability and conflicts over resources (Knogge et al., 2004).

Table 4-3: Social Risks of CC on Building.

| Code | Risks | Category | Reference |
|---|---|---|---|
| SR1 | Occupant's dispersion. | W | Penner, 2010; WHO, 2003 |
| SR2 | Reduce the level of security of the population<br>Or<br>Higher levels of street violence and attacks, as well as rioting between the occupants of the building. | W | Peek, A. and Peek, L., 2006 |
| | | T | Rotton and Cohn, 2000a, 2000b; Hajat, 2010; Vandentorren et al., 2003 |
| | | F | Committee on World Food Security 2003; Walid Hussein, 2013; UN News Centre, 2013 |
| SR3 | Negative effects on the psychological consequences | W | A. and L. Peek, 2006 |
| | | SLR | Knogge et al., 2004 |
| SR4 | loss of services in building | W | Stephens, 2008 |
| SR5 | Lack of supplies, and the deterioration of the quality of supplies for the occupants. | PC | Adam, 2005 |
| SR6 | Lower enjoyment of leisure for the occupants | PC | Arthur, 2004; Connolly, 2008 |
| SR7 | Cancellation of occupant’s activity. | PC | Arthur, 2004; Connolly, 2008 |
| SR8 | Health risks | T | McMichael, Woodruff and Hales, 2006; Journal of International Politics. 2012; Johnson et al., 2005; Hertfordshire County Council, 2013; Epstein, 2002; Hajat, 2010; Vandentorren et al, 2003 |
| | | F | Committee on World Food Security, 2003; Walid Hussein, 2013 |
| SR9 | Reduce the Indoor air quality | T | Hajat, 2010; Vandentorren et al, 2003; Ilham, 2010 |
| | | SLR | Knogge et al., 2004 |
| SR10 | Loss the function of the building | T | Chennai, 2012; Grimmer et al., 2006 |
| | | F | Ramirez and Miranda, 2012 |
| SR11 | Cancelation of some building activities | T | Chennai, 2012; Grimmer et al., 2006 |
| SR12 | absence from work | F | Committee on World Food Security 2003; Walid Hussein Sophie, 2013 |
| SR13 | Continuing concern for the building occupants to loss of valuables of the building. | F | Committee on World Food Security 2003; Walid Hussein, 2013; UN News Centre, 2013 |
| | | SLR | Knogge et al., 2004 |
| SR14 | Reduce social communication between the building occupants. | F | Cooper of JBA Consulting, 2013 |
| SR15 | Temporary or permanent displacement in building occupants | F | Cooper of JBA Consulting, 2013; Hertfordshire County Council, 2013 |
| | | SLR | Worldwatch Institute, 2013 |
| SR16 | Occupants concerned that the building may not Stand up to the flood | F | Ramirez and Miranda, 2012 |
| SR17 | Scary of building resources | SLR | Worldwatch Institute, 2013 |

### 4.5.4 Management risks from climate change on buildings

#### *4.5.4.1 Introduction*

Building operation and management will face mounting challenges due to the effects of climate change. These effects may disrupt the operational capacity of a building to perform its functions and, in turn, the running of an organisation. The knock-on risks to management include uncertainties in financial markets, legal liabilities, project failures, and credit risks (Khatta, 2008). Climate change has far-reaching impacts on building operation because it influences processes such as contracting, planning, safety, procurement, legal, operations, emergency services and policy (American Society of Civil Engineers, 2002). However, List of management risks on building is placed on the end of this section (see table 4-4).

#### *4.5.4.2 Management risks from windstorms*

Management of climate change-related impacts from storms will prioritise the rescue and evacuation of victims from the risk, but at other times involve ensuring compliance with ordinances and regulations related to safety in order to ameliorate the effects of other events. Climate change puts management under pressure to find the tools to offset future risk to the wellbeing of buildings and their occupants (Pollner et al., 2010).

Information and communications systems, critical to management functions, are also vulnerable to severe storms (Pulwarty, 2013). Likewise, strengthening and more frequent incidences of strong winds may bring down power lines, which can disrupt the ability to operate a building and manage it effectively (Department for Environment, 2011).

#### *4.5.4.3 Management risks from precipitation*

As with other phenomena related to climate change and their impact on buildings, shifting patterns of precipitation will require that management adopt new policies and planning strategies to compensate (Dischel, 2002). Communication is fundamental because of its critical role during evacuation as well as the operation of a building. The management will thus be compelled to establish effective communication platforms with government agencies concerned with occurrences of extreme weather.

#### *4.5.4.4 Management risks from temperature change*

In regions affected by rising temperatures due to climate change, the onus is on management to ensure the safety and comfort of people working in buildings. Among the challenges to management in this regard is including developing new policies for buildings that are better suited to a changing environment (Goncalves and Umakoshi, 2010).

#### *4.5.4.5 Management risks from flooding*

In addressing the issue of increased flooding risk caused by climate change, management will need to develop long-term policies that may involve relocating to safer ground, decisions that have major financial implications. Another crucial issue is to determine how communication is maintained, and how access to facilities continues to be enabled, in the event of floods (Henschel, 2008).

#### *4.5.4.6 Management impacts from sea-level rise*

Sea-level rise due to climate change is an issue that calls for long-term planning. Management must take account of global warming projections to decide where to safely erect new buildings or adapt and protect existing ones (Gormley and Mansergh, 2009).

Table 4-4: Management Risks of CC on Building.

| Code | Risks | Category | References |
|---|---|---|---|
| MR1 | Stress on emergency plans | W | Pollner et al., 2010 |
| MR2 | Constant pressure to find the tools use in avoiding any risk | W | Pollner et al., 2010 |
| MR3 | More frequent information and communication systems breakdowns | W | Pollner et al., 2010 |
| MR4 | Increased insurance risks | W | (Simon, Maybauer, and Boensch, 2007. p 64) |
| MR5 | Bear the burden of impact of contracts cancellation | W | Simon, Maybauer and Boensch, 2007 |
| MR6 | Business continuity | PC | Dischel, 2002; Chew, 2009 |
| MR7 | Increased maintenance regimes | PC | Dischel, 2002; Lockwood, 2014 |
| | | T | Goncalves and Umakoshi, 2010 |
| | | F | Henschel, 2008; Chew, 2009 |
| MR8 | Increased downtime due to deficiency in manpower | T | Goncalves and Umakoshi, 2010 |
| | | SLR | Gormley and Mansergh, 2009 |
| MR9 | Additional expense in insuring buildings | T | Royer, 2001 |
| | | SLR | Gormley and Mansergh, 2009 |
| MR10 | pressure on services | T | Principal Sustainability and Climate Change Coordinator, 2011 |
| | | F | Principal Sustainability and Climate Change Coordinator, 2011; Hertfordshire County Council, 2013 |
| MR11 | Restrictions on water use | T | Hertfordshire County Council, 2013 |
| MR12 | Increase in administrative expenses due to addition work times | F | Benton, 2005 |
| MR13 | Temporary closure of facilities | F | North Somerset Partnership, n.d. |
| MR14 | Increased insurance claims | F | Hertfordshire County Council, 2013 |
| MR15 | Demands for create safe areas for building | SLR | Gormley and Mansergh, 2009 |
| MR16 | Increase of operational costs for heating, cooling, irrigation, water supply and food supply | T | TUI AG, 2011 |

### 4.5.5 Summary

The impact of climate change on buildings may be analysed in a variety of different ways. For the purposes of this study, the impacts will be dealt with in four different dimensions: physical, economic, social, and management. For each of these, the impacts will be considered as they arise from the following effects that are tied to climate change: windstorms, precipitation, temperature change, flooding, and sea-level rise.

# Chapter 5: Resilience Overview

## 5.1 Introduction to resilience

### 5.1.1 Concept of resilience

It has become more and more common to see the term ‘resilience’ used in connection with adaptation to climate change and reduction of disaster risk. In common parlance, ‘resilience’ signifies the characteristic of being able to return quickly to a previous (and good) condition. Similar definitions have been put forward to describe its meaning in the context of climate change adaptation and, in particular, climate change adaptation in the built environment, as discussed below.

Some recent natural disasters, such as Hurricane Katrina in 2005, are of the type expected to become more frequent and severe as global warming intensifies. Such events, together with others associated with climate change, illustrate the need for communities and properties to be made more resilient to the new environmental challenges (IPCC, 2001). In the case of buildings, this means designing or retrofitting them with measures aimed at coping with more extreme weather. Such measures may include making designs more flexible to allow for new building types and changes of use of spaces if required (Waskett, 2003) and also with the ability to survive and recover from adverse events due to climate change.

### 5.1.2 Definitions of resilience

There have been many different definitions of ‘resilience’ to suit different contexts. These definitions embrace properties such as the ability to recover, robustness, survivability, safety, and reliability. The Table (5-1) below summarises a wide variety of definitions from different fields.

## Selected definitions of ‘resilience’

Table 5-1: Selected definitions of ‘resilience’. 1 = adaptation, 2 = mitigation, 3 = recovery, 4 = Robustness, 5 = Environmental responsiveness, 6 = persistence, 7 = Redundancy.

| No. | Definition | Concepts included | | | | | | | References |
|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
| 1. | Something that can come back to where it began or what it started from (or its true/original form) even after being tampered with or altered. | | | **X** | | | | | Horrocks, L., Beckford, J., Hodgson, N., Downing, C., Davey, R. and Sullivan, A., 2010 |
| 2. | An infrastructure that has the ability to work under difficult circumstances and challenges. | | | | **X** | | | | Horrocks, L., Beckford, J., Hodgson, N., Downing, C., Davey, R. and O’Sullivan, A., 2010 |
| 3. | “*the ability of a system or organisation to withstand and recover from adversity*”. | | | **X** | | | **X** | | (Cabinet Office, 2010). |
| 4. | “*The ability of a social or natural system to absorb disturbances while retaining the same basic structure and ways of functioning, the capacity of self-organisation and the capacity to adapt to stress and change*”. | **X** | | **X** | | **X** | | | UK Climate Impacts Programme |
| 5. | “*An infrastructure element is resilient when, although dependent on other systems, it can continue to function effectively when one or more of those dependencies are broken. It can do this because there are multiple paths to enable its operation such that no single dependency failure can prevent its operation*.” | | | | **X** | | | **X** | Horrocks, L., Beckford, J., Hodgson, N., Downing, C., Davey, R. and O’Sullivan, A., 2010 |
| 6. | “*The capacity of a system to survive, adapt and grow in the face of turbulent change*”. | **X** | | | | | **X** | | Fiksel, J., 2006 |
| 7. | *“…a measure of persistence of systems and their ability to absorb change and disturbance and still maintain the same relationships between populations or state variables*”*.* | | | | **X** | | | | Holling, C. S., 1973 |
| 8. | “*The ability of a system and its component parts to anticipate, absorb, accommodate or recover from the effects of a hazardous event in a timely and efficient manner, including through ensuring the preservation, restoration or improvement of its essential basic structures and functions*”. | | | | **X** | | | | IPCC, 2012 |
| 9. | “*The ability to self-organise is the strongest form of system resilience. A system that can evolve can survive almost any change by changing itself… insistence on a single culture shuts down learning and cuts back resilience*”. | | | | | X | X | | Meadows, 2011 |
| 10. | “*The capacity to absorb shocks while maintaining function*”. | | | | **X** | | | | Holling, C. S., 1996.<br>Holling, C. S., 1986.<br>Holling, C. S., 2001. |
| 11. | “*When change occurs, resilience provides the components for renewal and reorganization*” | | | **X** | | **X** | | | Berkes F., Colding, J. and Folke, C., eds., 2002.<br><br>Gunderson LH and Holling CS., eds., 2002. |
| 12. | *“As applied to integrated systems of people and nature, the (a) the amount of disturbance a system can absorb and still remain within the same state or domain of attraction (b) the degree to which the system is capable of self-organisation and c) the degree to which the system can build and increase the capacity for learning and adaptation”.* | **X** | | | **X** | **X** | | | Carpenter, S. R., Walker, B., Anderies, J. M. and Abel, N., 2001. |
| 13. | *“Resilience owing to adaptive measures to anticipate and reduce future harm”.* | **X** | | | | | | | Kasperson, J. X. and Kasperson, R. E., eds., 2001a |
| 14. | “*The less resilient the system, the lower is the capacity of institutions and societies to adapt to and shape change. Managing for resilience is therefore not only an issue of sustaining capacity and options for development, now and in the future, but also an issue of environmental, social and* | **X** | | | | | | | German Advisory Council on Global Change, 2000.<br><br>Adger, W., Kelly, N. P. and Huu Ninh N., 2001 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | *economic security*" | | | | | | | | |
| 15. | *"The buffer capacity or the ability of a system to absorb perturbations".* | | | | **X** | | | | Adger, 2000 |
| 16. | "*The ability to adapt to change by exploiting instabilities" and that it is not simply "the ability to absorb disturbance by returning to a steady state after being disturbed*". | **X** | | **X** | | | | | Walker, B. H., Ludwig, D., Holling, C. S. and Peterman, R. M., 1981 |
| 17. | "*The ability to persist and the ability to adapt*". | **X** | | | | | **X** | | Adger, W. N., 2003 |
| 18. | *"The capacity of systems, communities, households or individuals to prevent, mitigate or cope with risk, and recover from shocks".* | **X** | **X** | **X** | | | | | Gitz, V. and Meybeck, A. [Accessed June 2013] |
| 19. | *"The speed with which a system returns to its original state following a perturbation".* | | | **X** | | | | | Pimm, 1984 |
| 20. | *"A buffer capacity or ability of a system to absorb perturbation, or the magnitude of the disturbance that can be absorbed before a system changes its structure by changing the variables and processes that control behavior".* | | | | **X** | | | | Holling, C. S., Schindler, D. W., Walker, B. W., and Roughgarden, J., 1995 |
| 21. | *"The ability to resist downwards pressures and to recover from a shock. From the ecological literature – property that allows a system to absorb and use and even benefit change. Where resilience is high, it requires a major disturbance to overcome the limits to qualitative change in a system and allow it to be transformed rapidly into another condition".* | | | **X** | **X** | | **X** | | Alwang, J., Siegel, P. S. and Jorgensen, S. L., 2001 |
| 22. | *"Resilience is a potential of a system to remain in a particular configuration and to maintain its feedbacks and functions, and involves the ability of the system to reorganize following the disturbance driven change".* | | | | | **X** | **X** | | Walkers et al., 2002 |
| 23. | *"The capacity of the damaged ecosystem or community to absorb negative impacts and recover from these".* | | | **X** | **X** | | | | Cardona, O. D., 2003 |
| 24. | *"Ecosystem resilience is the capacity of an ecosystem to tolerate disturbance without collapsing into a qualitatively different state that is controlled by different set of processes. Thus, a resilient ecosystem can withstand shocks and rebuild itself when necessary".* | | | | | **X** | **X** | | Resilience Alliance, 2005 |
| 25. | *"The measure of a system's or part of the system's capacity to absorb and recover from occurrence of a hazardous event".* | | | **X** | X | | | | Timmerman, 1981 |
| 26. | *"The capacity to cope with unanticipated dangers after they have become manifest, learning to bounce back".* | **X** | | **X** | | | | | Wildavsky, 1988 |
| 27. | *"A measure of how quickly a system recovers from failures".* | | | **X** | | | | | EMA, 1998 |
| 28. | *"Local resiliency with regard to disasters means that a locale is able to withstand an extreme natural event without suffering devastating losses, damage, diminished productivity, or quality of life without a large amount of assistance from outside the community".* | | | | | | **X** | | Mileti, 1999 |
| 29. | *"The capacity to adapt existing resources and skills to new systems and operating conditions".* | **X** | | | | | | | Comfort, 1999 |
| 30. | *"Resilience describes an active process of self-righting, learned resourcefulness and growth – the ability to function psychologically at a level far greater than expected given the individual's capabilities and previous experiences".* | | | | | **X** | | | Paton et al.,<br>2000 |
| 31. | *"The ability of an actor to cope with or adapt to hazard stress".* | **X** | | | | | | | Pelling, 2003 |
| 32. | *"The capacity of a group or organization to withstand loss or damage or to recover from the impact of an emergency or disaster. The higher the resilience, the less likely damage may be, and the faster and more effective recovery is likely to be".* | | | **X** | | | | | Department of Human Services, 2000 |
| 33. | *"The ability to anticipate, prepare for, respond to, and recover from, a disturbance".* | | | **X** | | | | | Foster, 2006 |
| 34. | *"The capacity of a system maintains an acceptable level of functioning and structure. This is determined by the degree* | | | | | **X** | **X** | | UNISDR, 2005 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | *to which the social system is capable of organizing itself to increase this capacity for learning from past disasters for better future protection and to improve risk reduction measures".* | | | | | | | | |
| 35. | *"Resilience is a measure of how well can adept to a changed reality and capitalizes on the new possibilities offered".* | **X** | | | | | | | Paton and Johnston, 2006 |
| 36. | *"Resilience is the ability of a population to recover after an extreme event. The higher the resilience, the more a society is capable of recovery from disaster".* | | | **X** | | | | | Plate, 2006 |
| 37. | *"Disaster resilience refers to the capability to prevent or protect against significant multihazard threats and incidents, including terrorist attacks, and to expeditiously recover and reconstitute critical services with minimum damage to public safety and health, the economy, and national security".* | | | **X** | | | | | TISP, 2006 |
| 38. | *"Resilience in the face of shock or stress, so that a system returns to normal (i.e. equilibrium) rapidly afterward or at least does not easily get pushed into a new alternative equilibrium".* | | | **X** | | | **X** | | Pendall et al., 2007 |
| 39. | *"The capacity to withstand or recover from the emergencies and which can stand as a counterbalance to vulnerability".* | | | **X** | | | **X** | | Buckle, 1998 |
| 40. | *"The ability of a system, community or society exposed to hazards to resist, absorb, accommodate and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures".* | | | **X** | **X** | | **X** | | Jha, A. K., Miner, T. W Stanton-Geddes, Z., 2011 |

Common to many of the definitions or resilience presented in Table 5-1 is the notion that to be considered resilient, a system must be able to survive and recover; that is, it must be able to withstand or cope with adverse or challenging events, and must preserve or quickly recover its important qualities or essential functionality (e.g., IPCC, 2012). Many definitions include the idea that the system must have the capacity to anticipate and mitigate the severity of events (Jackson, 2007). Some embrace the idea that a system should be sufficiently adaptable that it can change while still maintaining its essential properties (Alwang et al., 2001). Other definitions of resilience lean toward the idea of a system being able to gracefully degrade in function without failing completely.

Bruneau et al. (2003) argue that resilience must incorporate the four 'R's of robustness, redundancy, resourcefulness and rapidity (see Figure 5-1). By robustness here is meant the strength of a system to withstand an external challenge without loss of functionality. Redundancy is the capacity to deploy alternative options or strategies under stress.

Resourcefulness is the ability to mobilise the necessary resources and services in an emergency. Rapidity, as the name suggests, is how quickly a system returns to full functionality after being disrupted.

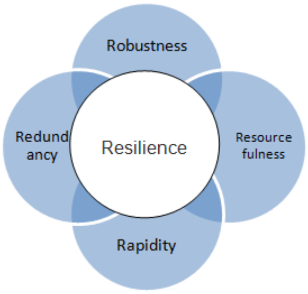


Figure 5-1: Characteristics of building's resilience according to Bruneau et al. (2003).

The four resilience characteristics selected – robustness, redundancy, capacity for adaptation, and environmental responsiveness – were the ones that stood out as a result of the literature review of resilience definitions and that best encapsulated, within these categories, the most important aspects involved in the definition of building resilience. In the table "Selected definitions of 'resilience'" that appears earlier in this chapter, 41 different definitions of the term 'resilience' are presented. Each definition is shown as referring to one or more of seven concepts, as follows: adaptation, mitigation, recovery, absorption, self-organisation, persistence, and multiple paths. Two of these concepts, adaptation and multiple paths, were referred to only once each and so are deemed to be not significant enough to include within the selected resilience characteristics. However, the other five concepts are represented from 8 to 19 times in the definitions shown. Thus it is important that these concepts be encompassed by the chosen resilience characteristics. The correspondence between the significant concepts and resilience characteristics is as follows: robustness incorporates persistence; resilience includes absorption and persistence; capacity for change encompasses adaptation; and environmental responsiveness incorporates recovery.

## 5.2 Definition of resilience used in this research

From a consideration of the various definitions of resilience, and particularly as they apply to climate change and the built environment, the researcher will define building resilience as the extent to which a building can resist events due to climate change, and mitigate or quickly recover from them through a variety of strategies that may involve multiple paths, adaptation, and absorption. Four specific resilience characteristics of buildings will next be discussed. Four characteristics were chosen in order to cover all the main aspects of resilience most relevant and significant to buildings in the context of climate change. These will now be described.

## 5.3 Resilience characteristics

### 5.3.1 Robustness

Bruneau et al. (2003) defines robustness as: "*strength, or the ability of elements, systems and other units of building, to withstand a given level of stress or demand without suffering degradation or loss of function*". Robustness in the context of climate change events implies buildings and their systems that are able function under severe hydro-meteorological stress without disruption of the building operation.

### 5.3.2 Redundancy

Redundancy is another attribute that allows a building system to meet the challenges of climate change events. Bruneau at al. (2003) defined it as: "*the extent to which elements, systems, or other units exist of the building that are substitutable, i.e., capable of satisfying functional requirements in the event of disruption, degradation, or loss of functionality*". It involves having multiple copies of the same component or element of a system so that there are back-ups in case the original component needs repair or replacement. Redundancy increases resilience by acting as a buffer from external shocks, although it also increases costs and reduces efficiency (Patricia H, et al. 2010). The notion of redundancy here is equated with safety and integrity of the building components and systems under the influence of climate change impact.

### 5.3.3 Capacity for adaptation

By capacity for adaptation, in the present context, is meant a building system that can adjust when exposed to disruptive climatic events (Smit et al., 2000). Thus this involves coming up with design solutions that are able to cope with disruption and disturbance and still perform adequately when faced with a crisis. Adaptive capacity is a dynamic property of a system that refers to being able to reactively respond to an event or condition thus reducing overall vulnerability and increasing the building's resilience.

### 5.3.4 Environmental responsiveness

This refers to how responsive to, and integrated with, the systems and functions of a building, or collection of buildings, are with its surroundings and interior spaces. It is based on elements that react to indoor and outdoor environmental changes and to the requirements of occupants in an appropriate way so as to maintain optimal and adaptive comfort conditions, simultaneously contributing to minimise energy consumption for the control of the indoor environment.

Environmental responsiveness may involve controlling parameters such as insulation value, light transmission, and speed and direction of the passage of media such as air or water. A well-laid-out and intelligible smart interface is necessary to provide the user of such a system with the necessary level of control. Through this interface the user controls the performance of the building's element to manage conditions in the indoor environment. Environmental responsiveness and integration is based on high-technology solutions but can serve to lessen the cost of producing and maintaining a building and also lessen the probability of the building being negatively impacted by severe events linked to climate change.

## 5.4 Importance of a building's resilience

Resilience to the effects of climate change is important in a number of respects (Bosher, Carrillo, Dainty, Glass, and Price, 2007). First, it enhances the ability of a building to continue to function in the face of severe events that may result from climate change; this functionality includes maintaining the comfort and safety of occupants. Second, it makes economic sense, reducing costs that would otherwise follow if buildings, services and productivity (in the case of a commercial building) were damaged or degraded after an extreme weather event (Horrocks et al., 2010). Resilience implies that a building's systems may be any or all of the following: robust, independent, diverse, functionally redundant, adaptable, and autonomous (Foster, 2006). These characteristics reflect the changing nature of design in the built environment needed to confront the new challenges of climate change.

## 5.5 Summary

A specific definition of 'resilience' is adopted in terms of the extent to which a building can resist events due to climate change, and mitigate or quickly recover from them through a variety of strategies. Four characteristics are selected to cover all the main aspects of resilience most relevant and significant to buildings in the context of climate change. These are robustness, redundancy, capacity for change, and environmental responsiveness.

# Chapter 6: Resilience Strategies

## 6.1 Introduction

"Resilience" in the context of the built environment means incorporating into the design of a building, aspects and features that will allow the building to carry out all of its intended functions, now and in the foreseeable future. Specifically, with regard to the present work, it refers to the ability of a building to continue to function as intended in the face of environmental stresses imposed by climate change (Greden, 2005). This involves locating, orientating, erecting, and equipping a structure so that it can not only withstand adverse variations anticipated due to climate change but can also continue to meet the needs, including comfort, of its occupants. Various definitions of resilience design as a central concept applied to the built environment will be reviewed next and, in particular, resilience design strategies as they apply to climate change.

## 6.2 Resilience design strategies

Resilience was conceived as the ability of a building to carry out its intended functions and, at the same time, have the capacity to take on new functions or capabilities, or cope with anticipated changes over time (Slaughter, 2001). Resilience design strategies are approaches to incorporating resilience into the built environment.

In the first place, the spaces within a building must be designed to accommodate the flow of how people and things occupy and utilise the building. The internal environment is controlled through the design while treating the building as a physical entity enclosing the space. Future possible usages and conditions must be borne in mind at the design stage, which means that a crucial aspect of resilience design is incorporating sufficient and appropriate flexibility (Greden et al., 2005). According to Liu (2007), flexibility is when a building is able to maintain its original function and structures to support continuous development, even in the event of disturbances. Rose (2007) emphasises that a resilient design is one that is able to protect the building's functions in a hazardous situation. In this study, a selection of best practices will be compiled with the aim of improving the resilience of buildings to current and emerging multiple hazards related to climate change.

## 6.3 Classification of resilience design strategies

Different researchers have focused on different design aspects of buildings in relation to resilience strategies. These aspects include system and structure (Pektaş et al., 2006); adaptability and flexibility of function (Glen, 1997; Slaughter, 2001); interaction between the building and its surroundings (Langston and Ding, 2001; Roaf, 2006; Smith, 2001); interaction between the building and its occupants (Du Plessis, 2001); interior and exterior spaces (Nicholls, 2001); layout and envelope (Vakili-Ardebili and Boussabaine, 2005; Landis, 2008); reliability and usability (Markeset and Kumar, 2003); site analysis (Los Alamos, n.d); and environmental stresses (Fiksel, 2006; Nicholls, 2001).

For the purposes of the present study, building resilience design will be addressed in six categories (as shown in Figure 6-1). The first of these – site – has been emphasised by Larsen et al. (2011) in relation to increasing a project's resiliency to storm events, and by Keung (2010) in that the initial site planning is pivotal to achieving long-term resilience. Structure, another of the selected six categories here, is highlighted by Newman et al. (2013) in terms of its vulnerability to climate change, while the envelope and its attributes are regarded as decisive factors, for example, in insulating the building from extremes of heat and cold high (ORNL, 2014). Coltart et al., (2009) argue that good layout facilitates many of the resilience strategies, notably in consideration of lighting, ventilation and thermal mass.


Figure 6-1: Classification of resilience design strategies.

### 6.3.1 Site resilience design strategies

To ensure that all stages in the design process are implemented properly, the first step is to perform a detailed site analysis. Optimisation of design functions is only possible once the conditions and natural environment at the site are known. Data from the site analysis, together with information on the landscape and site climate, can then be fed into the design process to evolve a resilient design aimed at addressing the risks of climate change (Coltart et al., 2009). Central to the success of the design is interoperability between the occupants, the exterior of the building and the building itself, and how this is impacted by hydro-meteorological events associated with climate change.

Taking into account details of the terrain and topography at and around the site is important irrespective of whether the site has been landscaped or not. These details assist the designer in orienting the building with respect to solar access and prevailing winds.

Based on a literature review (see Table 6-1) seven distinct strategies are proposed here to incorporate in a site design to achieve resilience against climate change. They are as follows:

1. Use of site stabilisation techniques to prevent erosion.
2. Provision of a direct runoff to a catchment basin or holding area to reduce erosion.
3. Planting of mature trees to assist wind dissipation.
4. Use of a catchment system or cistern to reduce flooding.
5. Preparation of the landscape to ameliorate the effects of high winds and other extreme phenomena associated with climate change.
6. Use of optimum building orientation to improve resistance to changing average temperatures and extreme heat or cold.
7. Use of permeable surfaces in landscaping to decrease vulnerability to flooding.

How these strategies are implemented in terms of landscaping and building orientation will be considered next.

#### *6.3.1.1 Landscaping*

The amount of sunlight exposure (or shading) and wind to which a building is subjected, as well as the risk of flooding and erosion, can be managed to some extent through appropriate landscape design (Akashi et al., 2006). The annual pattern of the movements of the sun across the sky is specific to the latitude of the site, and, taking into account local topography, a computer program can be used to calculate solar access throughout the year (Coltart et al., 2009).

The risk of flooding and erosion at a site may be alleviated by providing adequate runoffs or drains to a catchment system, using permeable surfaces where necessary to absorb moisture, and taking steps to stabilise any steep slopes and areas of unstable soil (Newman et al., 2013). The need for surface water drains is lessened or may be removed altogether if there is provision for runoff to escape by way of a porous substance, such as crushed stone or permeable concrete blocks. Local ground conditions will dictate whether the runoff may pass directly in the subsoil or be held temporarily in an underground reservoir before being absorbed into the ground (Watson and Adams, 2010).

As well as topography, landscape factors such as trees, vine trellises, and other plants can be interoperable with the local climate and human aspects of the design to help offset some of the impact of climate change at the site (Brown and Gillespie, 1995). By suitable positioning of trees and other plants around a building, airflow can be controlled rather than hindered, and incident solar flux moderated (Building Information Modelling, 2011).

The shading and solar access factors of a site can only be determined through an accurate site analysis. Overheating may happen due to topographical conditions. In this case, solutions to protect the building from overheating, which may include the use of vegetation, must be incorporated. Self-shading is another technique that can be used to protect a building from the heat of the sun (Nikolopoulou et al., 2001).

#### *6.3.1.2 Orientation*

The orientation of a building is important in determining how much incident solar energy contributes to thermal gain and to what extent prevailing winds are used for natural ventilation and cooling. Optimising building orientation is therefore a significant strategy in improving resistance to extremes of heat or cold, more of which are anticipated due to climate change. Figure 6-2 illustrates how, for different orientations of a building in the northern hemisphere, the amount of sunlight received from that direction varies (Crobu, 2010).

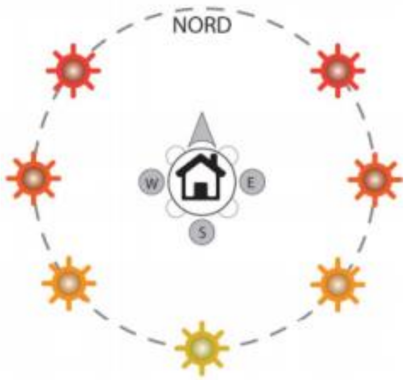

Figure 6-2: Different building orientations (Crobu, 2010).

An accurate site analysis is required to determine the optimum orientation. In the northern hemisphere, solar exposure can be increased, and thermal transmittance reduced, by facing the largest elevations of the building towards the north and the south (Fernandez-Gonzalez, 2007). However, wind exposure and other environmental factors must be considered. Moreover, climate change introduces the prospect of more extreme conditions of heat and cold, wind and precipitation, all of which must be taken into account. Maximum benefit is extracted from the existing wind, topographical, sunlight and shade conditions by accurately positioning the building on site.

Many researchers have investigated orientation in different locations and settings around the world. In general, a south-facing orientation is best for solar gain, while the north-facing side experiences the severest winter conditions. A building can maximise the advantages of the natural environment of the site by keeping the largest facade facing south in the northern hemisphere. The opening sizes on the south-facing facade are typically increased as compared to those on the other sides; though solar access may need to be minimised in summer and maximised in winter (US Department of Energy, 2000). North and south facing sides are better suited to solar gain than those directed to the east and west, as the sun is very low in the former two (Baker and Koen, 2002). Various authors, for example Badeseu et al. (2011), have indicated an optimum orientation to the south of 30° to maximize heat gain. Warm climates will however have a different situation.

Wind exposure is another factor in optimum orientation. This can be illustrated through the example of the University of Newcastle's Design Faculty building, which takes full advantage of natural ventilation and prevailing winds for its occupants (Prasad and Fox, 1996).

Surrounding structures should also be considered when orienting a building. The chances of benefitting from the wind and other natural resources can be increased through an accurate distribution of buildings on the site. On the other hand, building functionality may be affected by obstructions in the form of surrounding buildings, for example in an urban environment (Hoof and Blocken, 2009).

Table 6-1: Site resilience design strategies.

| Code | Factors | Aim of this strategy | References |
|---|---|---|---|
| SS1 | Site stabilisation techniques to prevent erosion | The ability to face risk, raise the level of durability | Newman, et al., 2013 |
| SS2 | Direct runoff to a catch basin or holding area to reduce erosion | The ability to meet risk, raise the level of Redundancy | Newman, et al., 2013 |
| SS3 | Plant mature trees to assist in dissipation of the wind | Components interact with the environment | Newman, et al.. 2013 |
| SS4 | Use water catchment systems/cistern to reduce flooding | Components interact with the environment | Newman, et al. 2013 |
| SS5 | Prepare site landscape and landforms for high wind conditions as well as to reduce the noise, pollution, energy consumption, temperature degree, relative humidity | Components interact with the environment Reduce noise, pollution, energy consumption, temperature, relative humidity, and enhance occupants psychologically | Ahsan, 2009; Brown and Gillespie, 1995; Newman, et al., 2013 |
| SS6 | Use optimum building orientation to improve resilience to high/low temperature | Components able to work with changing conditions ( optimum building orientation )Improve resilience to high/low temperatures and reduce energy consumption | US Dept. of Energy, 2000 and 2001; BIM, 2011; Ministry for the Environment, 2008; Li et al., 2006; Capeluto, 2003; Crobu, 2010; Fernandez-Gonzalez, 2007; Norton and Christensen, 2006; Badescu et al., 2011; Baker and Koen, 2002; Garcia-Hansen et al., 2002; Ekici and Aksoy, 2008; Jiang and Chen, 2002; Hoof and Blocken, 2009; Tantasavasdi et al., 2001; Prasad and Fox, 1996; Dept. of Education, Northern Ireland, 1998 |
| SS7 | Use permeable surfaces in landscaping | Components able to work with changing conditions ( permeable surfaces) Decrease vulnerability to flooding | (Watson and Adams, 2010) & (Environment Agency, 2007) |

### 6.3.2 Layout resilience design strategies

A good interior layout facilitates many resilience strategies adopted with climate change in mind, particularly as they relate to future use, thermal mass, lighting and ventilation (Coltart et al., 2009). Based on a literature review (see Table 6-2) Fourteen distinct strategies are proposed here to incorporate in a layout design to achieve resilience against climate change. They are as follows:

1. Plan spaces and layout based on future use scenarios to create usage resilience.
2. Specify multiple accesses within and between spaces.
3. Minimise partitions between spaces.
4. Use appropriate floor-to-floor height for ventilation.
5. Use appropriate floor-to-floor height to allow for future modification.
6. Specify spaces to perform multi-functionality.

7. Use stack ventilation.
8. Use cross ventilation.
9. Oversize space.
10. Specify "generic layout and program spaces" for future flexibility of use.
11. Specify for maximum daylighting.
12. Specify layout of rooms, corridors, stairwells etc. in a way that enables a low resistance airflow path through the building (both in plan and section).
13. Provide ‘safe places’ in the building.
14. Specify thermal zones, by facing rooms of high-energy demand on the south and put rooms such as cellars, stairs, garages and laundry rooms on the north to act as buffer space.

#### *6.3.2.1 Layout resilience for future usage changes*

Designers must take into account risks of dysfunctionality in buildings linked to climate change and evaluate ways to reduce these risks. Fernandez (2003) discussed such risks and how designs should be considered that are sufficiently adaptable and flexible that they allow for different future utilisation. Slaughter (2001) discussed ways to classify strategies aimed at changes of function.

Changes to a building may be necessitated by changes in the environment, new requirements of tenants, or changes in rules and regulations (which may, themselves, be connected with shifting climatic conditions). In any event, the design of the layout should be sufficiently flexible and resilient to allow components or elements of a space to be added or replaced while maintaining functionality of other spaces nearby (Blok and Herwijnen, 2005). Thus incorporating fixed elements is disadvantageous (Fernandez, 2003); rather, elements should be simple to change or reposition, and other spaces should not be interrupted or disturbed, when carrying out modifications in a space, such as changing a window. A prevailing theme in this approach is that of neutrality among elements and spaces (Finch, 2009).

Buildings should be adaptable enough to conform to, and remain in harmony with, future regulations or safety procedures (Niklas and Bengt, 2009). A building designed with good layout resilience, should, for example, allow removal or modification of any part, while at the same time its skeleton can remain untouched (Till and Schneider, 2006). “Independence” is an important resilience characteristic in this regard, meaning that the elements of the building should be sufficiently independent that they can be easily separated for repair or replacement if necessary, to cope with the effects of climate change (Slaughter, 2001).

There are various ways by which a design may enable adaptation to altered future circumstances. The ability of a building to accommodate changes in spatial dimensions – known as changes in volume – is a significant aspect of resilience design (Slaughter, 2001). The integration of new technology is another (Finch, 2009).

#### *6.3.2.2 Floor height*

Allowing sufficient floor-to-floor height is a significant aspect of design that impacts on resilience, enabling modifications to be made to the space to address future needs (City of New York, 1999). For example, environmental changes might imply that the height of a window must be increased or decreased accordingly (IBEC, 2008). In general, it will be easier to remodel a building to adapt to change or take on new functions if it has a long span and sufficient height between floors (Saari and Heikkila, 2008).

#### *6.3.2.3 Partitions and spaces*

The importance of using modular spaces and the manner in which these spaces play an important role in the designing of resilience has been discussed by Till and Schneider (2006) and Finch (2009). According to the needs of a building to be able to respond to climatic risks, it may be necessary to combine or separate spaces to create a new configuration. For instance, to benefit from optimum sun exposure provided on the southern side a space may be reconfigured on that side.

The importance of designing a space that is conveniently divisible was highlighted by Saari and Heikkila (2008). The design should be adjustable to accommodate changing conditions and usage. . Also, where possible, spaces should be oversized to reduce stress on the occupants (Blakstad et al., 2008).

#### *6.3.2.4 Access with and between spaces*

Sufficient flexibility is needed in the design to support the full functionality of the building and continuity of access through and between spaces should there be modifications in the spaces and linkages (Moharram, 1980). Resilience to the effects of climate change involves maintaining undisrupted access both within and outside the space in the event of extreme events or an emergency. This includes multiple methods of access with and between spaces, and minimising partitions between spaces.

#### *6.3.2.5 Multi-functionality*

When applied to a space, multi-functionality implies a full integration of different functions of a building, both in space and time (Heerwagen and Zagreus, 2005).. The manner in which several functions can be catered to simultaneously and provide functions best suited to the tenant must be taken into account by the designer.

#### *6.3.2.6 Ventilation*

Designing a space that allows for both cross and stack ventilation is an important means of achieving passive cooling on warm days. Cross ventilation utilises the air pressure from wind to remove heat from a space. Stack ventilation works by allowing heat to rise up and out of a space. Both methods of ventilation enable a building continue functioning normally and to remain occupied even if in the absence of mechanical cooling (Newman et al., 2013). In addition, Liu, et all (2007) point to the importance of specifying the layout of rooms, corridors, and stairwells, etc. in such a way as to enable a low resistance airflow path through the building, both in plan and section.

#### *6.3.2.7 Energy considerations*

To take advantage of naturally available light and heat, the design should be specified for maximum daylighting (BIM, 2011). In addition, thermal zones should be specified by a having rooms with a high-energy demand face south and those with low-energy demand (cellars, garages, etc.) on the north side to as to serve as a buffer space (Lomas and Giridharan. 2012).

Table 6-2: Layout resilience design strategies.

| Code | Resilience factor | Aim of this strategy | References |
|---|---|---|---|
| SL1 | Plan spaces and layout based on future use scenarios to create usage resilience | Its characteristic (diversity also has the ability of backup) Reduce energy consumption, moderate temperatures and relative humidity, and provide healthy, comfortable living space | Niklas and Bengt, 2009 |
| SL2 | Specify multiple access within and between spaces | Its characteristic of diversity<br>Avoid access shut down | Moharram, 1980 |
| SL3 | Minimise partitions between spaces | Components interact with the environment<br>Allow for thermal bounce effect | Moharram, 1980 |
| SL4 | Use appropriate floor height | Components able to work with changing conditions ( height floor to thermal and ventilation)<br>Optimise thermal and ventilation | City of New York, 1999 and IBEC, 2008; Saari and Heikkila, 2008 |
| SL5 | Use appropriate floor height to allow for future modification | adaptablet to future changes ( height floor for future)<br>Future expansion in time of need | City of New York, 1999 and IBEC, 2008; Saari and Heikkila, 2008 |
| SL6 | Specify spaces to perform multi-function | spaces multiple function (diversity)<br>Enhance use resilience | Hassanain, 2011; Fowler et al., 2005; Cutler and Kane, 2009; Komuro, 2004; Heerwagen and Zagreus, 2005; Khalil and Husin, 2009; WBDG Productive Committee, 2011 |
| SL7 | Use stack ventilation | Components interact with the environment<br>Passive cooling | Newman et al., 2013 |
| SL8 | Use cross ventilation | Ability to utilize from environmental and Ability to environmental interaction<br>Passive cooling | Newman et al., 2013 |
| SL9 | Oversize space | Increase in space means characteristic of backup<br>Reduce occupants stress | Hansen et al., 2005 |
| SL10 | Specify "generic layout and program spaces" for future flexibility of use (use of modularity and standardization) | characteristic of diversity<br>Flexible space towards the social aspect | Slaughter, 2001; Finch, 2009; Fitzgerald et al., 2009; Slaughter, 2001; Vakili-Ardebili and Boussabane, 2006; Till and Schneider, 2006; Saari and Heikkila, 2008 |
| SL11 | Specify for maximum day-lighting | Components interact with the environment (daylighting)<br>Take advantage of light and thermal energy | BIM, 2011 |
| SL12 | Specify the layout of rooms, corridors, stairwells etc. in a way that upholds a low resistance airflow path through the building (both in plan and section) | Ability to utilize from environmental and Ability to environmental interaction<br>Improve thermal comfort | Liu and Nazaroff, 2001 |
| SL13 | Provide ‘safe places’ in the building | Components interact with the environment Protect occupants from extreme events | Turnbull, Sterrett, and Hilleboe, 2013; The LifE Project, 2013 |
| SL14 | Specify thermal zones, by facing rooms of high energy demand on the south and put rooms such as cellars, stairs, garages and laundry rooms on the north to act as buffer space | safe spaces , means incloud the characteristic of strength and durability | Lomas and Ji, 2009 |

### 6.3.3 Structure resilience design strategies

This section deals with resilience factors that reduce the vulnerability of the structure of a building to the impacts of climate change (Saavedra, Budd, and Lovrich 2012). To begin with, the researcher will review various definitions of structure resilience provided by other authors in order to ascertain its most important characteristics.

Many definitions of this term share some common features, including the capacity to survive or bounce back after some type of traumatic stress or adverse circumstance. Walker (2004) defines structure resilience broadly as: "*The capacity of a system to absorb disturbance and reorganise while undergoing change so as to still retain essentially the same function, structure and feedbacks*". Mileti (1999) puts it this way: *"(The ability to) withstand an extreme event without suffering devastating losses, damage, without a large amount of assistance from outside the community"*. Allenby (2005) recognises graceful degradation as a valuable component in his definition: "*The capability of a system to maintain its function and structure in the face of internal and external change and to degrade gracefully when it must.*" In the context of environmental traumas, such as might accompany severe hydro-meteorological events, Gibson and Tarrant give the following definition: "The ability of systems to perform during and after disasters".

For the purposes of the present study, structure resilience will be taken to mean: the capability of a building's structural system, materials and foundations to maintain functionality, and degrade gracefully when necessary, when confronted with stresses related to climate change.  In addition, list of structure resilience design strategies is placed on the end of this section (see Table 6-3).

Among the components of a building that may contribute to structure resilience are: the use of strong yet flexible materials; the use of flexible joints in the case of shift soil; the raising of a building and the use of barriers in flood-threatened areas, and the provision of openings in a building to increase permeability in the face of strong winds.

Due to the increased threat of flooding in some regions due to climate change, one way to enhance structure resilience is to raise the construction as shown in Fig 6-3. In the US, the Federal Emergency Management Agency (FEMA) has prepared flood maps and issued advice that in areas where floods are likely to exceed the elevation of a site there is a need to lift or otherwise flood proof buildings so that they remain structurally sound and able to safeguard their occupants and contents (Di Girolamo et al., 2013). Steps that can be taken to improve flood resilience include lifting the levels of floors, equipment, and electrical fittings so that they are located above the maximum level predicted for any flooding (Bowker BA, et al 2007). Such a strategy can be incorporated into the design of new buildings or implemented in the form of a retrofit package (Newman et al., 2013), for example, to a residential structure (Figure 6-3).

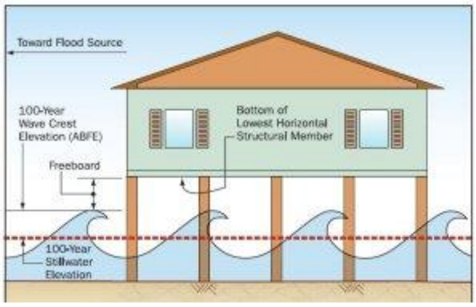


Figure 6-3: Elevating a building from flood.

Additionally, to maximize future structure resilience, buildings should use materials and construction methods that are durable when confronted with more energetic weather, and an increasing number of severe weather events that are the product of climate change (Turnbull, et al, 2013). The ability of buildings to withstand powerful winds can be enhanced by ensuring permeability Keung (2010). Ways to do this include installing void decks on the ground floor, greater floor-to-floor distances, and providing empty spaces between buildings to enable air to flow through and around buildings (Figure 6-4).

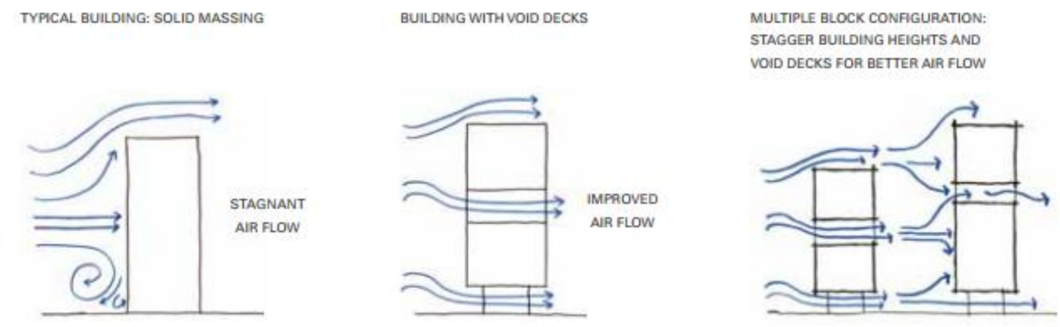


Figure 6-4: Improvements to building permeability (Keung, 2010).

By specifying oversized roof coverings and fixings, the threat of windblown debris can be reduced (Newman et al., 2013). In addition, the use of an appropriate shape and angle of roof helps optimise ventilation and thermal comfort.

Newman et al. (2013) also cite the importance of employing increased structural bracing and oversized walls and roofs to provide strength redundancy to cope with unusually high wind and snow loads. Among other structural resilience factors they identify are: providing anchorage between the superstructure and substructure of a building and constructing masonry chimneys with continuous reinforced steel bracing to increase the resistance to high wind; and, when and where appropriate, using structural materials that are more resistant to pests. Anh (2012) identifies as a resilience factor the use of oversize connections or attachments among building parts.

When it comes to structure resilience against potential flooding another type of permeability may be incorporated into the design (Newman et al., 2013). This involves placing openings in the building envelope to ensure that floodwaters can enter and exit to prevent structural failure (Figure 6-5). Additional strategies include installing overhangs to divert heavy rain away from doors and windows to minimize infiltration, and providing free-standing barriers to keep floodwater away from buildings (Watson and Adams, 2010).

Permanent flood defences are normally the preferred means of protection (Figure 6-6) but are not always appropriate due to cost, or environmental or other reasons. In these cases, free-standing barriers, such as flood boards or air brick covers, may be fitted temporarily to properties when needed (Shaw, et al, 2007).

Figure 6-5: Openings in the envelope for flood.

Figure 6-6: Use of removable flood barriers.

With regard to soil instability, some approaches to reducing vulnerability to subsidence or landslip may impact on other aspects of a building’s resilience, positively or negatively. For example, heavier foundations and infill may help reduce heat risks by acting as a thermal sink. On the other hand, a timber-framed construction, though effective in reducing the risk of subsidence, may reduce a building’s structure resilience to overheating and flooding (Shaw, et al, 2007). Where trees are used to reduce runoff and landslip, account needs to be taken of what species and size they are, and where the are placed to avoid the subsidence of buildings on shrink-swell soils or the displacement of nearby structures as they grow (Shaw, et al, 2007). In cases where the soil under a building has become unstable, it is possible to use underpinning with concrete supports that extend beneath the existing foundations into soils of greater stability (Figure 6-7). The use of flexible pipes and joints can prevent damage to services from ground movement (Ross, et al, 2007).

The problem of erosion, especially in regions rich in clay that are particularly susceptible to heavy rainfall that may accompany climate change, can be addressed in various ways. Among these is the use of products that help to reinforce slopes and stabilize the land (Hertfordshire County Council, 2013).

In some cases, the structure of the building itself may not be strong enough, for example where there is a particular risk of landslip. In such cases, the use of retaining walls (Figure 5-7) may be necessary (Hertfordshire County Council, 2013).

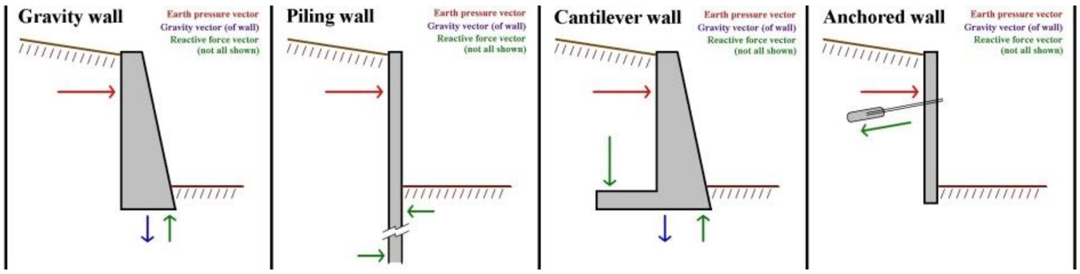


Figure 6-7: Retaining walls.

Table 6-3: Structure resilience design strategies.

| Code | Resilience factor | Aim of this strategy | References |
|---|---|---|---|
| TS1 | Elevate structure above flood level | Ensure that buildings remain structurally sound and protect contents during a flood event.<br>Keep heavy rain away from doors and windows and prevent infiltration. Keep floodwater away from buildings.<br>Protect the foundation and ground floor | Di Girolamo et al., 2013; Newman et al., 2013; Hertfordshire County Council, 2013; Ross, Saunders and Novakovic, 2007 |
| TS2 | Use of flexible pipes and joints | Components able to work with changing conditions ( flexible pipes)<br>Resist high wind and other pressures | Ross, Saunders and Novakovic, 2007 |
| TS3 | Use of an appropriate shape and angle of roof | Components interact with the environment<br>Optimise ventilation and thermal comfort | United States Department of Energy (2000), Ahsan (2009), Prasad and Fox (1996), Biwole et al (2008), Susanti et al (2008) |
| TS4 | Oversize roof coverings fixings | The ability to meet risk, raise the level of durability (Oversize)<br>Reduce windblown debris | Newman et al., 2013 |
| TS5 | Increase structure bracing | The ability to meet risk, raise the level of durability (Increase structure bracing)<br>Create strength redundancy to wind and snow loads | Newman et al., 2013; Tran, Tuan Anh et al., 2012 |
| TS6 | Oversize walls and roofs | The ability to face risk, raise the level of durability (Oversize walls and roofs)<br>Create strength redundancy for wind and snow loads | Newman et al., 2013 |
| TS7 | Provide anchorage between superstructure and substructure | The ability to meet risk, raise the level of durability (anchorage between superstructure)<br>Increase resistance to high wind | Newman, et al., 2013 |
| TS8 | Use structure materials that are more resistant to pests | Components able to work with changing conditions ( structure materials that are more resistant)<br>Mitigate high temperature | Newman et al., 2013 |
| TS9 | Construct masonry chimneys with continuous reinforced steel bracing | The ability to meet risk, raise the level of durability (continuous reinforced steel)<br>Increase resistance to severe weather | Newman et al., 2013 |
| TS10 | Use thermal mass on floor/celling/walls | Increase in space means characteristic of backup (Oversize connections)<br>Moderate internal temperatures and reduce electricity demand | Newman et al., 2013 |
| TS11 | Specify durable and robust materials and construction methods to face the increasing number of extreme weather events | Components able to work with changing conditions<br>Cope with the increasing number of extreme weather events | Keung, 2010 |
| TS12 | Oversize connections or attachments among building parts | The ability to face risk, raise the level of durability (durable and robust materials)<br>Facilitate operation | Tran, Tuan Anh et al., 2012 |

### 6.3.4 Envelope resilience design strategies

The envelope forms the connection between the interior space of a building and the surrounding environment. With respect to climate change effects, it plays a vital role in regulating such factors as solar access and ventilation, and providing a secure, comfortable place for the building’s occupants in the face of more severe hydro-meteorological conditions.

Based on a literature review (see Table 6-4 part 1 and part 2) thirty-two distinct strategies are proposed here to incorporate in a building design to achieve envelope resilience against climate change. These are:

1. Use of appropriate insulation systems to reduce conduction through the thermal envelope.
2. Use of expansion joints within materials that are vulnerable to expansion.
3. Employment high solar reflectance to reflect sunlight and heat away from a building
4. Use of appropriate materials to mitigate the effects of flood.
5. Use of an appropriate shape and angle for the roof.
6. Use of energy efficient windows and shading devices.
7. Specification of window film.
8. Deployment of wall and framing techniques that reduce energy loss.
9. Selection of windows, doors, and openings that can withstand wind loads and windblown debris.
10. Use of oversize framing and bracing.
11. Use of oversize anchors for roof/wall mounted heating, ventilation, and air conditioning units.
12. Employment of green roofs to reduce heat island effect in urban settings.
13. Use of appropriate exterior shading on vulnerability to overheating.
14. Employment of green roofs minimise runoff of rainwater.
15. Selection of appropriate openings in the envelope.
16. Use of light shelves or specially designed reflective-louvered blinds.
17. Selection of materials that can get wet and dry out without permanent damage.
18. Use of airtight junctions and details.
19. Use of light paint colours for interior ceilings and walls.
20. Use of fenestration high on walls or roofs.
21. Dry flood-proofing e.g., watertight structure using sealants, flood shields, etc.
22. Avoiding use of forms and shapes that create wind-suction bag effect during storm.
23. Avoiding use of long rectangular plans with the ratio between the length and width over 2.5.
24. Avoiding use of long roof eaves.
25. Use of double façades.

26. Specification of appropriate roof shape and orientation.
27. Specification of roofs sloping upward towards the outlet.
28. Specification of smaller windows for spaces to the north of the building.
29. Specification of a glazing ratio 30-50% for vertical surfaces and 20% for rooflights.
30. Specification of buffer spaces such as earth sheltering and conservatories.
31. Specification of forms that follow many future functions.
32. Use of mass construction with suitable insulation to moderate the effects of high external temperatures.

#### *6.3.4.1 Thermal envelope insulation*

The selection of materials for the envelope is important because this element of the building plays a major role in controlling heat transmission. Insulation in the envelope limits the conduction of heat into and out of the enclosed space thus reducing the loss of heat in winter months and reducing heat gain in summer months (Hertfordshire County Council, 2013). With climate change resulting in greater temperature extremes, the selection of insulation, such as ceramics or glass fibre reinforced concrete, becomes more and more significant. Reducing solar heat gain of low-rise buildings can be achieved to a large extent through the use of effective roof insulation (Keung, 2010).

The colours, too, of the envelope influence thermal performance; thus white, or other light tones, absorb less heat than darker hues. Breaks in framing systems can also reduce direct heat flow (Keung, 2010).

#### *6.3.4.2 Choice of glazing for envelope resilience*

As it is an essential feature used in facades, openings and doors, the specification of glazing must be accurate. The choice of the ratio of glazed area to non-glazed should be carefully made in order maximize daylighting and ventilation without giving rise to overheating or cooling (Bateson and Hoare Lea, 2011). Glazing areas high on walls, above about 2.1 metres, is a useful way of increasing daylight penetration, while at the same time avoiding glare, especially when used in conjunction with light-reflecting shelves (NASA, 2008). A number of sources, including Franco (2007) and Bateson and Hoare Lea (2001), refer to the importance of energy efficient windows and shading devices to reduce energy use.

Heat flow is one of the most important issues to consider with regard to the envelope, so that careful choice and location of glazing materials is essential. ARUP (2012), for example, found that the optimum facade for a particular project involved the interoperability of three layers of clear glass, with the inner layer forming a cavity that contained movable blinds.

As well as size, the orientation of the glazing must be accurate in order, for example, to optimise winter heat (US Department of Energy, 2000). The designer may choose to use different glass on the different facades – that on the south being accurate for balancing of heat gain and heat loss without causing overheating, and that on the west, east and north facades being suitable size to enable high visibility without resulting in too much heat loss (Ahsan, 2009). For buildings in the northern hemisphere it is often the case that smaller windows should be specified for spaces to the north of the building to minimise heat loss in winter (Lomas and Giridharan. 2012). These same authors also indicate that a glazing ratio of 20% for rooflights and 30–50% for vertical surfaces is optimal to achieve adequate daylighting and, at the same time, avoid overheating.

Glazing should also be secured from shattering, and thereby harming occupants, in the event of extreme weather, such as a windstorm, through the use of window film (Newman et al., 2013).

#### *6.3.4.3 Building form*

Envelope resilience is optimised through selection of a suitable building form, which is partly determined by the interior and the exterior conditions. The form is also dependent on the building's functions. A tall, slender building tends to maximise natural lightning (BIM, 2011), whereas thermal comfort and cooling can be provided naturally in compact buildings. The surface area of compact buildings tends to be low, which automatically reduces heat gains. A building having a form that can be opened and is outward oriented will benefit from natural ventilation (Ahsan, 2009).

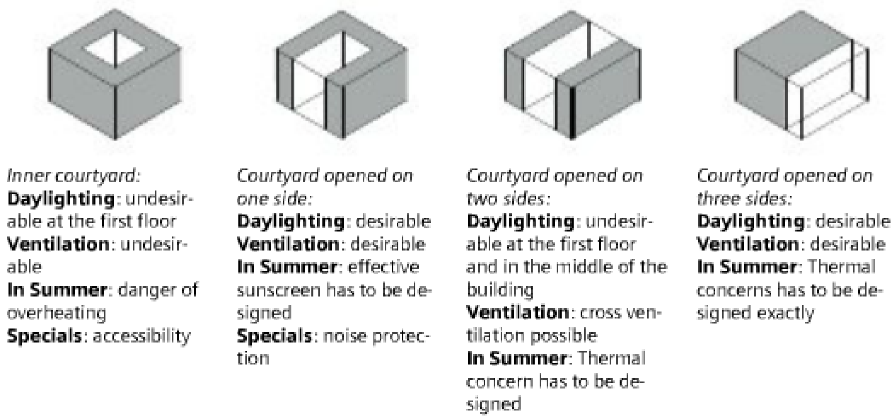


Figure 6-8: Buildings with different forms (Sigg et al, 2006).

Building forms may be classified in many different ways as shown in Figure 6-8. Various forms with courtyards, for example, were classified by Sigg et al. (2006), each with its own advantages and disadvantages with regard to characteristics such as daylighting and ventilation (as shown in Figure 6-8). Forms that can be used to extract maximum benefit from the natural environment on site have been classified by BIM (2011). More surfaces are provided in some building forms as compared with others, which means increased opportunities to provide windows. A linear form, too, can be used to provide an increased surface area for the provision of windows, and with an atrium in the core level access to natural light is maximised.  A designer uses knowledge of forms to help meet lighting and ventilation requirements and enhance interoperability between the functions (Baker and Koen, 2002), thereby increasing resilience.

At the same time, the forms a building can take are influenced by site limitations. To optimise the use of natural resources, the circumstances of the site topography must be taken into account along with the building's shape and size, local legislation and planning code, and sun obstructions. Both traditional and modern buildings have used features such as courtyards, atria, galleria and light wells to maximize natural resources.

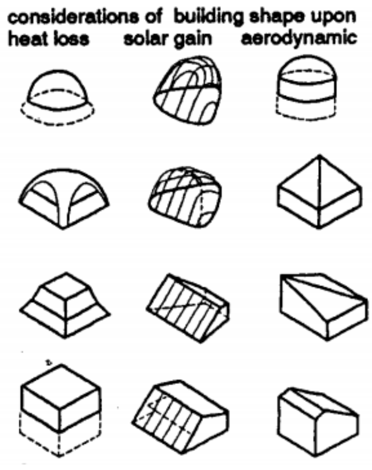


Figure 6-9: Different types of shapes (Prom et al, 1989).

The application of a resilient design is governed by the volume of a building and its surface area. Thermal comfort, ventilation and solar access are all heavily dependent on form (Prom et al., 1989). Figure 6-9 gives a summary of all the various types of built forms. Building resilience can be effectively applied to each type of geometry, but each form provides a different level of performance. Climatic factors and seasonal variation should also be given due importance in the planning of a built form.

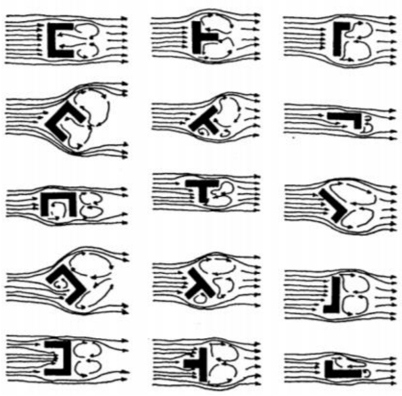

Figure 6-10: Reduction of wind by shapes (Prom et al., 1989).

The building level can be expressed in the form of suitable horizontal and vertical plans. Wind patterns can also affect the optimum building shape and selection of form should involve a detailed wind analysis (Figure 6-10). According to the US Green Building Council (1996), the reduction of wind tolerance should be a key target when selecting a suitable building form. Suitable shapes should be first considered by the designer and a selection made that supports maximum exposure to the winter sun and the summer breezes. The risks attached to climatic variations must also be factored in. For example, the increased prevalence of strong windstorms should be addressed by choosing forms that minimize wind tolerances. In general, the form of a building should be such that the building has the flexibility to continue to perform well despite changing conditions and requirements, and thus contribute to the overall resilience.

Slaughter (2001) stresses the need to specify forms that are flexible enough to allow for many future functions and that allow expansion to take on these functions when needed.

Anh (2012) identifies a number of other factors connected with building form that increase resilience of the building to the effects of windstorms. These include avoiding the use of: (a) forms and shapes that create a wind-suction bag effect; (b) long rectangular plans with a ratio between the length and width over 2.5; and (c) long roof eaves.

#### *6.3.4.4 Envelope materials*

Crucial to envelope resilience is the choice of material, which must be able to respond to changes in climate and provide both longevity and durability. Although suitable materials may cost more initially, they will result in cost savings due to lower maintenance in the long run (Wood, 2005). Choosing high quality materials is particularly critical in portions of the envelope that face the harshest aspects of the climate.

The materials selected should be able to perform efficiently through all environmental changes expected at the site, including during extreme events and emergencies. One particularly important aspect is to consider the rate of expansion and contraction of materials (Booth, Hammond, and Lamond, 2012), which is closely linked to the responses to different environmental agents, whether in the summer or winter. The designer may also incorporate expansion joints to cope with thermal changes.

Water-resistant materials such as vinyl, ceramic and concrete tiles and pressure-treated timber are ideal for use in buildings that may be subject to flooding. They can withstand lengthy immersions in water without being significantly damaged (Hertfordshire County Council, 2013). Materials that can get wet and dry out without permanent damage.

Newman et al. (2013) identify a number of other resilience factors related to the materials and construction of the envelope, including the use of: wall and framing techniques that reduce energy loss; windows, doors, and openings that withstand wind loads and windblown debris; oversize framing and bracing, and oversize anchors for roof/wall mounted heating, ventilation, and air conditioning units.

#### *6.3.4.5 Roofs*

The material, shape and orientation of roofs are key factors in determining envelope resilience (Anh, 2012). God insulation in the roof is essential to keep loss from the interior space to a minimum. Additionally, the shape and slope angle of the roof require accurate design to remove rainwater efficiently, and the orientation should be such as to optimise ventilation (Susanti et al., 2008). Anh (2012) also refers to the specification of roofs sloping upward towards the outlet to assist in ventilation. Both Newman et al. (2013) cite the importance in some circumstances of specifying high solar reflectance of the envelope in order to prevent penetration of heat into a building and reduce the need for mechanical cooling.

In both cold and hot climates, the green roof has become a significant consideration in building design. In a cold climate, for example, the green roof's purpose is to store and filter rainwater (Gedge et al., 2008). In an urban setting, its primary function may be to reduce the heat island effect (Panagopoulos, 2008).

So-called "cool" roofs, constructed of light-coloured materials, reduce the requirement for mechanical cooling by reducing heat gain because of their high solar reflectance. They are effective in the case of high roof to volume ratios. However, they cannot match benefits of climate change adaptation of green roofs and their use must be weighed against the benefits of installing photovoltaic or hot water panels (Saiz, s., et al 2006).

Eaves and other types of roof overhangs afford protection for façades against extreme weather conditions, more surface area from which to collect rainwater, and solar shading to reduce excessive solar gain (Hertfordshire County Council, 2013). However, they are also susceptible to high wind loads and therefore more likely to suffer damage, so that some adequate method of restraint must be included in the design (Ross, et al, 2007).

#### *6.3.4.6 Use of coloured materials and sunspaces*

Light colored materials reflect more light and are therefore useful in paving to reflect solar wavelengths and reduce solar gain (Newman et al., 2013). Light paint colours for interior ceilings, walls and other surfaces improve internal distribution of daylight (Li and Isang, 2008).

A sunspace, such as a conservatory, is an interoperable element to both the façade and internal space. It provides a buffer space that heats up and cools down naturally thus permitting temperatures during the day to climb higher and at night to fall lower than the 'comfort zone' temperatures of the adjacent living space (Lomas and Ji, 2009).

#### *6.3.4.7 Shading*

As a resilience strategy, shading is important as a way of limiting solar gain, which can lead to overheating in interior spaces (as indicated, for example, by Nikolopoulou et al., 2001 and Akashi et al., 2006). It is important that the design maximizes solar shading in the summer while enabling as much daylight and natural warmth to enter in the winter to lessen the need for artificial heating and cooling (Hertfordshire County Council, 2013).

The designer must also take into account the possibility for interoperability between shading devices and glazing types as a means of controlling solar gain and glare (Smith, 2005; Bateson and Hoare Lea, 2001). Accuracy with respect to their location and interoperatility is needed to ensure avoiding any conflict between them.

Light shelves – horizontal or inclined surfaces that reflect daylight deep into a space – also are interoperable with shading devices and glazing types to reduce solar gain and glare, while allowing light to penetrate a building. Again, accuracy of design is important regarding the size of shelves, and their material, location and angle (Ahsan, 2009).

#### *6.3.4.8 Other envelope-related factors*

Newman et al. (2013) cite the importance, where site location and local climate make it appropriate, to provide openings in the envelope to ensure that floodwaters can enter and exit the building. The provision of airtight junctions and details to resist infiltration of moisture or deleterious materials is indicated as an envelope resilience factor by Wright and Frohnsdorff (1985).

In locations prone to climate change related flooding, Shaw, Colley and Connell (2007) emphasise the need for dry flood-proofing of the envelope through the use of such measures as sealants and flood shields.

The use of double façades to provide natural ventilation as an outlet or inlet path is advocated by Roders et al. (2013). The specification of buffer spaces, such as earth sheltering and conservatories, in order to reduce heat losses or increase heat gain, is a strategy indicated by Lomas and Ji (2009). Finally, Hillson et al. (2007) and Balasbanch (2010) indicate as a resilience strategy the use of mass construction with suitable insulation to moderate the effects of high external temperatures, promote night ventilation, and allow the quick heating and cooling of a structure.

Table 6-4: Envelope resilience design strategies (part 1)

| Code | Resilience factor | Aim of strategy | References |
|---|---|---|---|
| SE1 | Appropriate insulation systems to reduce conduction through the thermal envelope | Components interact with the environment ( insulation)<br>Keep heat\cold inside the building, as well as reduce energy bills.<br>Reduce energy use and retain heat | Feist et al., 2005; Keung, 2010; Hertford-shire County Council, 2013; UNEP, 2007; Newman et al., 2013<br>Ross, Saunders and Novakovic, 2007<br>City of Santa Barbara Community Develop-ment Dept., 2006; ARUP, 2012; Ahsan, 2009; Newman et al., 2013 |
| SE2 | Expansion joints within materials that are vulnerable to expansion | Components able to work with changing conditions (expansion joints )<br>Cope with changes that conducting on the materials, lead to cracks. such (expansion and contraction) | ABCB, 2006; PERD, 1997 |
| SE3 | High solar reflectance to reflect sunlight and heat away from a building | Components interact with the environment (solar reflectance)<br>Prevent penetration of heat into a building and reduce the need for mechanical cooling. | Hertfordshire County Council, 2013<br>Newman et al., 2013) |
| SE4 | Appropriate materials to mitigate the effects of flood | The ability to face risk, raise the level of durability<br>These materials can withstand being immersed in water for long periods without significant damage | Hertfordshire County Council; 2013; Ross, Saunders and Novakovic, 2007 |
| SE5 | Appropriate shape and angle for the roof | Components interact with the environment<br>Optimise ventilation and thermal comfort. Reduce impact of wind | US Dept. of Energy, 2000; Ahsan, 2009; Prasad and Fox, 1996; Biwole et al., 2008; Susanti et al., 2008 |
| SE6 | Energy efficient windows and shading devices | Components interact with the environment<br>Reduce energy use | Ministry for the Environment, 2008; Bateson and Hoare Lea, 2011; Franco, 2007; Nature Conservancy, 2013; Hertfordshire County Council, 2013; Newman et al., 2013 |
| SE7 | Specify window film | The ability to face risk, raise the level of durability<br>Prevent injuries from shattered glass<br>Protect openings from wind loads and windblown debris | Newman et al., 2013 |
| SE8 | Wall and framing techniques that reduce energy loss | Components interact with the environment ( framing wall) | Newman et al., 2013 |
| SE9 | Windows, doors, and openings that withstand wind loads and windblown debris | The ability to meet risk, raise the level of durability ( windows, doors, and openings to withstand) | Newman et al., 2013 |
| SE10 | Oversize framing and bracing | The ability to meet risk, raise the level of durability (Oversize framing)<br>Increase redundancy | Newman et al., 2013 |
| SE11 | Oversize anchors for roof/wall mounted heating, ventilation, and air conditioning units | characteristic of backup through (Oversize anchors for …) | Newman et al., 2013 |
| SE12 | Green roofs | Components interact with the environment (green roofs)<br>Reduce heat island effect in urban settings | Panagopoulos, 2008; ARUP, 2012; Royal Academy of Engineering, 2011; Keung, 2010 |
| SE13 | Appropriate exterior shading on vulnerability to overheating. | Components interact with the environment (green roofs)<br>Protect openings from wind loads and windblown debris | Nikolopoulou et al., 2001; Akashi et al., 2006; Crobu, 2010; Panagopoulos, 2008; US Dept. of Energy, 2000; Hongbinget et al., 2001; Shashua et al., 2000; BIM, 2011; Ahsan, 2009; Lechner, 2009; Oke, 1989; Brown and Gillespie, 1995; Hartig, 1991; Brown et al., 1995; Sigg et al., 2006; Baker and Koen, 2002; Prom et al., 1989; US Green Building Council, 2006 |
| SE14 | Green roofs | Components interact with the environment<br>Minimise runoff of rainwater | Gedge et al., 2008 |

Table 6-5: Envelope resilience design strategies (part 2)

| Code | Resilience factor | Aim of strategy | References |
|---|---|---|---|
| SE15 | Openings in the envelope | Components able to work with changing conditions (openings in the envelope) Ensure that floodwaters enter and exit the home | Newman et al., 2013 |
| SE16 | Light shelves or specially designed reflective-louvered blinds | Components interact with the environment Allow daylight to penetrate deep into a building | Ahsan, 2009; Dept. of Education, Northern Ireland, 1998 |
| SE17 | Materials that can get wet and dry out without permanent damage | Components able to work with changing conditions (such as; materials that can get wet and dry,….) | Di Girolamo et al., 2013 |
| SE18 | Airtight junctions and details | The ability to face risk, raise the level of durability Resist infiltration of moisture or deleterious materials | Wright and Frohnsdorff, 1985 |
| SE19 | Light paint colours for interior ceilings and walls | Components able to work with changing conditions Improve internal distribution of daylight | Li and Isang, 2008; Ross, Saunders and Novakovic, 2007; Newman et al., 2013 |
| SE20 | Fenestration high on walls or roofs | Components interact with the environment (daylight) Bring daylight deep into rooms | NASA, 2008 |
| SE21 | Dry flood-proofing e.g., watertight structure using sealants, flood shields, etc. | The ability to face risk, raise the level of durability Protect against flooding | Shaw, et al , 2007 |
| SE22 | Avoid use of forms and shapes that create wind-suction bag effect during storm | Components able to work with changing conditions | Tran, Tuan Anh et al., 2012 |
| SE23 | Avoid use of long rectangular plans with the ratio between the length and width over 2.5 | Move away from any growths enhances strength Reduce vulnerability to storms | Tran, Tuan Anh et al., 2012 |
| SE24 | Avoid use of long roof eaves | Move away from any growths enhances strength Reduce vulnerability to storms | Tran, Tuan Anh et al., 2012 |
| SE25 | Double façades | Components interact with the environment (natural ventilation) Provide natural ventilation as an outlet or inlet path | Roders et al., 2013 |
| SE26 | Specify roofs' shape and orientation | Components able to work with changing conditions Strengthen the natural driving forces | Tran, Tuan Anh et al., 2012 |
| SE27 | Specify roofs sloping upward towards the outlet | Components interact with the environment (natural ventilation) Lead the ventilation air to the outlet | Tran, Tuan Anh et al., 2012 |
| SE28 | Specify smaller windows for spaces to the north of the building | Components interact with the environment Minimise heat loss | Lomas and Ji, 2009 |
| SE29 | Specify glazing ratio 30-50% for vertical surfaces and 20% for rooflights | Components interact with the environment (daylight) Provide adequate day light and avoid overheating | Lomas and Ji, 2009 |
| SE30 | Specify buffer spaces such as earth sheltering and conservatories | characteristic of backup (such as earth sheltering r …) Reduce heat losses or increase heat gain | Lomas and Ji, 2009 |
| SE31 | Specify forms that follow many future functions | Its characteristic of diversity (future functions) Enable future expansion when needed | Slaughter, 2001 |
| SE32 | Use mass construction with suitable insulation to moderate the effects of high external temperatures | The ability to face risk, raise the level of durability ( enhances mass) Promote night ventilation. Allow quick heating and cooling of structure | Murray et al., 2009; Balasbanch, 2010; The Concrete Centre, 2010 |

### 6.3.5 System resilience design strategies

Building system resilience may be defined broadly in terms of designs that incorporate the resources and flexibility within the overall system to withstand shocks and disruption (Wales, 2013). This system resilience may extend beyond physical factors to include economic and other aspects (Boussabaine and Kirkham, 2004). Mileti (1999) offers this definition: "*The ability to withstand an extreme event without suffering devastating losses, diminished productivity, without a large amount of assistance from outside the community*". Perrings (2006) stresses resource allocation in his definition: "*The ability of the system to withstand either market or environmental shocks without losing the capacity to allocate resources efficiently*". Rose (2007), on the other hand, defines building system resilience as: "*The ability of an entity or system to maintain function (e.g., continue producing) when shocked*".

In all these definitions is the concept of a system being able to respond to, and continue to function as normally as possible, through a crisis situation. The researcher will take "system" to mean any distinct physical system or subsystem associated with a building, such as heating, cooling, HVAC, electrical, lighting, and water. "Building system resilience" as it applies to climate change risks, and, in particular, to designs that incorporate sufficient capacity, flexibility, and redundancy at a system level to continue to support all of its intended functions.

Based on a literature review (see Table 6-6) Sixteen distinct strategies are proposed here to incorporate in a building design to achieve operation resilience against climate change. These are:

1. Provision of sufficient HVAC redundancy or overcapacity.
2. Provision of protection for mains electric system during flooding.
3. Specification of appropriate cogeneration and solar power capabilities.
4. Provision of site drainage to offset vulnerability to high levels of precipitation.

5. Provision of separate power system from roof and walls.
6. Specification of water efficient fittings and devices to ensure continuity of building operations.
7. Specification of ductile utility connectors.
8. Building of a permanent water-resistant barrier around HVAC equipment.
9. Separation of electrical circuits, under and above expected flood levels.
10. Use of multi-lighting resources.
11. Elevation of electrical service above expected flood levels.
12. Specification of backup power to avoid electricity shutdown.
13. Provision of onsite renewables to protect against power shutdown and create redundant sources of energy.
14. Specification of heat and cold storage in the ground.
15. Specification of spray system on roofs and terraces.
16. Specification of water features in an atrium.

#### *6.3.5.1 Provision of heating and cooling redundancy and overcapacity*

With regard to building heating and cooling, incorporating natural and passive principles into the design increases system resilience and decreases reliance on external power supplies (Hertfordshire County Council, 2013). Principles of passive design that embrace many aspects of building such as the envelope, shading, natural ventilation, and water capture and storage, let a building provide comfortable living spaces, availability of water, and so forth, even when deprived of external sources. This capacity to continue to supply a comfortable and safe environment is valuable during, for example, extreme weather events that may be accompanied by excessive heat or cold or severe storms (Nesler, 2012).

A specific instance of this strategy is passive ventilation. To enhance system resilience, such an approach should be given priority over mechanical ventilation wherever possible. A key feature of naturally ventilated buildings is effective window design, which allows for ease of use of windows by all building occupants (Hertfordshire County Council, 2013).

Stack ventilation can be particularly effective for passive cooling. In this, spaces are designed to enable hot air to rise up and out of a building on warm days, thus providing an effective to maintain thermal comfort in the event of a power failure (Newman et al., 2013).

Thermal energy storage is another passive technique that provides backup in the case of hydro-meteteorological events severing connection with the grid by producing chilled water at night. At other times it allows a building to respond to elevated temperatures without putting excessive demands on the mains supply or requiring reconfiguration (Newman et al., 2013).

In some situations, such as the case of office buildings, it is impossible to avoid the use of mechanical ventilation and cooling. An reasonable approach in meeting climate change risks, when the design cannot exploit exclusively natural ventilation and cooling, is to choose low-carbon solutions, such as chilled beams and absorption chillers (Hertfordshire County Council, 2013).

#### *6.3.5.2 Protection of the electrical system during flooding*

Systems resilience also means ensuring that in the event of climate change related flooding, a building's mains electric system is protected. In general, all electrical systems and HVAC, along with fuel, potable water, and sewage management systems, need protection from floodwaters, either by means of barriers or by elevating the components above the highest anticipated water level (Newman et al., 2013).

Socket outlets and other electrical points should all be fitted above the expected maximum level of flooding. Moreover, electrical cables should descend from ceiling level and, preferably, be contained within plastic conduits to protect them and make replacement, if necessary, easier. Newman et al. (2013) point to the importance of separating electrical circuits that are under and above expected flood levels to mitigate the effects of flooding to the electrical system. Finally, there should be a separation of the power system from the roof and walls (Ross, et al, 2007).

#### *6.3.5.3 Cogeneration, solar power and other onsite renewables*

Because cogeneration and solar power systems are always in use, they can be more reliable than generators that are only turned on during emergencies. Electrical equipment that will run on backup power should be prioritised so that buildings can remain habitable during extended blackouts (Newman et al., 2013).

Both solar (PV) and wind power generation systems provided the means for building system resilience in the face of mains power outages. Solar collection panels use the sun's energy to heat hot water, which is then stored in insulated storage tanks, and may also be used to drive adsorption/absorption chillers for cooling (Keung, 2010).

#### *6.3.5.4 Site drainage*

Effective site drainage strategies are an essential part of the design process in areas where climate change is likely to lead to higher levels of precipitation. A first step towards implementation of effective drainage is to understand the local hydrology and geology, with a view, for example, to determining if the land at the site may be susceptible to instability after a flooding episode (Turnbull, et al, 2013; Hertfordshire County Council, 2013).

Among the relatively straightforward options available for reducing flood risk are installing one-way valves in drains and sewer pipes to inhibit backflow, or laying down self-maintaining drainage ditches. Sustainable urban drainage systems (SUDs), where appropriate, offer a number of benefits, including natural infiltration, cooling in urban areas and the possibility of increased biodiversity (Hertfordshire County Council, 2013).

SUDs, which mimic natural drainage patterns, are valuable because they can harvest rainwater, channeling it into basins and ponds for later use, trap pollutants to protect water quality, and reduce surface water runoff (Shaw, et al, 2007).

Rainwater collection and storage is a synergistic approach that simultaneously reduces the risk of localised flooding by buffering runoff before it puts a load on the drainage system, and makes available the captured water for washing, toilets, irrigation, and so forth. Collection typically takes place from roofs and paved areas, and is filtered before use. Green roofs not only lower the risk of flood and store water but also can regulate the interior temperature (Shaw, et al, 2007)

#### *6.3.5.5 Water efficient fittings and devices*

The installation of water efficient appliances and devices increases building system resilience by reducing water consumption and, when used in conjunction with other efficiency measures, such as rainwater harvesting, reducing dependency on external supplies. Examples include taps with flow restrictors and motion sensors, low-flush, dual-cistern toilets and low-flow showers. This strategy is particularly effective in dense, residential developments (Hertfordshire County Council, 2013).

#### *6.3.5.6 Multi-lighting resources*

Designing buildings so as to make optimum use of daylight in interior spaces reduces dependency on lighting powered by a vulnerable mains supply (Kane, 2009). A variety of strategies are available to do this, including: the location of spaces to the outside, the use light pipes, and the provision of internal courtyards and atria with curtain glass walls (Khalil and Husin, 2009). Increasing the overall surface area of glazing in a building envelope improves daylighting performance but also increases the potential for solar gain or energy loss, depending on circumstances.

Another effective resilience strategy is to use LED task lighting in combination with natural daylighting (ResilientCity, 2014).

#### *6.3.5.7 Other factors*

Newman et al. (2013) indicate the significance of using ductile utility connectors to reduce chance of breakage during extreme climate change related events.

In localities where appropriate, Newman et al. (2013) point to spray systems on roofs and terraces as a resilience strategy to assist in evaporative cooling. The same outcome can be achieved, indicate Bowman et al. (2001), through the use of water features in atria.

Table 6-6: System resilience design strategies.

| Code | Resilience factor | Aim of this strategy | References |
|---|---|---|---|
| YS1 | HVAC system redundancy or overcapacity | Its characteristic of Redundancy<br>Provide capability to cope with unexpected load | Fowler et al., 2005; Kane, 2009; Hassanain, 2011; Fowler et al., 2005; Khalil and Husin, 2009; WBDG Productive Committee, 2011; ResilientCity, 2014; Los Alamos, 2013; Hertfordshire County Council, 2013; Newman et al., 2013 |
| YS2 | Protection for the main electrical system from flooding | The ability to meet risk, raise the level of durability ( Provide protection)<br>Avoid disruption of electricity | Nesler, 2012; Hertfordshire County Council, 2013; Ross, Saunders and Novakovic, 2007; Newman et al., 2013 |
| YS3 | Cogeneration and solar power capability | Using cogeneration (Back up)<br>Enable continuity of electric supply during blackouts | Keung, 2010; Newman et al., 2013 |
| YS4 | Drainage system able to handle expected levels of precipitation | Its characteristic of abundance ( Size drainage)<br>Protect/retrofit water supply and sanitation systems to prevent damage and contamination from floods | Turnbull, Sterrett and Hilleboe, 2013; Hertfordshire County Council, 2013; Ross, Saunders and Novakovic, 2007 |
| YS5 | Power system separate from the roof and walls | Its characteristic of diversity<br>Facilitate maintenance and replacement | Ross, Saunders and Novakovic, 2007 |
| YS6 | Water efficient fittings and devices to ensure the continuity of operation of the building | The ability to face risk, raise the level of durability<br>Reduce water consumption. Ensure continuity of operation | Hertfordshire County Council, 2013 |
| YS7 | Ductile utility connectors | Components interact with the environment<br>Reduce chance of breakage during hazardous events | Newman et al., 2013 |
| YS8 | Build a permanent water-resistant barrier around HVAC equipment | The ability to meet risk, raise the level of durability (water-resistant barrier )<br>Protect HVAC from flooding | Newman et al., 2013 |
| YS9 | Separate electrical circuits, under and above expected flood levels | Its characteristic of diversity<br>Mitigate effects of flooding to electrical system | Newman et al., 2013 |
| YS10 | Use multi-lighting resources | Its characteristic of diversity (multiple lighting)<br>Provide backup light sources in case of power outage | Kane, 2009; Khalil and Husin, 2009 |
| YS11 | Raise electrical service above expected flood levels | The ability to face risk, raise the level of durability ( proved electrical service) | Newman et al., 2013 |
| YS12 | Specify backup power to avoid electricity shutdown | characteristic of backup<br>Continuity of operation of the building | Newman et al., 2013 |
| YS13 | Provide onsite renewables to protect against power shutdown and create redundant sources of energy | Its characteristic of diversity<br>Reduces cost of the bill, energy demand | UNIDO, 2009; Committee on Climate Change, 2010 |
| YS14 | Specify heat and cold storage in the ground | characteristic of backup (such as power storage …)<br>Protect against power shot down. | Hertin et al., 2003 |
| YS15 | Specify spray systems on roofs and terraces | Components able to work with changing conditions<br>Provide evaporative cooling | Newman et al., 2013 |
| YS16 | Specify water features in an atrium | Components interact with the environment<br>Provide evaporative cooling | Bowman et al., 2001 |

### 6.3.6 Operation resilience design strategies

This section addresses factors that impact upon building operation resilience with respect to climate change. Wildavsky (1991) defines operation resilience as: "*The capacity to cope with unanticipated dangers after they have become manifest*". Bruneau (2003) puts it in these terms: "*The ability of a unit to mitigate hazards, contain the effects of disasters when they occur, and carry out recovery activities in ways that minimise social disruption*". Norris (2008) sees operation resilience as: "*A process linking a set of adaptive capacities to a positive trajectory of functioning after a disturbance*". A common thread among these is the notion of continuity of function in the face of challenging conditions. With regard to buildings, operation resilience will, for the purposes of this research, be taken to mean the ability to adapt and continue functioning when confronted with phenomena due to climate change without external support.

Based on a literature review (see Table 6-7) four distinct strategies are proposed here to incorporate in a building design to achieve operation resilience against climate change. These are:

1. Specification of early warning systems
2. Securing of internal furnishings and equipment
3. Design for emergency repairs
4. Specification of temperature controls panel

Careful consideration should be given to the location of equipment that might be susceptible to damage during severe weather events. For example, equipment near large windows could be damaged during a severe storm (Newman et al., 2013).

In the event of emergency repairs being necessary, Aris (1995) and Chew et al. (2004) stress the importance of elements or components being easy to remove or replace. The ease of removal, especially in the case of electrical or electronic equipment, demands that the element be readily accessible for diagnosis and testing. Moreover, it is important that a component can be removed or replaced without endangering the whole system or design, or other components (NASA, 2008).

In some situations, operation resilience might also involve training building and facility management staff to operate any backup systems, such as generators and battery lighting (Newman et al., 2013). Moreover there would need to be contingency plans for water, food, energy and communications.

Any control equipment should be easy to use, preferably manual, and with controls that are easily located (Brown et al., 2010). Operation resilience also requires that thermal comfort be maintained (Thomas and Baird, 2006), so temperature controls especially should be well designed for ease of use and that the system responds quickly (Zachary et al., 2010).

Table 6-7: Operation resilience design strategies

| Code | Resilience factor | Aim of this strategy | References |
|---|---|---|---|
| SO1 | Specify early warning systems | characteristic of backup (such as early warning …)<br>Alert vulnerable building occupants | Turnbull, Sterrett and Hilleboe, 2013 |
| SO2 | Secure interior furnishings and equipment | The ability to face risk, raise the level of durability<br>Ensure continuity of operation | Newman et al., 2013 |
| SO3 | Design for emergency repairs | Components able to work with changing conditions<br>Ensure readiness for any risks and continuity of operation | Newman et al., 2013 |
| SO4 | Specify temperature control panel | characteristic of backup<br>Provide for different needs of occupants | Zachary et al, 2010; Thomas and Baird, 2006 |

## 6.4 Summary

A critical literature review was used to extract a large number (85) of resilience strategies. These were then coded and grouped into six different classes: site, layout, structure, envelope, system, and operation. The strategies form the basis for the resilience design model.

# Chapter 7: Mapping CCR to SFs

## 7.1 Introduction

This chapter discusses in detail the connections between resilience strategies (SFs) and climate change risks (CCRs), and, in particular, how the former map to the latter. The open-source network analysis and graphing package Gephi was used to generate network visualisations showing all the links between nodes representing both SFs and CCRs.

The interactions between the emerging risk from climate change and design resilience strategies is modelled using social network analysis techniques. Gephi is an open-source social network software package which is being used extensively for data visualisation. Social network analysis is a recent research tool for studding patterns of relationships between entities. The network provides information about linkage behaviour of its complements. In this work Gephi is used to visualise the relationship between risk and design resilience strategies. Social network is normally represented in terms of a graph which consists of nodes and edges. In this study nodes consist of risks and design resilience strategies, and the edges consist of the relationships or interaction between the two entities (i.e. risk and resilience strategies). Thus to create the relationship each risk and strategy are named as nodes and assigned labels or names. Then a matrix is formed to show the interaction between risks and resilient strategies. The interaction information is extracted from the literature review. Then a data set is formed from the matrix and the list of nodes. Subsequently, the data is loaded in Gephi and applied the ForceAtlas layout (a visualisation algorithm) to get an overview of the network structure. In this study node size is used to interpret the network graphs. The relative size of the node, as displayed by Gephi, is determined by the number of connections it has to other nodes. (Bastian, Heymann, and Jacomy, 2009). Larger resilience strategy nodes indicate their importance in mitigating climate change risks.

Chapter 6 presented all of the resilience design strategies, extracted from the literature review, and showed how, for the purposes of this study, they could be grouped into six building design resilience categories: site, layout, structure, envelope, system and operation. In these categories were placed the following resilience factors: site, SS1–SS7; layout, LS1–LS14; structure, TS1–TS12; envelope, ES1–ES32; system, YS1–YS16; and operation, OS1–OS4. Climate changes risks have been grouped into four classes: physical, PR1–PR22; economic, ER1–ER13; social, SR1–SR17; and management, MR1–MR13.

SFs and CCRs are listed as codes ( as shown in Table 5.5 in Appendix F) how the various SF and CCR codes – 153 in total – were assigned a number for use by the Gephi software in generating network maps. Six of these network maps have been prepared showing the connections between SF nodes and CCR nodes for each of the categories of resilience factors: Figure 7.1 (site), Figure 7.2 (layout), Figure 7.3 (structure), Figure 7.4 (envelope), Figure 7.5 (system), and Figure 7.6 (operation). The mappings for each of these categories of resilience factors will now been discussed.

## 7.2 Mapping of site resilience factors to climate change risks

Referring to Figure 7-1, it is clear that the largest node, i.e. the one that has the most connections to other nodes, is 72. From the Gephi code table (Table 7.5) it can be seen that this is SS4 ("Use water catchment systems/cistern to reduce flooding"), which is cited by Newman, et al. (2013) as a significant site resilience factor. This is linked to 19 climate change risks – 12 physical, 1 economic, 3 social, and 3 management risks. The connections between CCRs and design building resilience strategies, for the various CCR categories, is summarised in Tables 7-1 to 7-4.

Among the risks to which SS4 is linked is Gephi code 1, equivalent to PR1 ("Reduce the structure strength"), which, as the literature review revealed, is referenced as an important

CCR by numerous authors, including Moncmanova (2007), Hobson and Wassenaar (2008), and Ramirez et al. (2012). PR2 (“Structure’s corrosion”), with Gephi code 2, is also connected to SS4 and is identified as a CCR by Berg (2009) and McCauley (2004). To give one more example, SS4 links to Gephi node 17, which is equivalent to PR17 (“Reduce the foundation’s strength”) and is referenced, among others, by Needham and Keim (2011). This CCR is also linked to another important site resilience factor node, namely, SS7 (“Use permeable surfaces in landscaping”), which has the Gephi code 75 and is cited by Hertfordshire County Council (2013) as a significant resilience factor.

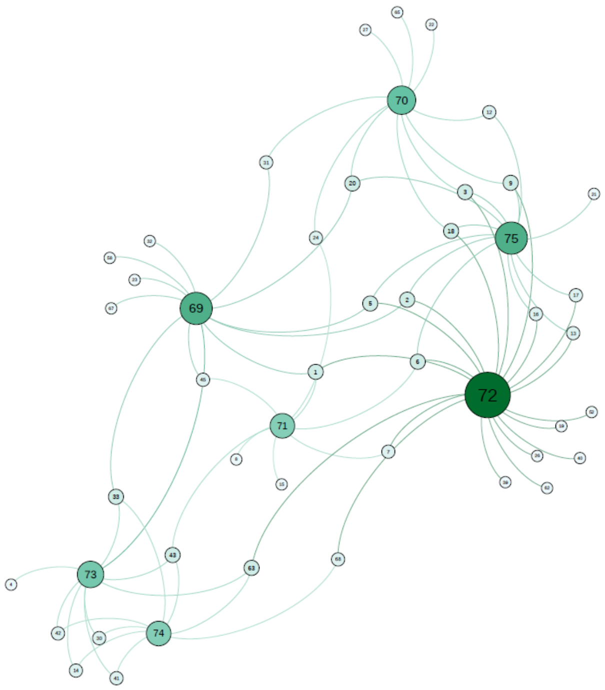


Figure 7-1: Gephi map for site resilience factors and CCRs.

## 7.3 Mapping of layout resilience factors to climate change risks

Two nodes stand out as being particularly prominent in the Gephi mapping of layout SFs to CCRs as shown in Figure 7-2. These are 87 (LS12, “Specify the layout of rooms, corridors, stairwells etc. in a way that maintains a low resistance airflow path through the building”, cited by Liu and Nazaroff (2001)) and 89 (LS14, “Specify thermal zones, by facing rooms of high energy demand on the south and put rooms such as cellars, stairs, garages and laundry rooms on the north to act as buffer space", cited by Lomas and Ji (2009)). Both these are connected to about a dozen CCRs. For example, 87 (LS12) connects directly to the CCR represented by node 10 (PR10, "Reduce the efficiency of the ventilation system"), which, in turn, is linked to four other resilience factors. PR10 is identified, in the literature review, by Richardson (2001) as a CCR associated with a building's layout.

Among the connections to node 89 (LS14) are several to social CCRs, including Gephi node 36 (SR1, "Occupants' dispersion", cited by Penner (2010)) and 50 (SR16, "Occupants concerned that the building may not stand up to the flood", referenced by Ramirez and Miranda (2012)).

Figure 7-2: Gephi map for layout resilience factors and CCRs.

## 7.4 Mapping of structure resilience factors to climate change risks

The dominant node in the structure resilience Gephi map (see Figure 7-3) is node 90 (TS1, "Elevate structure above flood level", cited by a number of authors in the literature review, such as Di Girolamo et al. (2013) and Ross, Saunders and Novakovic (2007)) with 18 connections to CCRs. To give just two examples, TS1 maps directly to CCRs 7 (PR7, "Change colours of the exterior walls") and 10 (PR10, "Reduce the efficiency of ventilation system"), both cited by Richardson (2001).

Second in prominence among resilience nodes in this mapping is 95 (TS6, "Oversize walls and roofs", indicated to be a resilient factor by Newman et al. (2013)), which is linked to CCRs such as 9 (PR9, "Leaks in the façade", referenced by, among others, Sanders and Phillipson (2003)), 17 (PR17, "Reduce the foundation's strength", cited by Needham and Keim (2011) among others), and 65 (MR13, "Temporary closure of facilities", indicated as a risk by North Somerset Partnership (n.d.)).

The third most significant node in this category of connections is node 93 (TS4, "Oversize roof coverings fixings", Newman et al. (2013). This has connections to various CCRs including 24 (ER2, "Materials replacement due to damage", cited by Nott (2003)) and 32 (ER10, "Insurance losses for the building", identified as a risk by the Third Assessment Report of IPCC).

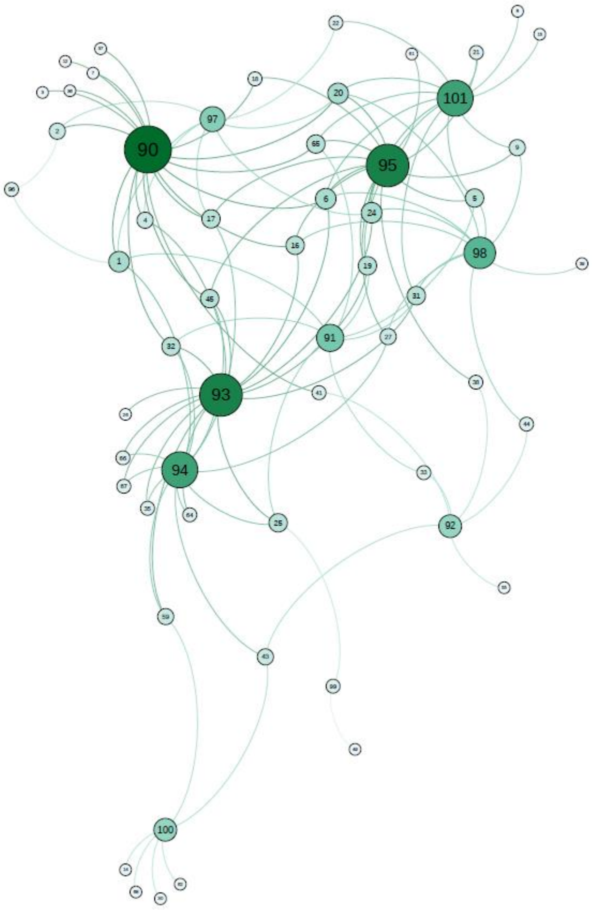


Figure 7-3: Gephi map for structure resilience factors and CCRs.

## 7.5 Mapping of envelope resilience factors to climate change risks

Nodes 105 (ES4, “Appropriate materials to mitigate the effects of flood”, cited as a resilience factor by Ross, et al, (2007)) and 68 (MR16, “Increase of operational costs for heating, cooling, irrigation, water supply and food supply”, a CCR indicated by TUI AG (2011)) are the two most highly connected in the envelope resilience mapping (see Figure 7-4). The ES4 node links to, among others, nodes 6 (PR6, “Damage to the exterior walls resulting from cracking”, identified by Campbell and Corley (2012) and others as a CCR), 21 (PR21, “Damage to materials due to the stability of moisture in small gaps”, cited by Shultz, Russell and Espinel (2005)), and 119 (ES18, “Airtight junctions and details”, which is indicated by Wright and Frohnsdorff (1985) to be a resilience factor).

Node 68 (MR16) has connections to, among others, nodes 102 (ES1, “Appropriate insulation systems to reduce conduction through the thermal envelope”, identified from literature review by, for example, Feist et al. (2005) and Keung (2010)), 107 (ES6, “Energy efficient windows and shading devices”, cited by several references from the review, such as Bateson and Hoare Lea (2011) and Franco (2007)), and 131 (ES30, “Specify buffer spaces such as earth sheltering and conservatories”, indicated as a resilience factor by Lomas and Ji (2009)).

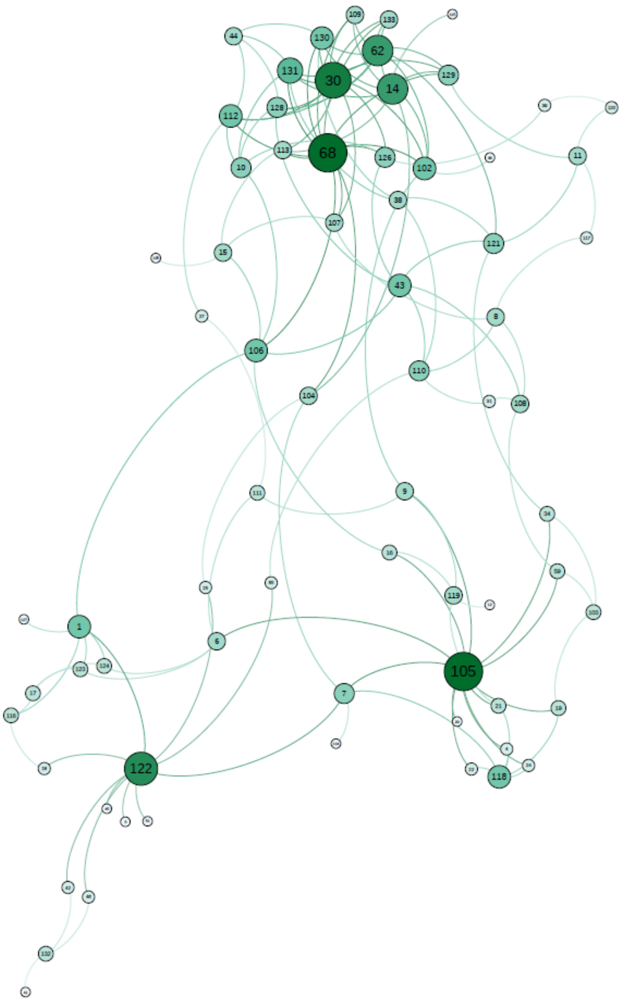


Figure 7-4; Gephi map for envelope resilience factors and CCRs.

## 7.6 Mapping of system resilience factors to climate change risks

The primary node of the system resilience mapping (see Figure 7-5) is node 134 (YS1, "HVAC system redundancy or overcapacity", cited by Fowler et al. (2005) and Kane (2009) among others). Among the neighbouring nodes to which this is connected are 39 (SR4, "Loss of services in building", indicated as a risk factor by Stephens (2008)), 62 (MR10, "Pressure on services", referenced by Hertfordshire County Council (2013)), and 68 (MR16, "Increase of operational costs for heating, cooling, irrigation, water supply and food supply", cited by TUI AG (2011)).

Another significant node in this network is 135 (YS2, "Protection for the main electrical system from flooding", cited by a number of references from the literature review including Ross, Saunders and Novakovic (2007) and Newman et al. (2013)). This links to nine other nodes, including nodes 10 (PR10, "Reduce the efficiency of ventilation system", cited by Richardson (2001)), 31 (ER9, "Increases in maintenance costs of the building", indicated as a resilience factor by Hertfordshire County Council (2013)), and 59 (MR7, "Increased maintenance regimes", referenced by a number of different authors, including Dischel (2002) and Goncalves and Umakoshi (2010)).

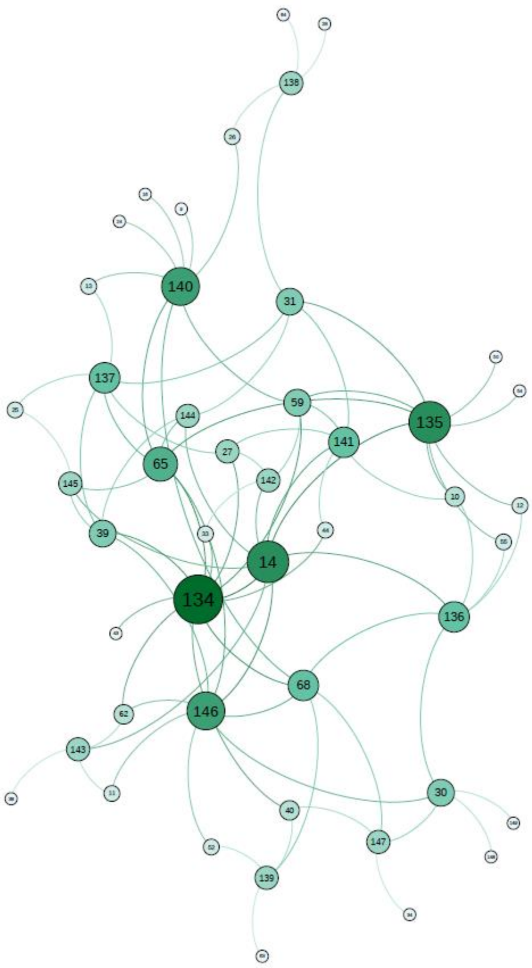


Figure 7-5: Gephi map for system resilience factors and CCRs.

## 7.7 Mapping of operation resilience factors to climate change risks

Two nodes dominate the operation resilience map generated by Gephi, as shown in Figure 7-6. These are nodes 151 (OS3, “Design for emergency repairs”, indicated as a resilience factor by Newman et al. (2013)) and 152 (OS4, “Specify temperature control panel”, cited by both Zachary et al. (2010) and Thomas and Baird (2006)). OS3 and OS4 share eight nodes in common. Each also connects separately to a number of nodes. In the case of OS3, for example, there are connections to nodes 13 (PR13, “Sanitation system capacity efficiency”, indicated by Sanders and Phillipson  (2003) and others), 39 (SR4, “Loss of services in the building”, referenced as a CCR by Stephens (2008)), and 45 (SR10, “Loss of function of the building”, cited by Chennai (2012) and Grimmer et al. (2006)). OS4 is linked, among other nodes, to 12 (PR12, “Damage to overhead power lines in buildings”, identified as a risk by The Secretary of State for Environment, Food and Rural Affairs (2011)), 57 (MR5, “Bear the burden of impact of contracts cancellation”, cited by Simon, Maybauer and Boensch (2007)), and 64 (MR12, “Increase in administrative expenses due to addition work times”, referenced by Benton (2005).

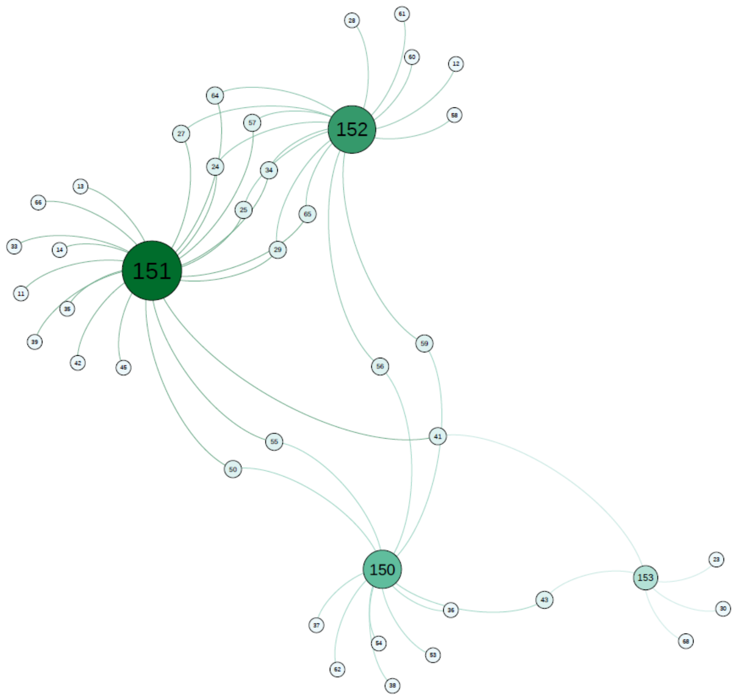


Figure 7-6; Gephi map for operation resilience factors and CCRs.

## 7.8 Physical risks and design building resilience strategies

Table 7-1: Connections between physical risks and design building resilience strategies.

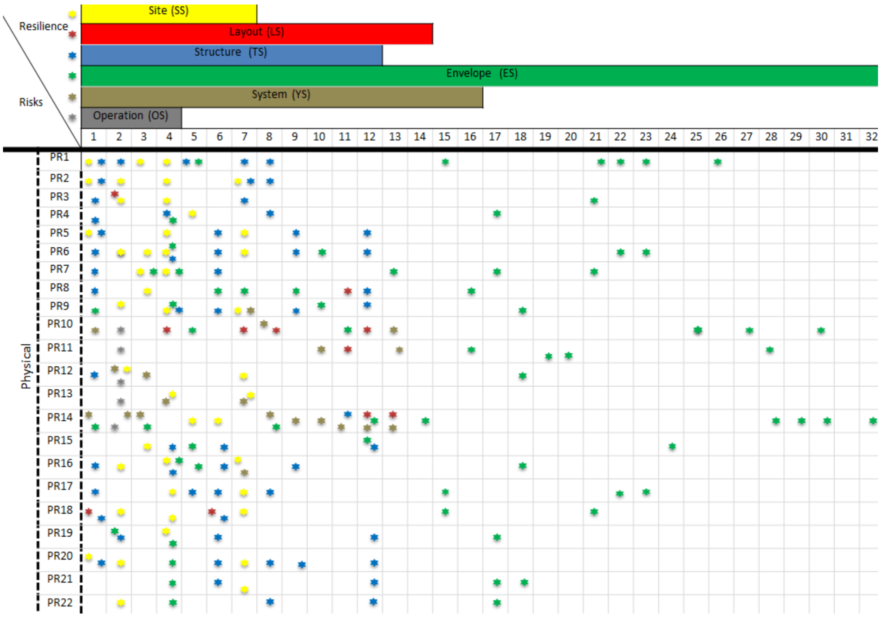


Table 7-1 shows, in colour-coded form, all the connections between physical climate change risks (PR1–PR22) and resilience strategies, for each of the categories of strategy (site, layout structure, envelope, system, and operation).

## 7.9 Economic risks and design building resilience strategies

Table 7-2: Connections between economic risks and design building resilience strategies.

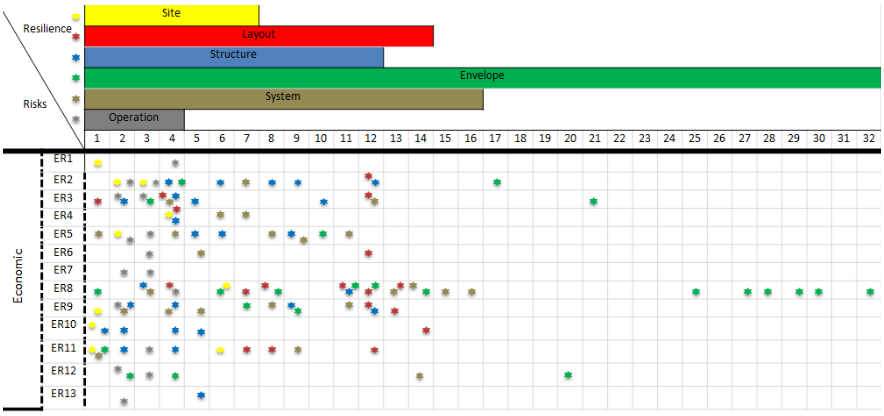


Table 7-2 shows, in colour-coded form, all the connections between economic climate change risks (ER1–ER13) and resilience strategies, for each of the categories of strategy (site, layout structure, envelope, system, and operation).

## 7.10 Social risks and design building resilience strategies

Table 7-3; Connections between social risks and design building resilience strategies.

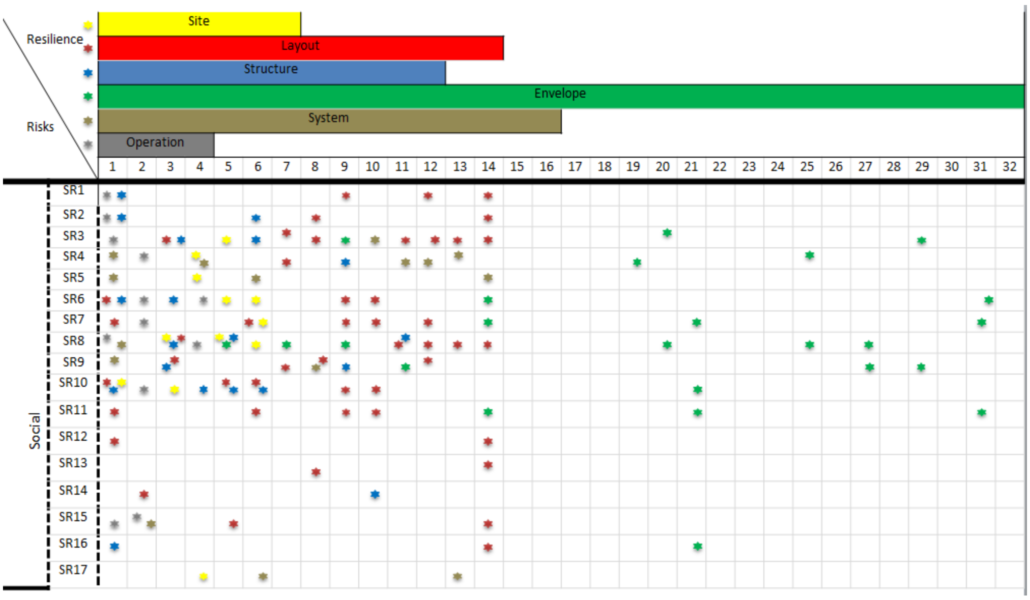


Table 7-3 shows, in colour-coded form, all the connections between social climate change risks (SR1–SR17) and resilience strategies, for each of the categories of strategy (site, layout structure, envelope, system, and operation).

## 7.11 Management risks and design building resilience strategies

Table 7-4: Connections between management risks and design building resilience strategies.

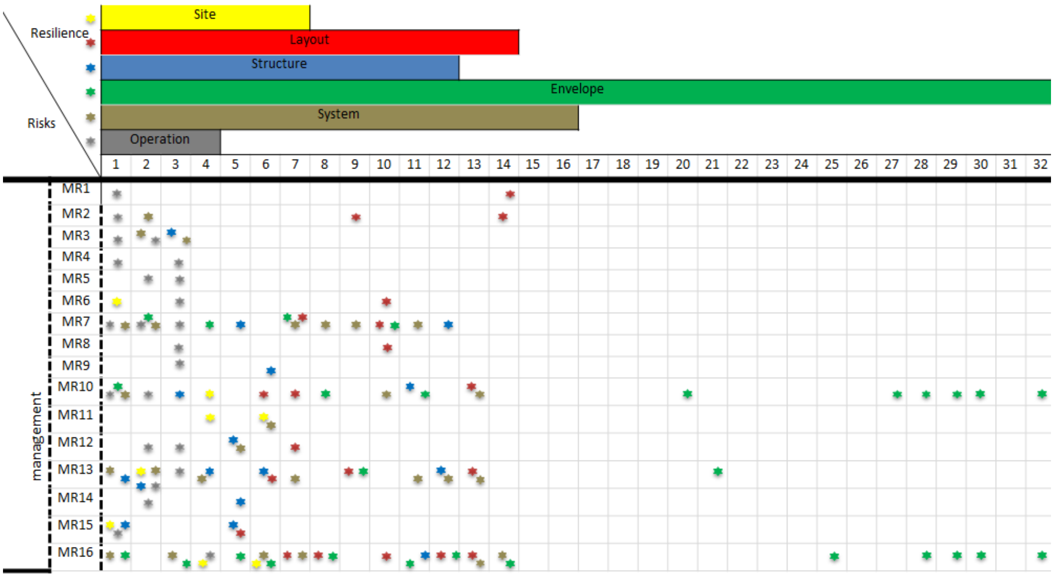


Table 7-4 shows, in colour-coded form, all the connections between management climate change risks (MR1–MR16) and resilience strategies, for each of the categories of strategy (site, layout structure, envelope, system, and operation).

## 7.12 Building resilience characteristics and corresponding resilience factors

In each of the following tables, one of the four building resilience characteristics – robustness (RO), redundancy (R), capacity for adaptation (CA), and environmental responsiveness (ER) – is matched to a corresponding set of resilience factors from the 85 SFs included the Design Resilience Model. In the case of robustness, for example, all of the SFs are connected in some way with the durability or safety of the building in confronting CCRs. Into the redundancy category fall all of the SFs that have to do with back-up systems and over-capacity to deal with extreme events, such as flooding.

Table 7-5: Resilience characteristics of robustness and corresponding resilience factors.

| resilient categories | indicators | Why |
|---|---|---|
| **Robustness (RO)** | ST4: Oversize roof covering fixings to reduce windblown debris | The ability to meet risk, raise the level of durability (Oversize) |
| | ST5: Increase structure bracing to create strength redundancy to wind and snow loads | The ability to meet risk, raise the level of durability (Increase structure bracing) |
| | ST7: Provide anchorage between superstructure and substructure to increase resistance to high winds | The ability to meet risk, raise the level of durability (anchorage between superstructure) |
| | ST9: Construct masonry chimneys with continuous reinforced steel bracing to increase the resistance | The ability to meet risk, raise the level of durability (continuous reinforced steel) |
| | SE10: Oversize framing and bracing to increase redundancy | The ability to meet risk, raise the level of durability (Oversize framing) |
| | SY2: Provide protection for the main electrical system from flooding | The ability to meet risk, raise the level of durability ( Provide protection) |
| | SY8: Build a permanent water-resistant barrier around HVAC equipment to protect from flooding. | The ability to meet risk, raise the level of durability (water-resistant barrier ) |
| | SS2: Direct runoff of water to a catch basin or holding area to reduce erosion | The ability to meet risk, raise the level of durability |
| | SE9: Specify windows, doors, and openings to withstand wind loads and windblown debris | The ability to meet risk, raise the level of durability ( windows, doors, and openings to withstand) |
| | SS1: Use site stabilization techniques to prevent erosion | The ability to face risk, raise the level of durability |
| | LS14: Provide 'safe spaces' in the building to protect the occupants from extreme events | safe spaces , means incloud the characteristic of strength and durability |
| | TS1: Elevate structure above flood level | (raise the level of durability ) Elevate structure |
| | TS6: Oversize walls and roofs to create strength redundancy for wind and snow loads | The ability to face risk, raise the level of durability (Oversize walls and roofs) |
| | TS12 :Specify durable and robust materials and construction methods to resist the increasing number of significant extreme weather events | The ability to face risk, raise the level of durability (durable and robust materials) |
| | ES4 Use appropriate materials to prevent the effects of flooding | The ability to face risk, raise the level of durability |
| | ES7 Specify window film to prevent injuries from shattered glass | The ability to face risk, raise the level of durability |
| | ES18 Specify airtight junctions and details | The ability to face risk, raise the level of durability |
| | ES21 Specify dry flood-proofing e.g., watertight structure using sealants, flood shields, etc. to protect against floods | The ability to face risk, raise the level of durability |
| | ES23 Avoid the use of long rectangular plans with the ratio between the length and width over 2.5 (a ratio over 2.5 creates vulnerability to storms) | Move away from any growths enhances strength |
| | ES24 Avoid the use of long roof eaves due to vulnerability to storms | Move away from any growths enhances strength |
| | ES32 Use mass construction with suitable insulation to moderate the effects of high external temperatures | The ability to face risk, raise the level of durability ( enhances mass) |
| | YS6 Specify water-efficient fittings and devices to ensure the continuity of operation of the building | The ability to face risk, raise the level of durability |
| | YS11 Raise electrical service above expected flood levels (system) | The ability to face risk, raise the level of durability ( proved electrical service) |
| | OS2 Secure interior furnishings and equipment to ensure continuity of operation | The ability to face risk, raise the level of durability |

Table 7-5 shows that, the set of resilience factors corresponding to the building characteristic ‘robustness’ (RO) is identified. Examples of SFs in this category are TS1 (“Elevate structure above flood level”), ES24 (“Avoid the use of long roof eaves due to vulnerability to storms”), and YS6 (“Specify water-efficient fittings and devices to ensure the continuity of operation of the building”). All of the SFs connected with the robustness characteristic have to do with how well the physical elements of the building can stand up to additional environment stresses, such as windstorms and heightened precipitation, related to climate change

Table 7-6: Resilience characteristics of redundancy and corresponding resilience factors.

| resilient categories | indicators | Why this indicator with this category |
|---|---|---|
| **Redundancy (R)** | SY3: Specify cogeneration and solar power to run during blackouts. | Using cogeneration (Back up) |
| | SS2: Direct runoff of water to a catch basin or holding area to reduce erosion. | The ability to meet risk, raise the level of Redundancy |
| | ST5: Increase structure bracing to create strength redundancy to wind and snow loads. | Its characteristic of redundancy (create strength redundancy……) |
| | SY4: Size drainage system to vulnerability to high level of rain. | Its characteristic of abundance ( Size drainage) |
| | LS1: Plan spaces and layout based on future use scenarios to create usage resilience | Its characteristic (diversity also has the ability of backup) |
| | LS2: Specify multiple access within and between spaces to avoid access shutdown | Its characteristic of diversity |
| | LS6: Specify spaces to perform multiple functions to enhance use resilience | spaces multiple function (diversity) |
| | LS9: Oversize space to reduce occupants’ stress | Increase in space means characteristic of backup |
| | LS10: Specify "generic layout and program spaces" for future flexibility of use (use of modularity and standardization) | characteristic of diversity |
| | TS10: Oversize connections or attachments among building parts to facilitate the operation | Increase in space means characteristic of backup (Oversize connections) |
| | ES11: Oversize anchors for roof-/wall-mounted heating, ventilation, and air conditioning units | characteristic of backup through (Oversize anchors for …) |
| | ES30: Specify buffer spaces such as earth sheltering and conservatories to reduce heat losses or increase heat gains | characteristic of backup (such as earth sheltering r …) |
| | ES31 Specify forms that follow many future functions | Its characteristic of diversity (future functions) |
| | YS1: Ensure the provision of HVAC systems redundancy or overcapacity to cope with unexpected load | Its characteristic of Redundancy |
| | YS5: Separate the power system from the roof and walls to facilitate the process of replacement and maintenance | Its characteristic of diversity |
| | YS9: Separate electrical circuits between levels under and above expected flooded levels | Its characteristic of diversity |
| | YS10: Use multiple lighting resources to avoid electricity shutdown | Its characteristic of diversity (multiple lighting) |
| | YS13: Provide onsite renewables to protect against power shutdown and create redundant sources of energy | Its characteristic of diversity |
| | YS14: Specify heat and cold storage in the ground to protect against power shutdown | characteristic of backup (such as power storage …) |
| | OS1: Specify early warning systems, to alert vulnerable building occupants | characteristic of backup (such as early warning …) |
| | OS4: Specify temperature controls to cater for different needs of occupants | characteristic of backup |
| | YS12: Specify backup power to avoid electricity shutdown | characteristic of backup |

Table 7-6 show that, the set of resilience factors corresponding to the building characteristic ‘redundancy’ (RO) is identified. Examples of SFs in this category are SS2 (“Direct runoff of water to a catch basin or holding area to reduce erosion”), ES11 (“Oversize anchors for roof-/wall-mounted heating, ventilation, and air conditioning units”), and YS10 (“Use multiple lighting resources to avoid electricity shutdown”). All the SFs conned with the redundancy characteristic are related to providing sufficient capacity or alternative resources to keep the building functioning adequately when confronted with events related to climate change.

Table 7-7: Resilience characteristics of capacity for adaptation and corresponding resilience factors.

| resilient categories | indicators | Why this indicator with this categorie |
|---|---|---|
| Capacity for adaptation (CA) | SL5: Use appropriate floor height to allow for future modification. | adaptablet to future changes ( height floor for future) |
| | SS7: Use permeable surfaces in landscaping against vulnerability to flooding | Components able to work with changing conditions ( permeable surfaces) |
| | SE2: Provide expansion joints within the materials on vulnerability to expansion | Components able to work with changing conditions (expansion joints ) |
| | SS6: Use optimum building orientation to improve resilience to high/low temperature | Components able to work with changing conditions ( optimum building orientation ) |
| | SL4: Use appropriate floor height to enhance and optimize thermal and ventilation processes. | Components able to work with changing conditions ( height floor to thermal and ventilation) |
| | ST8: Use structure materials that are more resistant to pests to mitigate high temperature | Components able to work with changing conditions ( structure materials that are more resistant) |
| | TS2: Use flexible pipes and joints to resist high wind and other pressures | Components able to work with changing conditions ( flexible pipes) |
| | TS11: Use thermal mass on floor/ceiling/walls to moderate internal temperatures and reduce electricity demand | Components able to work with changing conditions |
| | ES15: Use openings in the envelope to ensure that floodwaters enter and exit | Components able to work with changing conditions (openings in the envelope) |
| | ES17: Specify materials that can get wet and dry out without permanent damage | Components able to work with changing conditions (such as; materials that can get wet and dry,….) |
| | ES19: Specify light paint colours for interior ceilings and walls to improve internal distribution of daylight | Components able to work with changing conditions |
| | ES22: Avoid the use of forms shapes that create a wind-suction bag effect during storms | Components able to work with changing conditions |
| | ES26: Specify roofs’ shape and orientation to strengthen the natural driving forces | Components able to work with changing conditions |
| | YS15: Specify spray systems on roofs and terraces for evaporative cooling | Components able to work with changing conditions |
| | OS3: Design for emergency repairs to ensure readiness for any risks and ensure continuity of operation | Components able to work with changing conditions |

In this table 7-7, the set of resilience factors corresponding to the building characteristic 'capacity for adaptation' (CA) is identified. Examples of SFs in this category are SL5 ("Use appropriate floor height to allow for future modification"), ES17 ("Specify materials that can get wet and dry out without permanent damage"), and OS3 ("Design for emergency repairs to ensure readiness for any risks and ensure continuity of operation"). All of the SFs in this grouping are connected with the ability of the building and to components to respond flexibly and adaptively to CCRs.

Table 7-8: Resilience characteristics of Environmental responsiveness and corresponding resilience factors.

| Resilient categories | indicators | Why this indicator with this category |
|---|---|---|
| **Environmental responsiveness (ER)** | SL8: Use secure cross-ventilation for passive cooling and occupants' comfort. | Ability to utilize from environmental and Ability to environmental interaction |
| | SL12: Specify the layout of rooms, corridors, stairwells etc. in a way that upholds a low-resistance airflow path through the building (both in plan and section) to thermal comfort | Ability to utilize from environmental and Ability to environmental interaction |
| | SE14: Use appropriate exterior shading to reduce vulnerability to overheating | Components interact with the environment |
| | SE6: Use energy-efficient windows and shading devices to reduce energy use | Components interact with the environment |
| | SE3: Use a high solar reflectance to reflect sunlight and heat away from a building | Components interact with the environment (solar reflectance) |
| | SE8: Use advanced wall and framing techniques to reduce energy loss | Components interact with the environment ( framing wall) |
| | SL13: Specify thermal zones, by facing rooms of high energy demand on the south and putting rooms such as cellars, stairs, garages and laundry rooms on the north to act as buffer space. | Components interact with the environment |
| | SE1: Use appropriate insulation systems to reduce conduction through the thermal envelope. | Components interact with the environment ( insulation) |
| | SS3: Plant mature trees to assist in dissipation of the wind force | Components interact with the environment |
| | SS5: Prepare site landscape and landforms for high wind conditions as well as to reduce the noise, pollution, energy consumption, temperature degree and relative humidity | Components interact with the environment |
| | SE5: Use an appropriate shape and angle of the roof to optimize ventilation and thermal comfort, as well as, to resist storms | Components interact with the environment |
| | SS4: Use water catchment systems/cistern to reduce flooding | Components interact with the environment |
| | LS3 Minimize partitions between spaces to allow for thermal buoyancy effect | Components interact with the environment |
| | LS7: Use stack ventilation for passive cooling | Components interact with the environment |
| | LS11: Specify layout for maximum daylighting to take advantage of light and thermal energy | Components interact with the environment (daylighting) |
| | TS3: Use an appropriate shape and angle of the roof for optimum ventilation and thermal comfort | Components interact with the environment |
| | ES12: Use green roofs to reduce the heat island effect in urban settings | Components interact with the environment (green roofs) |
| | ES13: Use green roofs to minimize runoff rainwater | Components interact with the environment (green roofs) |
| | ES16: Use light shelves or specially-designed reflective-louvered blinds to reflect light deep into rooms | Components interact with the environment |
| | ES20: Use fenestration high on walls or roofs to bring daylight deep into rooms | Components interact with the environment (daylight) |
| | ES25: Use double façades for natural ventilation as an outlet or inlet path | Components interact with the environment (natural ventilation) |
| | ES27: Specify roofs sloping upward towards the outlet to lead the ventilation air to the outlet | Components interact with the environment (natural ventilation) |
| | ES28: Specify smaller windows for spaces to the north of the building to minimize heat loss | Components interact with the environment |
| | ES29: Specify glazing ratio of 30-50% for vertical surfaces and 20% for rooflights to provide adequate daylight and avoid overheating | Components interact with the environment (daylight) |
| | YS7: Specify ductile-utility connectors to reduce breakage during disturbance events | Components interact with the environment |
| | YS16: Specify water features in an atrium to provide evaporative cooling | Components interact with the environment |

Table 7-8 show that, the set of resilience factors corresponding to the building characteristic ‘environmental responsiveness’ (ER) is identified. Examples of SFs in this category are SE3 (“Use a high solar reflectance to reflect sunlight and heat away from a building”), SE5 (“Use an appropriate shape and angle of the roof to optimize ventilation and thermal comfort, as well as, to resist storms”), and ES16 (“Use light shelves or specially-designed reflective-louvered blinds to reflect light deep into rooms”). All the SFs in this group are related to how the building responds to internal and external environmental changes and the occupants’ demands in such a way as to maintain optimum and adaptive relief situations,

## 7.13 Summary

A series of networks are presented, drawn with the use of the Gephi package, which has shown the interconnectivity between resilience factors and climate change risks for six different aspects of building resilience: site, layout, structure, envelope, system, and operation. Some of the more significant nodes and their links to other nodes are described.

# Chapter 8: Design Resilience Strategic Conceptual Model

## 8.1 Introduction

In the prior chapters, strategies for designing resilient buildings to climate change risks were investigated. In this chapter, describes a conceptual model that would ensure that all requirements of building resilience to climate change risks are meet. The purpose here is to develop a model based on the RIBA plan of work for incorporating resilience into the design process. The chapter introduce the componrnts of the proposed model. Then the chapter describes how to integrate the building design resilience strategies into design.

## 8.2 Components of the Model

Figure 8-1 shows the proposed Building design resilience Model that consists of several interrelated design strategies. The model consists of site, layout, structure, envelope, system and operation design strategies. These strategies are directly connected and assessed through the resilience characteristics as shown in Figure 8-1. The six design strategies at the core of the model act as the first gateway where the designer must specify design features that are resilient to the climate change. In doing so the designer must make sure to take into consideration the interaction between the six core design function in way that will lead to a robust design that provides substantially performing building assets that comply with all design' targets to be resilience. The outer ring in figure 8-1 shows the resilience characteristics that each of the core design function must comply with. These resilience characteristics consist of Robustness, Redundancy, Capacity for adaptation and Environmental responsiveness. Resilience in this study is defined as building design solutions that are equipped with resilience strategies to cope with climate change risks through; Robustness, Redundancy, Capacity for adaptation and Environmental responsiveness. Further discussion of these characteristics is provided in section.

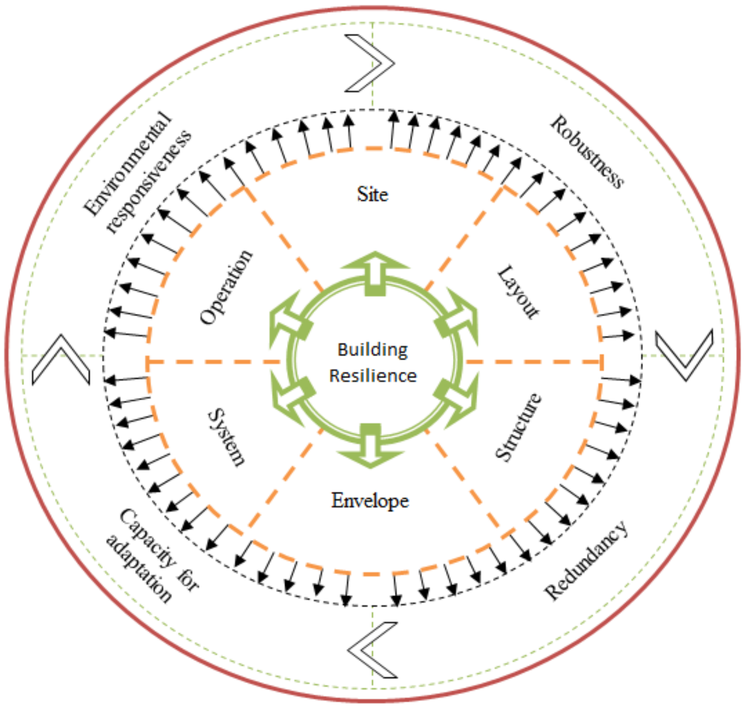


Figure 8-1: Building Design Resilience Conceptual Model

## 8.3 Building Design Resilience Strategies

The core design resilience strategies evolve around the following six dimensions of design as depicted in Figure 8-2. These core functions must exhibit resilience characteristics in relation to the climate change impacts. In a nutshell these functions must act as a cushion to soak perturbation, disturbances due to climate change impacts by incorporation design features that influence behaviour of components, systems and occupants (Resilience was defined by Holling, et al, 1995). The definition of the core functions are elaborated on further in the following sections:

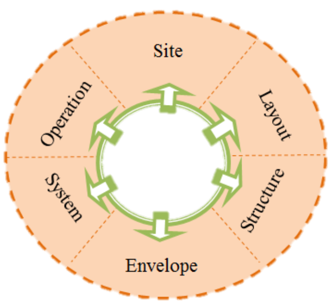


Figure 8-2: Sub-Model Resilience Design Strategies' Dimensions

## 8.4 Compounds of building design resilience

Solutions must be made or found that enhance building resilience through design steps, using the many available resilience strategies. Larsen et al. (2011) stated that consideration should be given to the site in order to increase a building's resilience to the risks of storm. In addition, the initial site planning (layout) of a building has significant impact towards achieving resilience (Keung, 2010). In addition, Coltart et al (2009) pointed that, a good layout that incorporates small number of features and details can increase the resilience of the site to risks of flooding etc. There are many incidences with climate change causing significant damage to building structures.  Thus there is an urgent need to develop design solutions that allow the structure to absorb or mitigate against climate change risks (Newman et al., 2013). It is pointed out that many of the envelope's design attributes can increase the building resilience (Larsen et al., 2011). FEMA (2014) mentioned that, to protect the property from climate change risks a building envelope must incorporate several resilience features. ORNL (2014) and plaNYC (2013) reported that building systems (i.e., HVAC) play an important role in providing resilience to climate change risks. Gething and Puckett (2013) point out that aspect of the building operation must be designed and specified in a way that allows coping with climate change risks impact.

Therefore, the following sections will extract strategic design solutions to mitigate and improve building against climate change risks impact. These design solutions are extracted based on whether they comply with resilience characteristics of Robustness, Redundancy, Capacity for adaptation and Environmental responsiveness.

### 8.4.1 Site design

To ensure that all the design solutions are specified appropriately, the site analysis must be carried out properly to determine the extended of resilience requirements. The designer can only optimise the design functions if he is aware of the site conditions, and its natural environment. The designer must correlate the site analysis, landscape, site climate and orientation, to develop resilient site design solutions that are able to cope with the risks of climate change. Maximum benefits can be reaped from the natural environment when an ideal interoperability between the building elements and the site conditions is obtained. The orientation will help the designer to take advantage of natural resources, such as the solar access and the prevalent winds. Irrespective of whether the site has been landscaped or not, the area surrounding the built space must be analysed in terms of landscaping suitability to climate change impact. The resilience strategies as shown in Table 8-1 will influence the relationship between the indoors and the outdoors. Nikolopoulou et al, (2001) reported that, there are many site planning strategies which promote resilience to climate change impacts, such as using a self-shading technique, which can be used to protect the building from the hot sun. This strategy can be attributed directly to environmental responsiveness. Moreover, one of the essential aspects of the site to be determined is the position of the sun in reference to the latitudes. Nowadays, different software, are available which provide a better understanding of the sun's position and its impact on the proposed design solutions (Coltart et al., 2009). The design resilience strategies that should be considered during the site planning to promote resilience to climate change are shown in Table 8-1.

Table 8-1: Site resilience strategies.

| | |
|---|---|
| Use site stabilization techniques to prevent erosion | Direct runoff of water to a catch basin or holding area to reduce erosion |
| Plant mature trees to assist in dissipation of the wind force | Use water catchment systems/cistern to reduce flooding |
| Prepare site landscape and landforms for high wind conditions as well as to reduce the noise, pollution, energy consumption, temperature degree and relative humidity | Use optimum building orientation to improve resilience to high/low temperature |
| Use permeable surfaces in landscaping against vulnerability to flooding | |

An example of the application of one of these design strategies (use site stabilization techniques to prevent erosion) is shown in Figure 8-3 and 8-4. Different materials such as concrete, aggregates and stagnated soil can be used to fill a cellular confinement system (such as EnviroGrid) or other soil stabilisation system (Bromhead, Hosseyni, and Torii, 2012).

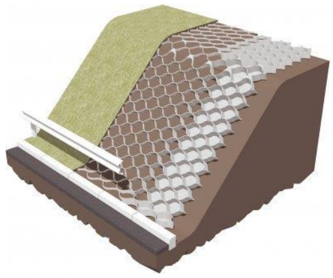

Figure 8-4

Figure 8-3


Figure 8-5: Sub-Model Site Design Dimension.

### 8.4.2 Building layout design

Layout is one of the most important design planning aspects that need to be considered during the brief and specification development of resilient buildings. There are two design strategies that are necessary in resilient building layout design; firstly indirect effects for flexibility, and secondly indirect effects of flexibility. Building regulation is classified under the indirect effects. This means the building regulations must follow the predicted climate changes impacts rather than concentrate only on the current climate conditions. There is also the possibility that the tenant's lifestyle and activities may change due to CCR, which may lead to modifications in the space layout.  According to Coltart et al, (2009), a good layout can be enhancing the design resilience. The design resilience strategies that should be considered during the planning of the building layout to promote resilience to climate change are shown in Table 8-2.

Table 8-2: Layout resilience strategies

| | |
|---|---|
| Plan spaces and layout based on future use scenarios to create usage resilience | Specify multiple access within and between spaces to avoid access shutdown |
| Minimize partitions between spaces to allow for thermal buoyancy effect | Use appropriate floor height to enhance and optimize thermal and ventilation processes |
| Use appropriate floor height to allow for future modification | Specify spaces to perform multiple functions to enhance use resilience |
| Use stack ventilation for passive cooling | Use secure cross-ventilation for passive cooling and occupants' comfort |
| Oversize space to reduce occupants' stress | Specify "generic layout and program spaces" for future flexibility of use (use of modularity and standardization) |
| Specify layout for maximum daylighting to take advantage of light and thermal energy | Specify the layout of rooms, corridors, stairwells etc. in a way that upholds a low-resistance airflow path through the building (both in plan and section) to thermal comfort |
| Specify thermal zones, by facing rooms of high energy demand on the south and putting rooms such as cellars, stairs, garages and laundry rooms on the north to act as buffer space | Provide 'safe spaces' in the building to protect the occupants from extreme events |


Figure 8-6: Sub-Model Building layout design Dimension

### 8.4.3 Building structure design

This section of the research explains the strategies that allow flexibility, robustness and how they can be integrated in the structure. As a starting point, the researcher reviewed the definitions to determine the most important resilience characteristics of the building structure. Scholars have attributed resilience to the concept of structure flexibility in multiple ways. The common idea extracted from all definitions is the ability of the structure to withstand any kind of stress or shock beyond the basic functioning (Fredrickson et al., 2003). Gordon (1978) defined structure resilience as "*the ability to store strain energy and deflect elastically under a load without breaking or being deformed"*. Whereas Bodin (2004) defined structure resilience as "*the speed with which a system returns to equilibrium after displacement irrespective of how many oscillations are required*". Walker (2004) defined structure resilience as "*the capacity of a system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure, identity*". Additionally, it is defined as "*the capacity of a system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure and feedbacks—and therefore the same identity*" (Resilience Alliance, 2006). Resilience Alliance (2009) also defined structure resilience as "*the capacity to tolerate disturbance without collapsing into a qualitatively different state that is controlled by a different set of processes*". Mileti (1999) defined it as "*(The ability to) withstand an extreme event without suffering devastating losses, damage, without a large amount of assistance from outside the community"*. Godschalk (2003) defined structure resilience such that "*A sustainable network of physical systems must be able to survive and function under extreme stresse"*". Paton (2001) gives the definition of structure resilience as "*the capability to bounce back and to use* *physical and economic resources effectively to aid recovery following exposure to hazards*". Meanwhile, Quinlan (2003) stated that: "*Resilience consists of*

*(1) The amount of change a system can undergo and still retain essentially the same structure, function, identity, and feedbacks on function and structure,*

*(2) The degree to which a system is capable of self-organization (and reorganize after disturbance), and*

*(3) The degree to which a system expresses capacity for adaptation".*

Allenby (2005) supports the view that structure resilience as "*The capability of a system to maintain its function and structure in the face of internal and external change and to degrade gracefully when it must*". He went on to state that the structure resilience is "*The ability of systems to perform during and after disasters*" (Gibson and Tarrant, 2010). In this research building structure resilience is defined as: "*The capability of a building structure system, and fabric, to maintain its function in the face of internal and external change of climate, and to degrade gracefully towards its end service life*. Through a review of the literature, it is clear that one of the most important goals of structure resilience is to maintain the integrity of the building complements. The design resilience strategies that should be considered during the design and specification of the building structure to promote resilience to climate change are shown in Table 8-3.

Table 8-3: Structure resilience strategies.

| | |
|---|---|
| Elevate structure above flood level | Use flexible pipes and joints to resist high wind and other pressures |
| Use an appropriate shape and angle of the roof for optimum ventilation and thermal comfort | Oversize roof covering fixings to reduce windblown debris |
| Increase structure bracing to create strength redundancy to wind and snow loads | Oversize walls and roofs to create strength redundancy for wind and snow loads |
| Provide anchorage between superstructure and substructure to increase resistance to high winds | Use structure materials that are more resistant to pests to mitigate high temperature |
| Construct masonry chimneys with continuous reinforced steel bracing to increase the resistance | Oversize connections or attachments among building parts to facilitate the operation |
| Use thermal mass on floor/ceiling/walls to moderate internal temperatures and reduce electricity demand | Specify durable and robust materials and construction methods to resist the increasing number of significant extreme weather events |

An example of the application of one of tone of the above strategies (Raise structures above flood level) this can be achieved through numerous ways; some of which are by using: properly compacted fill, piles, posts, piers or columns. As shown in Figure 8-7, in order to protect buildings from any flood damage (Federal Emergency Management Agency 2014).

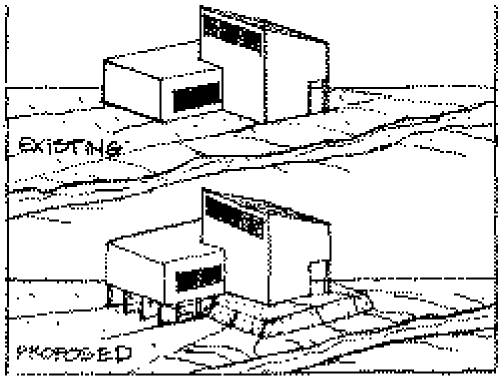


Figure 8-7: Elevate structure above flood level (Federal Emergency Management Agency (FEMA). 2014).

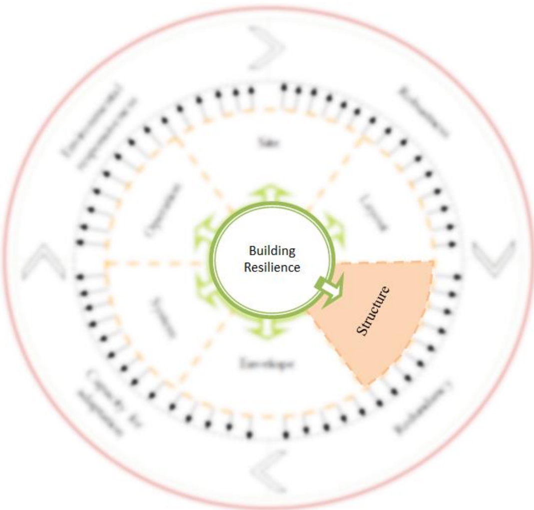


Figure 8-8: Sub-Model Building structure design dimension

### 8.4.4 Building envelope design

The façade or envelope ensures the climate control by monitoring the flow of air and solar access between the inside and outside environments. Holmes and Hacker (2007) clarify and stress the importance of selecting high quality materials for optimal thermal comfort. In terms of the ratio of the glazing, it should be specific, so that we can benefit from lighting and ventilation without generating overheating or unwanted cooling, as claimed by BIM (2011). The prominence and significance of rate of glazing on the envelope has been pointed by Bateson and Hoare Lea (2001) as it provides substantial temperature control. The Department of Education in Northern Ireland (DEND) and corp creator (1998) determined that the minimum rate of vertical glazing is equal to 20% and its maximum is 40% whether on an intimal or external wall. This is why the envelope area should be improved for optimum lighting and solar gain. ARUP (2012) states that interoperability of three layers of clear glass; with the inner layer creating a cavity consisting of movable blinds is mandatory for formation of a perfect envelope. The design resilience strategies that should be considered during the design and specification of the building envelope to promote resilience to climate change are shown in Table 8-4.

Table 8-4: Envelope resilience strategies

| | |
|---|---|
| Use appropriate insulation systems to reduce conduction through the thermal envelope | Provide expansion joints within the materials on vulnerability to expansion |
| Use a high solar reflectance to reflect sunlight and heat away from a building | Use appropriate materials to prevent the effects of flooding |
| Use an appropriate shape and angle of the roof to optimize ventilation and thermal comfort, as well as, to resist storms | Use energy-efficient windows and shading devices to reduce energy use |
| Specify window film to prevent injuries from shattered glass | Use advanced wall and framing techniques to reduce energy loss |
| Specify windows, doors, and openings to withstand wind loads and windblown debris | Oversize framing and bracing to increase redundancy |
| Oversize anchors for roof-/wall-mounted heating, ventilation, and air conditioning units | Use green roofs to reduce the heat island effect in urban settings |
| Use green roofs to minimize runoff rainwater | Use appropriate exterior shading to reduce vulnerability to overheating |
| Use openings in the envelope to ensure that floodwaters enter and exit | Use light shelves or specially-designed reflective-louvered blinds to reflect light deep into rooms |
| Specify materials that can get wet and dry out without permanent damage | Specify airtight junctions and details |
| Specify light paint colours for interior ceilings and walls to improve internal distribution of daylight | Use fenestration high on walls or roofs to bring daylight deep into rooms |
| Specify dry flood-proofing e.g., watertight structure using sealants, flood shields, etc. to protect against floods | Avoid the use of forms shapes that create a wind-suction bag effect during storms |
| Avoid the use of long rectangular plans with the ratio between the length and width over 2.5 (a ratio over 2.5 creates vulnerability to storms) | Avoid the use of long roof eaves due to vulnerability to storms |
| Use double façades for natural ventilation as an outlet or inlet path | Specify roofs' shape and orientation to strengthen the natural driving forces |
| Specify roofs sloping upward towards the outlet to lead the ventilation air to the outlet | Specify smaller windows for spaces to the north of the building to minimize heat loss |
| Specify glazing ratio of 30-50% for vertical surfaces and 20% for roof lights to provide adequate daylight and avoid overheating | Specify buffer spaces such as earth sheltering and conservatories to reduce heat losses or increase heat gains |
| Specify forms that follow many future functions | Use mass construction with suitable insulation to moderate the effects of high external temperatures |

An example of the application of one of these factors: the use of white roofs' or grids of 'cool' made of light coloured materials to decrease the necessity of mechanical cooling. This is because they guarantee high solar reflectance preventing the penetration of heat into the building as shown in Figure 8-9. Green roofs and walls are also can be specified to ensure cooling (Hertfordshire County Council  2013).


Figure 8-9: Sub-Model Building envelope design Dimension

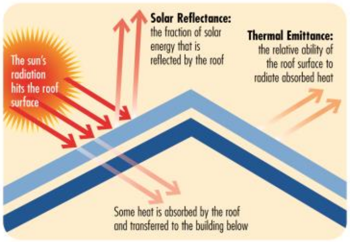


Figure 8-10: Cool or reflective roofing materials. (Hertfordshire County Council 2013)

### 8.4.5 Building systems

Part of building resilience is system (see Figure 8-12). Building system resilience may be defined broadly in terms of designing to incorporate the resources and flexibility effectively in order to withstand shocks and disruption within the system (Wales, 2013). This system resilience may extend beyond physical factors to include economic and other aspects (Boussabaine and Kirkham, 2004). Mileti (1999) offers this definition: "*The ability to withstand an extreme event without suffering devastating losses, diminished productivity, without a large amount of assistance from outside the community*". Perrings (2006) stresses resource allocation in his definition: "*The ability of the system to withstand either market or environmental shocks without losing the capacity to allocate resources efficiently*". Rose (2007), on the other hand, defines building system resilience as: "*The ability of an entity or system to maintain function (e.g., continue producing) when shocked*".

Inherent in all these definitions is the ability of the system to react to, and continue to function nominally through, a crisis. The researcher will take "system" to mean any distinct physical system or subsystem associated with a building, such as heating, cooling, HVAC, electrical, lighting, and water. "Building system resilience" as it applies to climate change risks, and, in particular, to designs that incorporate sufficient capacity, flexibility, and redundancy at a system level to continue to support all of its intended functions.The design resilience strategies that should be considered during the design and specification of the building HVAC electrical, power and drainage systems to promote resilience to climate change are shown in Table 8-5.

Table 8-5: System resilience strategies

| | |
|---|---|
| Ensure the provision of HVAC systems redundancy or overcapacity to cope with unexpected load | Provide protection for the main electrical system from flooding |
| Specify cogeneration and solar power to run during blackouts | Size drainage system to vulnerability to high level of rain |
| Separate the power system from the roof and walls to facilitate the process of replacement and maintenance | Specify water-efficient fittings and devices to ensure the continuity of operation of the building |
| Specify ductile-utility connectors to reduce breakage during disturbance events | Build a permanent water-resistant barrier around HVAC equipment to protect from flooding |
| Separate electrical circuits between levels under and above expected flooded levels | Use multiple lighting resources to avoid electricity shutdown |
| Raise electrical service above expected flood levels (system) | Specify backup power to avoid electricity shutdown |
| Provide onsite renewables to protect against power shutdown and create redundant sources of energy | Specify heat and cold storage in the ground to protect against power shutdown |
| Specify spray systems on roofs and terraces for evaporative cooling | Specify water features in an atrium to provide evaporative cooling |

For example to protect the main electrical system from drowning during the flood periods electrical systems should can be installed in such a way that it is above the ground level and the underground (see Figure 8-11) (Clay Nesler, 2012).

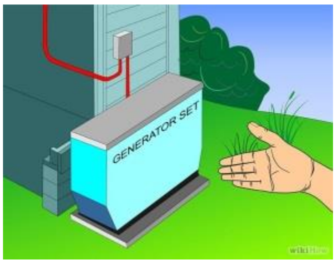


Figure 8-11: Protect the main electrical system from drowning (Clay Nesler , 2012).

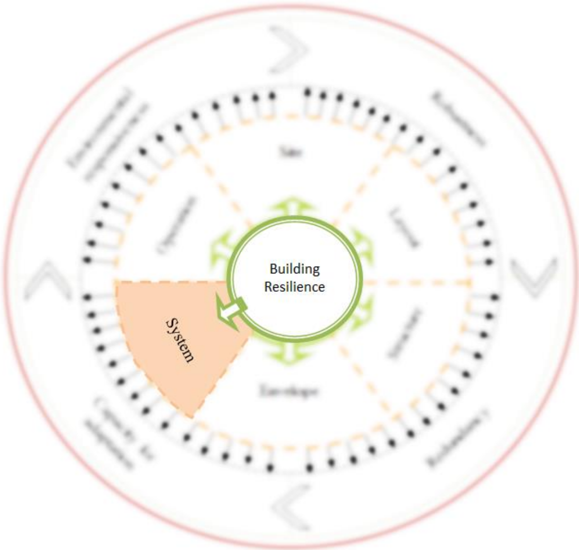


Figure 8-12: Sub-Model Building systems Dimension

### 8.4.6 Building operation

Last aspect of building resilience is operation (see Figure 8-13) This section will attempt to answer this question: how can we make the management of building operation resilient to climate change risks. At present, building operational systems are facing augmented complications. This is because of increased demand for reliability, resilience and capability of running building operations system without disruptions. The advancement in technology has greatly helped enhance the building operation system resilience to mitigate climate change risks (EPA Cool Roofs, 2013). Building operation can be defined as "*the ability of building operation to make decisions and take actions to reduce disaster vulnerability and impacts*" (Gibson and Tarrant, 2010). Norris (2008) defines building operation as "*A process linking a set of adaptive capacities to a positive trajectory of functioning after a disturbance*". the first definition show that the management of resilience of the building is to "take decisions" to mitigate the effects of climate change on the building, while other show that resilience is the management of strategies and solutions, the resilience of operation should be able to fulfil its mission even under stress or interruption and return back to its original state as soon as the interference is removed. The researcher defined building operational resilience as: as the design and specification of the building operation to be able to adapt and mitigate the against climate change risks impact. The design resilience strategies that should be considered during the design and specification of the building operation systems to promote resilience to climate change are shown in Table 8-6

Table 8-6: Operation resilience strategies

| | |
|---|---|
| Specify early warning systems, to alert vulnerable building occupants | Secure interior furnishings and equipment to ensure continuity of operation |
| Design for emergency repairs to ensure readiness for any risks and ensure continuity of operation | Specify temperature controls to cater for different needs of occupants |

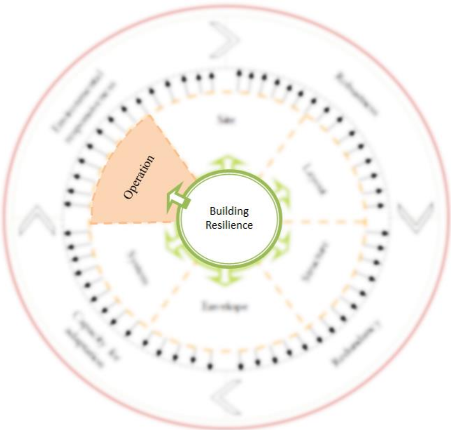


Figure 8-13: Sub-Model Building operation Dimension

## 8.5 Resilience assessment

An assessment of resilience can aid with developing design strategies for dealing with change and uncertainty that will emerge due to climate change. The outer layer of the proposed model consists of resilience measurement indicators. These are used to assess the compliance of the generated design solutions to resilience to climate change risks impact. Figure 8-14 shows the key resilience measurements that are adopted by this study. The assessment is considered as a dynamic process which aims to collect conditions which enable and effect resilience design, in order test through simulation and sensitivity analyses to create design solutions. From this perspective, the designer should take into consideration previous resilience design solutions and use them to generate future climate change compliant design solutions**.**

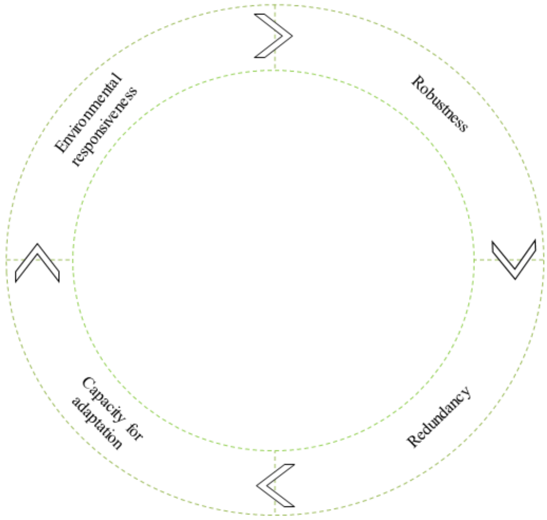


Figure 8-14: Sub-Model Evaluation Process.

### 8.5.1 Robustness:

Robustness (RO): is defined as "*strength, or the ability of elements, systems and other units of building, to withstand a given level of stress or demand without suffering degradation or loss of function*" (Bruneau et al 2003). Based on this definition the generate design solutions should be able function under extreme stress without the disruption of the building operation.

### 8.5.2 Redundancy:

Redundancy (R): is defined as '*'the extent to which elements, systems, or other units exist of the building that are substitutable, i.e., capable of satisfying functional requirements in the* *event of disruption, degradation, or loss of functionality*'' (Bruneau et al 2003). The notion of redundancy here is equated with safety and integrity of the building components and systems under the influence of climate change impact.

### 8.5.3 Capacity for adaptation:

Capacity for adaptation (CA): is defined as '*'the responsive reactions to a situation or happening*" (Smithers and Smit 1997). This characteristic is aimed at developing design solutions that are able to adjust in response to actual or expected climatic stimuli or their effects. Thus it is expected that the generated design solutions to have the capacity to withstand disruption, absorb disturbance and perform effectively in extreme events a crisis.

### 8.5.4 Environmental responsiveness:

Environmental responsiveness (ER): is defined as "*Environmental receptiveness is composed of components which react to the internal and external environmental changes and inhabitants demands in such a manner to maintain best and adaptive relief situations, at the same time contributing to lessening the energy ingestion for the control of the internal environment*". In the context of this resilience criterion is concerned with integrating environmentally responsive elements in building design solutions. In a perfect world all design solutions or elements should be able to dynamically adjust physical properties and energetic performance appropriately and accordingly to the changing demands from both indoor and outdoor conditions.

These resilience characteristics are large extent interrelated. It is evident from these definitions that there is a large element of coupling between building design resilience strategies and resilience characteristics. Hence, it is unimaginable that we can provide resilient design solutions to climate change impact without assessment them at least against these four resilience characteristics.

## 8.6 Implementing the conceptual model

The iterative processes displayed in Figure 8-15  shows how to integrate the proposed the model with the design process. The integration process is divided into five key stages. These stages are silimar to the new RIBA plan of work. The following section will demonstrate how to generate design solutions that are complinate with climate change impact as percieved in this study.

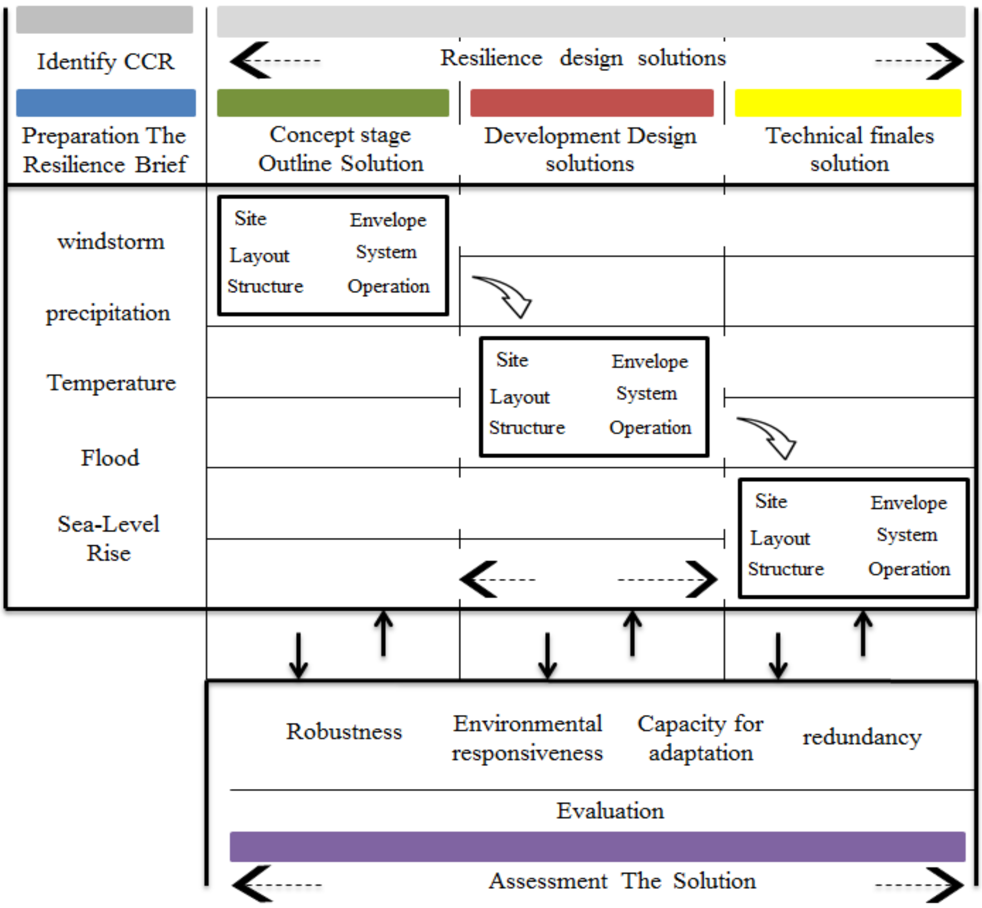


Figure 8-15: Application process of the conceptual model.

### 8.6.1 Preparation of the Resilience Brief

The primary aim of this stage is to ascertain the impact of the climate change risks on the proposed building through the analysis of windstorm, precipitation, temperature, flood and Sea-Level data. It is expected at this point of the design process the designers should identify the climate change treats from the data analysis convert them into design objectives, outcomes and aspirations. Also design issues that are related to climate change which may affect the project budget must be considered at this stage. Additionally all other parameters or constraints that may emerge from the climate change must be include the initial project brief. If it is necessary feasibility studies should be commissioned to investigate the proposed project viability in relation to climate change impacts. It is expected at the end of this stage the designers will have a complete set site and other contextual information. This information should be reviewed against the climate change predicted scenarios.

### 8.6.2 Resilience Design solutions

This is the coordination stage of the building, which needs to be resilient. The author concludes from the above investigation that the designer should in this stage be equipped the building needs with their appropriate design solutions (resilience strategies) through design aspects: site, layout, structure, envelope, system and operation. As well as these aspects will consider it in all the 3 following 3 stages. Which: Concept stage, Development design and Technical design. The designer should also have access to information or be equipped on the methods for deciding the building requirements to climate change risks. This is the point where the designer encounters the challenge of bringing together the contradictory demand functions and the building requirements to achieve resilience. This is the time when the designer is required to choose two or three substitute solutions that can ultimately secure building aspirations and be incorporated positively with the building functions.

#### *8.6.2.1 Concept stage: Outline Solution*

As pointed by Gething (2011), the concept design stage is where the design strategies are selected and evaluated. Andersen et al (2008), stated that the effort architects, engineers and others is brought together to define the design functions, structure and services strategies. During this Stage, the initial concept design is produced in relation with the requirements of the Initial Project Brief. It is vital to revisit the brief during this period to update any key design decisions. After the review and updating the reliance brief the designer will embark on preparing the concept design, including outline proposals for structural design, building services systems, and outline specifications along with relevant project resilient strategies in accord with design programme. At this point of the process all of the design resilience strategies described previously should be incorporated into the proposed design solutions. It is also imperative at this point to convert the design resilient strategies into workable and cost effective construction strategies. The resilience aspirations may also be reviewed and costed at this stage. All resilience proposal alterations must be agreed and this point and incorporated in the final project brief.

#### *8.6.2.2 Development Design stage: solutions*

The stage of concept design is further developed and may require several iterations to complete in this process. To extract effective resilient design solutions the designer may user design workshops and any other tools. It is expected at this point of the design progress the designer refines and updated resilience proposals for envelope, structural design, building services systems, outline specifications, and building operation strategies in accordance with the resilience brief. It is expected that at this stage the designer will carry out the following reviews:

- Review and update the adopted design resilience strategies
- Refine and distil the project's resilience strategies, checking against brief and targets.
- Refine the resilience strategy and make provision for future adaptation interventions.
- Incorporate climate change risks and resilience strategies in specifications, building regulations the planning application and design and access statement.
- All adopted design resilient strategies should be cross checked and coordinated building services and structural engineering designs

#### *8.6.2.3 Technical Design stage: finales solution*

The architectural, structural engineering and building services resilient designs strategies are further refined to produce technical definition of the project. It is expected at this state the technical design is prepared in accordance with the resilience with aspiration defined in the previous stages. This must include design strategies in relation to structural, architectural, building services information, specialist subcontractor design and specifications. The lead designer will provide will oversee the inclusion of the resilient strategies in each designer's work. Probably this is last gateway to review and redesign aspects of the projects that do not adhere to the climate change resilience brief.

### 8.6.3 Assessment the of the design solutions to resilience

As demonstrated in the figure the assessment processes is continuous during the duration of the design process. At each stage of the design the generated design solutions are assessed against the characteristics: Robustness, Redundancy, Capacity for adaptation and Environmental responsiveness. If the design solutions comply with the resilience criteria set by the design team then are adopted otherwise new search for new design solutions continuous until the problem is satisfactorily solved. At this point (evaluation) it will be cheaper to alter designs in the design stages than afterwards.

## 8.7 Summary

The systematisation of integrating resilience strategies into design process is the primary proposition of the suggested model. In increasing designer accountability to meet building resilience requirements to combat climate change risks is advocated by the proposed. The suggested model is an improvement on the existing design processes by which designers can incorporates resilience design solutions into buildings to mitigate against emerging climate change risks. It is essential to examine building design from various aspects to avoid any future potential dysfunction that may rise in the operation of building assets.

# Chapter 9: Findings and Descriptive Analysis

## 9.1 Introduction

This chapter describes the data obtained from the survey and the results of the analysis carried out on this data. Firstly, it restates the research hypotheses, stating the individual hypotheses for each category of potential respondent and resilience factors. Then research question is answered by performing a statistical analysis for each of the resilience design factor. Finally, the most effective factors are identified. The details for this analysis will be explained in the following section.

## 9.2 Restatement of the problem of the study

The main problem in this study is to investigate the effectiveness of the SFs on the design of buildings. The SFs will be assessed based on the respondents' professional role and their experience.

## 9.3 Restatement of the research hypotheses

The following are the hypotheses for the study:

### 9.3.1 General architect perception

1. $A_x$ ($p > 0.05$): There is no statistically significant difference between the respondents' perceptions on the effectiveness of resilience factors, based on their professional role.

   $A_y$ ($p < 0.05$): There is a statistically significant difference between the respondents' perceptions on the effectiveness of resilience factors, based on their professional role.

2. $A_x$ ($p > 0.05$): There is no statistically significant difference between the respondents' perceptions on the effectiveness of resilience factors, based on their experience.

   $A_y$ ($p < 0.05$): There is a statistically significant difference between the respondents' perceptions on the effectiveness of resilience factors, based on their experience.

### 9.3.2 Building resilience design attributes

#### *9.3.2.1 Resilience factors of building site design*

3. $A_1$ ($p > 0.05$): There is no statistically significant difference between the respondents' perceptions on the effectiveness of resilience factors of “building site design SFs: site analysis, orientation and landscape”, based on both their professional role and experience.

   $A_{01}$ ($p < 0.05$): There is a statistically significant difference between the respondents' perceptions on the effectiveness of resilience factors of “building site design SFs: site analysis, orientation and landscape”, based on both their professional role and experience.

#### *9.3.2.2 Resilience factors of building design layout*

4. $A_2$($p > 0.05$): There is no statistically significant difference between the respondents' perceptions on the effectiveness of resilience factors of “layout design LSs: spaces, entrance, spaces relation and height”, based on both their professional role and experience.

   $A_{02}$ ($p < 0.05$): There is a statistically significant difference between the respondents' perceptions on the effectiveness of resilience factors of “Layout Design LSs: spaces, entrance, spaces relation and height”, based on both their professional role and experience.

#### *9.3.2.3 Resilience factors of building design structure*

5. $A_3$($p > 0.05$): There is no statistically significant difference between the respondents' perceptions on the effectiveness of resilience factors of “building structure design TSs: foundation, building structure and materials”, based on both their professional role and experience.

$A_{03}(p < 0.05)$: There is a statistically significant difference between the respondents' perceptions on the effectiveness of resilience factors of “building structure design TSs: foundation, building structure and materials”, based on both their professional role and experience.

#### *9.3.2.4 Resilience factors of building design envelope*

6. $A_4(p > 0.05)$: There is no statistically significant difference between the respondents' perceptions on the effectiveness of resilience factors of “building design envelope ESs: form, façade, roof, external walls, internal walls and insulation”, based on both their professional role and experience.

   $A_{04}(p < 0.05)$: There is a statistically significant difference between the respondents' perceptions on the effectiveness of resilience factors of "building design envelope ESs: form, façade, roof, external walls, internal walls and insulation”, based on both their professional role and experience.

#### *9.3.2.5 Resilience factors of building system*

7. $A_5(p > 0.05)$: There is no statistically significant difference between the respondents' perceptions on the effectiveness of resilience factors of “building system YSs: HVAC system, electrical system, drainage, lighting, heat/cold and water”, based on both their professional role and experience.

   $A_{05}(p < 0.05)$: There is a statistically significant difference between the respondents' perceptions on the effectiveness of resilience factors of “building system YSs: HVAC system, electrical system, drainage, lighting, heat/cold and water”, based on both their professional role and experience.

#### *9.3.2.6 Resilience factors of building operation*

8. $A_6 (p > 0.05)$: There is no statistically significant difference between the respondents' perceptions on the effectiveness of resilience factors of "building operation OSs: warning system, equipment operation, maintenance and system control", based on their professional role and experience.

   $A_{06} (p < 0.05)$: There is a statistically significant difference between the respondents' perceptions on the effectiveness of resilience factors of "building operation OSs: warning system, equipment operation, maintenance and system control", based on their professional role and experience.

### 9.3.3 Current practice

#### *9.3.3.1 Integration of resilience factors of building design site*

9. $B_1 (p > 0.05)$: There is no statistically significant difference between the respondents' perceptions on the integration of SF into SS.

   $B_{01} (p < 0.05)$: There is a statistically significant difference between the respondents' perceptions on the integration of SF into SS.

#### *9.3.3.2 Integration of resilience factors of building design layout*

10. $B_2 (p > 0.05)$: There is no statistically significant difference between the respondents' perceptions on the integration of SF into LS.

    $B_{02} (p < 0.05)$: There is a statistically significant difference between the respondents' perceptions on the integration of SF into LS.

#### *9.3.3.3 Integration of resilience factors of building design structure*

11. $B_3 (p > 0.05)$: There is no statistically significant difference between the respondents' perceptions on the integration of SF into TS.

    $B_{03} (p < 0.05)$: There is a statistically significant difference between the respondents' perceptions on the integration of SF into TS.

#### *9.3.3.4 Integration of resilience factors of building design envelope*

12. $B_4 (p > 0.05)$: There is no statistically significant difference between the respondents' perceptions on the integration of SF into ES.

    $B_{04} (p < 0.05)$: There is a statistically significant difference between the respondents' perceptions on the integration of SF into ES.

#### *9.3.3.5 Integration of resilience factors of building system*

13. $B_5 (p > 0.05)$: There is no statistically significant difference between the respondents' perceptions on the integration of SF into YS.

    $B_{05} (p < 0.05)$: There is a statistically significant difference between the respondents' perceptions on the integration of SF into YS.

#### *9.3.3.6 Integration of resilience factors of building operation*

14. $B_5 (p > 0.05)$: There is no statistically significant difference between the respondents' perceptions on the integration of SF into OS.

    $B_{05} (p < 0.05)$: There is a statistically significant difference between the respondents' perceptions on the integration of SF into OS.

### 9.3.4 Description of participants' information

This part of the questionnaire included five questions. The first question, which requested the respondent’s name, was optional; the second question requested contact details, and the third asked for details about the company or institute to which the respondents were affiliated. The fourth question was about the professional role of the architects. The fifth question was about the experience of the architects. In this survey, the author paid attention to the last three questions, as will be described further in the next sections.

#### *9.3.4.1 Professional role*

The outcome of the questionnaire with respect to the professional capacity of respondents is shown in Table 9-1. Of the 77 individuals who replied, 21 (27%) were found to be practicing architects, 36 (47%) were both academic and practicing architects (the largest category), and 20 (26%) were academic architects.

Table 9-1: The professional roles of respondents.

| 1-Practising architects | | 2-Academic and practicing architects | | 3- Academic architect | | Total | |
|---|---|---|---|---|---|---|---|
| No | Percentage | No | Percentage | No | Percentage | No | Percentage |
| 21 | 27% | 36 | 47% | 20 | 26% | 77 | 100% |

#### *9.3.4.2 Respondents' years of experience*

The researcher considers experience of the respondents to be an important parameter when compare the respondents' answers and their prioritisation of SDFs. The respondents' level of experience is shown in Table 3.

Table 9-2: Years of experience or respondets.

| 0-5 years | | 5-10 years | | More than 10 years | | Total | |
|---|---|---|---|---|---|---|---|
| No. | Percentage | No. | Percentage | No. | Percentage | No. | Percentage |
| 14 | 18% | 21 | 27% | 42 | 55% | 77 | 100% |

As illustrated in Table 9-2, 42 (55%) of respondents have more than 10 years' experience, 21 (27%) have between 5 and 10 years' experience, and 14 (18%) have between 0 to 5 years' experience. This data will be used in Chapter 11 to when examining to what extent different levels of experience may affect the assessment of resilience design factors.

### 9.3.5 Reliability Statistic

SPSS was used to perform a check on the internal consistency or average correlation of the scores given to the 85 different resilience strategies. The measure of internal consistency used was Cronbach's Alpha, for which a value of > 0.70 is normally considered acceptable in research of this type (Pallant, 2004). The result is shown in the Table 9-3 below.

Table 9-3: Reliability Statistics

| Cronbach's Alpha | N of Items |
|---|---|
| .968 | 85 |

### 9.3.6 Questionnaire analysis

#### *9.3.6.1 Site design resilience strategies*

Table 9-4 illustrates the respondents' scores for each of the seven SFs of the aspect. As well as, shows the number of respondents in each score for each SF, and highlights the most effective SFs and the least effective SFs from the analysis of these sections.

The mean effectiveness for the "Prepare site landscape and landforms for high wind conditions as well as to reduce the noise, pollution, energy consumption, temperature degree and relative humidity" resilience factor is 4.34 with a standard deviation (S.D.) of 0.837. Most of those who responded gave this SF an effectiveness score of 5 (very effective). This corresponds well with the findings of several authors introduced in the literature review. Ahsan (2009), for example, considered the landscape a factor in reducing exposure to noise, pollution and thermal transmittance, and also reducing the energy consumption.

The mean effectiveness of the "Plant mature trees to assist in dissipation of the wind force" SF is 4.08, and with a S.D. of 0.623. Trees can play a significant role in dissipating the wind force on a space, and provision of shading devices should be accurate based on their orientation and compliance with site circumstances (Newman et al., 2013). There is an agreement between the literature review and participants' perspectives.

The SF "Use optimum building orientation to improve resilience to high/low temperature" scored a mean value 4.05 with S.D. of 0.826, and is therefore assessed as an effective factor by the architects who responded. Among sources cited in the literature review, BIM (2011) and Kruger and Dorigo (2008) referred to the importance of orientation and how it can affect optimisation of the air flow as well as cross-ventilation through the space.

The SF “Use permeable surfaces in landscaping against vulnerability to flooding” resilience factor carried a mean value of 4.01 (effective) with a S.D. of 0.786. Hertfordshire County Council (2013) is among sources that argue in favour of this strategy.

The SF “Direct runoff of water to a catch basin or holding area to reduce erosion” scored a mean value 3.96 (effective) with a S.D. of 0.880. The survey results show that 21 individuals allocated a score of 5, 38 a score of 4, 13 a score of 3 and 4 a score of 2 to this SF. 59 respondents out of 110 (84.5%) believe that this SF is an effective one, while 13 individuals (10.0%) believe it is possible SF, as illustrated in Table 9-4. From the literature review, Newman et al. (2013) referred to the importance of reducing erosion and how it can optimise direct runoff.

The SF “Use water catchment systems/cistern to reduce flooding" resulted in a mean value of 3.91 (effective) with a S.D. of 0.781. Newman et al. (2013) explained the importance and effectiveness of using water catchment, and the respondents generally agreed with this.

The “Use site stabilization techniques to prevent erosion” scored a mean value of 3.84 (effective) with a S.D. of 0.904. Newman et al. (2013) indicated the role of site stabilisation techniques in preventing erosion. Amajority of respondents gave this SF a score of 4 or 5 – 41 a score of 4 and 16 a score of 5. Indicating that it is accepted as an effective SF.

Table 9-4: Site design resilience strategies.

| Code | **Site design** resilience strategies | Total no. | Frequency of scores | | | | | Mean | Std. deviation | Ranki-ng |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | 4 | 5 | | | |
| SS1 | Use site stabilisation techniques to prevent erosion | 77 | 2 | 4 | 14 | 41 | 16 | 3.84 | .904 | 7 |
| SS2 | Direct runoff of water to a catch basin or holding area to reduce erosion | 77 | 1 | 4 | 13 | 38 | 21 | 3.96 | .880 | 5 |
| SS3 | Plant mature trees to assist in dissipation of the wind force | 77 | 0 | 1 | 9 | 50 | 17 | 4.08 | .623 | 2 |
| SS4 | Use water catchment systems/cistern to reduce flooding | 77 | 0 | 3 | 18 | 39 | 17 | 3.91 | .781 | 6 |
| SS5 | Prepare site landscape and landforms for high wind conditions as well as to reduce the noise, pollution, energy consumption, temperature degree and relative humidity | 77 | 1 | 0 | 12 | 23 | 41 | 4.34 | .837 | 1 |
| SS6 | Use optimum building orientation to improve resilience to high/low temperature | 77 | 0 | 5 | 9 | 40 | 23 | 4.05 | .826 | 3 |
| SS7 | Use permeable surfaces in landscaping against vulnerability to flooding | 77 | 1 | 1 | 14 | 41 | 20 | 4.01 | .786 | 4 |

#### *9.3.6.2 Layout design resilience strategies*

Table 9-5 illustrates respondents' scores for each SF of the aspect. This category, which includes 14 proposed resilience strategies.

The SF "Use secure cross-ventilation for passive cooling and occupants' comfort" scored a mean value of 4.36 with a S.D. 0.887. The majority of the respondents are concentrated at score 5 (very effective). Newman et al. (2013) referred to the need to design secure cross-ventilation that can cope with resilience needs.

The SF "Use appropriate floor height to allow for future modification" scored a mean value of 4.35 (effective) with a S.D. of 0.774, although individual scores ranged from 1 (very ineffective) to 5 (very effective). Various authors have discussed the effectiveness of this SF, for example: City of New York (1999), Saari and Heikkila (2008), and IBEC (2008).

The SF "Specify thermal zones, by facing rooms of high energy demand on the south and putting rooms such as cellars, stairs, garages and laundry rooms on the north to act as buffer space" scored a mean value 4.05 (effective) with an S.D. of 0.887. This S.D. value indicates a high level of agreement between the designers. In the questionnaire, 26 architects gave this SF a score of 5 and 34 a score of 4. The majority of designers considered this factor to be effective. As discussed in the literature review, Ji, Lomas and Cook (2009) indicated that a building's view and orientation to specify thermal zones should be considered.

The SF "Use appropriate floor height to enhance and optimise thermal and ventilation processes" scored a mean value of 4.03 (effective) with a S.D. of 0.794. Saari and Heikkila (2009) referred to how the floor height can affect a building's air quality.

The SF "Specify the layout of rooms, corridors, stairwells etc. in a way that upholds a low-resistance airflow path through the building (both in plan and section) to thermal comfort" scored SF a mean value of 4.01 (effective) with a S.D. of 0.678. In response to the survey, 15 designers gave a score of 5, 51 a score of 4, 8 a score of 3, 3 a score of 2, and 0 a score of 1 to this factor. Liu, De-Ling, Nazaroff and William (2001) focused on the airflow core and how this could help the design function to perform without any barrier.

The SF "Specify layout for maximum daylighting to take advantage of light and thermal energy" scored a mean value of 3.90 (effective) and a S.D. is 0.897. , indicating strong agreement between respondents. Of the 77 architects who replied, 22 gave a score of 5, 29 gave a score of 4, 23 gave a score of 3, 2 gave a score of 2 and 1 gave a score of 1 for this SF, so that majority considered it effective. BIM (2011) indicate the importance of simplified building element shapes for ease of getting daylighting.

The SF "Oversize space to reduce occupants' stress" scored SF a mean value 3.86 (effective) with a S.D. of 0.823. , indicating good agreement among respondents. Most considered it effective, with 15 architects out of 77 scoring it a 5 and 41 a 4. This SF was selected originally based on results by Hansen et al. (2005).

The SF “Plan spaces and layout based on future use scenarios to create usage resilience” scored a mean value of 3.79 with a S.D. of 0.879, showing good agreement between participants regarding the effectiveness of this SF. 18 respondents gave a score of 5 and 30 a score of 4 for this SF. 48 respondents (60%) accepted this SF as an effective SF. Dunne et al.(2011) emphasised the importance of this resilience factor.

The SF, “Specify (generic layout and program spaces) for future flexibility of use (use of modularity and standardization)” scored a mean value of 3.68 (between “effective” and “neutral”) with a S.D. of 0.818. Overall, this SF was selected as being effective by the majority of respondents. A total of 13 of the architects gave a score of 5 and 30 a score 4. Saari and Heikkila (2008) considered modularity and standardisation to be one of the solutions to building resilience.

The SF “Provide ‘safe spaces’ in the building to protect the occupants from extreme events” scored a mean value of 3.64 (between “effective” and “neutral”) with a S.D. of 0.986. , with 17 respondents giving it a score of 5, 25 a score of 4, and 26 a score of 3. 42 respondents out of 77 agreed that this SF was effective. This was a factor referred to by Turnbull, et al, (2013).

The SF “Specify multiple access within and between spaces to avoid access shutdown” scored a mean value of 3.58 (between “effective” and “neutral”) with a S.D. of 0.879. The outcome of the survey revealed that 39 architects considered this factor to be effective factor; 34 others ranked it as a possible factor. Moharram (1980) referred to how multiple accesses are important to maximise performance.

The SF “Use stack ventilation for passive cooling” scored a mean value of 3.44 (“neutral”) with a S.D of 0.966. Of 77 designers, only 10 gave a score of 5 and 28 a score of 4.In the opinion of respondents overall, this was one of the less effective resilience factors. In the opinion of respondents, this was rated one of the less effective resilience factors. Newman et al. (2013) discuss the importance of building geometry on resilience.

The SF “Minimise partitions between spaces to allow for thermal buoyancy effect” scored a mean value of 3.44 (“neutral’) with a S.D. of 0.866 Of the 77 respondents, 7 gave it a score of 5, 31 a score of 4, 29 a score of 3, 9 a score of 2 and 1 a score of 1. Only 38 respondents characterized this as an effective SF; the majority thought it ineffective In the opinion of respondents, in fact, this was rated one of the least effective resilience factors in the study. This is inconsistent with the literature. Moharram (1980), for example, referred to the importance of minimising partitions between spaces to promote a thermal buoyancy effect.

The SF “Specify spaces to perform multiple functions to enhance use resilience” scored a mean value of 2.97 (neutral) with a S.D of 0.778, making in the least effective of layout design resilience strategies in the eyes of the expert respondents to the survey. 3 architects out of 77 gave a score of 5, 12 a score of 4, and 43 a score of 3. Overall, 15 respondents considered it to be an effective SF; in contrast, 19 respondents considered it to be an ineffective SF.

Table 9-5: Layout design resilience strategies.

| Code | **Layout design** resilience strategies | Total no. | Frequency of scores | | | | | Mean | Std-deviation | Ranking |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | 4 | 5 | | | |
| LS1 | Plan spaces and layout based on future use scenarios to create usage resilience | 77 | 0 | 5 | 24 | 30 | 18 | 3.79 | .879 | 8 |
| LS2 | Specify multiple access within and between spaces to avoid access shutdown | 77 | 2 | 2 | 34 | 27 | 12 | 3.58 | .879 | 11 |
| LS3 | Minimise partitions between spaces to allow for thermal buoyancy effect | 77 | 1 | 9 | 29 | 31 | 7 | 3.44 | .866 | 13 |
| LS4 | Use appropriate floor height to enhance and optimize thermal and ventilation processes | 77 | 0 | 3 | 14 | 38 | 22 | 4.03 | .794 | 4 |
| LS5 | Use appropriate floor height to allow for future modification | 77 | 0 | 3 | 5 | 31 | 38 | 4.35 | .774 | 2 |
| LS6 | Specify spaces to perform multiple functions to enhance use resilience | 77 | 1 | 18 | 43 | 12 | 3 | 2.97 | .778 | 14 |
| LS7 | Use stack ventilation for passive cooling | 77 | 2 | 10 | 27 | 28 | 10 | 3.44 | .966 | 12 |
| LS8 | Use secure cross-ventilation for passive cooling and occupants' comfort | 77 | 2 | 2 | 3 | 29 | 41 | 4.36 | .887 | 1 |
| LS9 | Oversize space to reduce occupants' stress | 77 | 1 | 3 | 17 | 41 | 15 | 3.86 | .823 | 7 |
| LS10 | Specify generic layout and program spaces for future flexibility of use (use of modularity and standardisation) | 77 | 0 | 4 | 30 | 30 | 13 | 3.68 | .818 | 9 |
| LS11 | Specify layout for maximum daylighting to take advantage of light and thermal energy | 77 | 1 | 2 | 23 | 29 | 22 | 3.90 | .897 | 6 |
| LS12 | Specify the layout of rooms, corridors, stairwells etc. in a way that upholds a low-resistance airflow path through the building (both in plan and section) to thermal comfort | 77 | 0 | 3 | 8 | 51 | 15 | 4.01 | .678 | 5 |
| LS13 | Specify thermal zones, by facing rooms of high energy demand on the south and putting rooms such as cellars, stairs, garages and laundry rooms on the north to act as buffer space | 77 | 1 | 3 | 13 | 34 | 26 | 4.05 | .887 | 3 |
| LS14 | Provide 'safe spaces' in the building to protect the occupants from extreme events | 77 | 1 | 8 | 26 | 25 | 17 | 3.64 | .986 | 10 |

#### *9.3.6.3 Structure design resilience strategies*

Table 9-6 illustrates respondents' scores for each SF of the aspect, which includes 12 proposed resilience strategies.

The SF "Increase structure bracing to create strength redundancy to wind and snow loads" scored a mean value of 4.32 (effective) with a S.D. of 0.834. This strategy was discussed by Tran, Tuan Anh, et al (2012).

The SF "Construct masonry chimneys with continuous reinforced steel bracing to increase the resistance" scored a mean value of 4.29 (effective) with a S.D. of 0.792. Newman et al. ; however, overall there was agreement in the effectiveness of this factor. (2013) are among authors who have considered this resilience strategy.

The SF "Use structure materials that are more resistant to pests to mitigate high temperature" scored a mean value of 4.18 (effective) with a S.D of 0. Of the 77 respondents, 31 selected a score of 5, 33 a score of 4, 11 a score of 3, 0 a score of 2 and 1 a score of 1. Overall, 64 architects ranked this SF as effective, while 11 accepted it as a possible SF. Nylåna (2005) and Brown and Cole (2009) referred to the importance of using materials that are more resistant to cope with building resilience demands.

The SF "Provide anchorage between superstructure and substructure to increase resistance to high winds" scored a mean value of 4.06 (effective) with a S.D. of 0.848, indicating a high level of agreement among responding architects. 27 gave a score of 5, 31 a score of 4, 16 a score of 3, 3 a score of 2 and 0 a score of 1. This effective was ranked as effective by 58 respondents and as a possible SF by 16 respondents. Mitchell (2011), included in the literature review, addresses this factor.

The SF "Oversize roof covering fixings to reduce windblown debris" scored a mean value of 3.97 (effective) with a S.D. of 0.760. Newman et al. (2013) and Brown and Cole (2009) referred to the importance of this factor.

The SF "Oversize walls and roofs to create strength redundancy for wind and snow loads" scored a mean value is 3.81 (effective) with a S.D. of 0.795. 18 respondents gave a score of 5, 42 a score of 4, 14 a score of 3, 3 a score of 2 and 0 a score of 1 to this SF. 60 respondents out of 77 selected this SF as effective, whereas 14 of them ranked it as a possible SF. This factor was referred to by Newman et al. (2013).

The SF, “Use flexible pipes and joints to resist high wind and other pressures” scored a mean value of 3.79 (effective) with a S.D. of 0.848. Ross, Saunders and Novakovic (2007) discussed this as a resilience factor.

The SF “Oversize walls and roofs to create strength redundancy for wind and snow loads” scored a mean value is 3.81, with a S.D. of 0.795, and thus is considered overall by the respondents. This SF was selected based on Newman, et al (2013).

The SF “Specify durable and robust materials and construction methods to resist the increasing number of significant extreme weather events” scored a mean value of 3.66 (effective) with a S.D. of 0.952. A total of 15 of the architects gave a score of 5 and 37 a score 4 to this SF; it was selected as effective by 52 respondents. Among the references found in the literature review, Keung (2010) argued in favour of this resilience factor.

The SF “Specify durable and robust materials and construction methods to resist the increasing number of significant extreme weather events” scored a mean value of 3.66 (effective) with an S.D. of 0.952. 12 respondents gave it a score of 5, 33 a score of 4 and 27 a score of 3. In total, 45 respondents out of 77 agreed on selecting this SF as an effective SF, whereas 27 of them agreed to accept is as a possible SF. In Table 6, the majority of the respondents are seen to be concentrated between 3 and 4 scores. Keung (2010) was the source for this SF in the literature review.

The SF “Elevate structure above flood level” scored a mean value of 3.62 (marginally effective) with a S.D. of 0.904. 14 designers selected a score of 5, 27 a score of 4, 30 a score of 3, 5 a score of 2 and 1 a score of 1. The outcome of the survey is that 41 architects assumed that this factor to be an effective factor; 30 architects accepted it as a possible factor. Di Girolamo et al. (2013) supported this resilience strategy.

The SF “Use thermal mass on floor/ceiling/walls to moderate internal temperatures and reduce electricity demand” scored a mean value 3.58 (marginally effective) with a S.D. of 0.937. In this survey, 14 architects gave a score of 5 and 25 gave a score of 4 for this factor. 39 designers considered this factor as an effective factor; however, overall, this emerged as one of the lowest ranked resilience factors from the questionnaire. It was among those identified by Newman et al. (2013).

The SF “Use an appropriate shape and angle of the roof for optimum ventilation and thermal comfort” scored a mean value is 3.52 (marginally effective) with a S.D. of 0.898. Of the respondents, 9 gave it a score 5, 33 a score of 4, 25 a score of 3, 9 a score of 2 and 1 a score of 1. 42 respondents identified this effective factor, but overall it emerged from the survey as one lowest ranked SFs. Despite the relatively low assessment by respondents, the effectiveness of this strategy was discussed by the United States Department of Energy (2000), Ahsan (2009), Prasad and Fox (1996), Biwole et al (2008) and Susanti et al (2008).

The SF “Oversize connections or attachments among building parts to facilitate the operation” scored a mean value of 3.32 (neutral) with a S.D. of 0.802. . Only 5 responding architects gave a score of 5, 26 a score of 4, 35 a score of 3, and 11 a score of 2. It proved to be one of the least effective SFs according to the respondents. By contrast, several authors, such as Tran, et al, (2012), discuss the effectiveness of this strategy.

Table 9-6: Structure design resilience strategies

| Code | **Structure design resilience strategies** | Total no. | Frequency of scores | | | | | Mean | Std-deviation | Ranking |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | 4 | 5 | | | |
| TS1 | Elevate structure above flood level | 77 | 1 | 5 | 30 | 27 | 14 | 3.62 | .904 | 9 |
| TS2 | Use flexible pipes and joints to resist high wind and other pressures | 77 | 0 | 6 | 19 | 37 | 15 | 3.79 | .848 | 7 |
| TS3 | Use an appropriate shape and angle of the roof for optimum ventilation and thermal comfort | 77 | 1 | 9 | 25 | 33 | 9 | 3.52 | .898 | 11 |
| TS4 | Oversize roof covering fixings to reduce windblown debris | 77 | 0 | 3 | 14 | 42 | 18 | 3.97 | .760 | 5 |
| TS5 | Increase structure bracing to create strength redundancy to wind and snow loads | 77 | 1 | 1 | 9 | 27 | 39 | 4.32 | .834 | 1 |
| TS6 | Oversize walls and roofs to create strength redundancy for wind and snow loads | 77 | 1 | 1 | 24 | 37 | 14 | 3.81 | .795 | 6 |
| TS7 | Provide anchorage between superstructure and substructure to increase resistance to high winds | 77 | 0 | 3 | 16 | 31 | 27 | 4.06 | .848 | 4 |
| TS8 | Use structure materials that are more resistant to pests to mitigate high temperature | 77 | 2 | 0 | 11 | 33 | 31 | 4.18 | .869 | 3 |
| TS9 | Construct masonry chimneys with continuous reinforced steel bracing to increase the resistance | 77 | 0 | 3 | 7 | 32 | 35 | 4.29 | .792 | 2 |
| TS10 | Oversize connections or attachments among building parts to facilitate the operation | 77 | 0 | 11 | 35 | 26 | 5 | 3.32 | .802 | 12 |
| TS11 | Use thermal mass on floor/ceiling/walls to moderate internal temperatures and reduce electricity demand | 77 | 2 | 4 | 32 | 25 | 14 | 3.58 | .937 | 10 |
| TS12 | Specify durable and robust materials and construction methods to resist the increasing number of significant extreme weather events | 77 | 1 | 4 | 27 | 33 | 12 | 3.66 | .852 | 8 |

#### *9.3.6.4 Envelope design resilience strategies*

Table 9-7 and 9-8 illustrates respondents' evaluations for each SF of the aspect. This category includes 32 proposed resilience strategies.

The SF "Use energy-efficient windows and shading devices to reduce energy use" scored a mean value of 4.43 (effective) with a S.D. of 0.834. A number sources included in the literature review, cite this resilience strategy, including the Ministry for the Environment (2008), Bateson and Hoare Lea (2011), Franco (2007), The Nature Conservancy (2013), Hertfordshire County Council (2013) and Newman et al. (2013).

The SF “Use appropriate insulation systems to reduce conduction through the thermal envelope” scored a mean value is 4.40 (effective) with a S.D. 0.765. Newman et al. (2013) and Hertfordshire County Council (2013) are among sources that discuss this factor.

The SF “Specify windows, doors, and openings to withstand wind loads and windblown debris” scored a mean value 4.26 (effective) and a S.D. of 0.750. Of respondents, 32 gave a score of 5, and 35 gave a score of 4 for this SF; 76 designers considered it to be effective Newman et al (2013) referred to the importance of this resilience factor. Thus, there is an agreement between the literature review and participants' perspectives.

The SF “Specify windows, doors, and openings to withstand wind loads and windblown debris” scored a mean value 4.26 (effective) and a S.D. of 0.750. Newman et al (2013) referred to the importance of this resilience factor.

The SF “Oversize framing and bracing to increase redundancy” scored a mean value of 4.25 (effective) and S.D. of 0.725. Newman, et al (2013) referred to the importance of this factor.

The SF “Use appropriate exterior shading to reduce vulnerability to overheating” scored a mean value of 4.17 (effective) with a S.D. of 0.880. . Of all respondents, 31 allocated a score of 5, 33 a score of 4, 9 a score of 3 and 3 a score of 2 to this SF. 64 respondents out of 77 believe this SF to be effective, while 9 believed it was possibly effective. Akashi et al. (2006) referred to the importance of this factor.

The SF “Use an appropriate shape and angle of the roof to optimize ventilation and thermal comfort, as well as, to resist storms” scored a mean value of 4.09 (effective) with a S.D. of 0.830. This resilience factor was discussed by the United States Department of Energy (2000), Ahsan (2009), Prasad and Fox (1996), Biwole et al. (2008), and Susanti et al. (2008).

The SF "Use advanced wall and framing techniques to reduce energy loss" scored a mean value of 4.06 (effective) with a S.D. of 0.848. Of those participating in the survey, 24 gave a score of 5 and 39 gave a score of 4. Newman et al. (2013) indicated the significance of this resilience factor.

The SF "Use a high solar reflectance to reflect sunlight and heat away from a building" scored a mean value of 4.04 (effective) with a S.D. of 1.032. A total of 32 of the architects gave a score of 5 and 25 a score 4 to this SF. In total, it was selected as effective by 57 respondents. Hertfordshire County Council (2013) referred to the importance of this factor.

The SF "Provide expansion joints within the materials on vulnerability to expansion" scored a mean value of 4.04 (effective) with a S.D of 0.733. Of those responding to the survey, 19 gave a score of 5 and 45 a score of 4, making a total of 64 who scored this SF effective or very effective. ABCB (2006) referred to the effectiveness of this factor.

The SF "Specify light paint colours for interior ceilings and walls to improve internal distribution of daylight" scored a mean value of 3.94 (effective) with a S.D. of 0.800. This factor's effect on building design resilience was scored by the architects as follows: 19 out of 77 gave it a score of 5, 37 a score of 4, 18 a score of 3, 3 a score of 2 and 0 a score of 1. 56 respondents chose this SF as an effective SF. Li and Isang (2008) referred to this factor.

The SF "Use appropriate materials to prevent the effects of flooding" scored a mean value of 3.94 (effective) with a S.D. of 0.879. 22 respondents gave it a score of 5, 33 a score of 4 and 17 a score of 3. 5 respondents out of 77 agreed on selecting this SF as an effective SF, whereas 55 of them insicated a possible SF. The Ministry for the Environment (2008) referred to the importance of this factor.

The SF “Use mass construction with suitable insulation to moderate the effects of high external temperatures” scored a mean value of 3.92 (effective) with a S.D. of 0.870. Murray et al. (2009) discuss this factor. 21 designers gave a score of 5, 33 a score of 4, and 20 a score of 3. Murray et al. (2009) discuss the importance of this factor.

The SF “Specify buffer spaces such as earth sheltering and conservatories to reduce heat losses or increase heat gains” scored a mean value of 3.92 (effective) with a S.D of 0.870. Out of all the respondents, 18 gave a score 5 and 42 a score of 4, so that 60 out 77 believe that this SF is effective or very effective. Lomas and Ji (2009), from the literature review, commented on the importance of this strategy.

The SF “Use light shelves or specially-designed reflective-louvered blinds to reflect light deep into rooms” scored a mean value of 3.84 (effective) with a S.D. of 0.745. This indicates good agreement between respondents regarding the effectiveness. 11 architects gave a score of 5, 48 a score of 4, 13 a score of 3, 5 a score of 2, and 0 a score of 5 to this resilience factor. Several authors, such as Department of Education, Northern Ireland (1998) and Ahsan (2009), discuss this as a significant resilience strategy.

The SF “Use green roofs to minimize runoff rainwater” scored a mean value of 3.81 with a S.D. of 0.844. For this factor, 16 designers selected a score of 5, 35 a score of 4, 21 a score of 3, 5 a score of 2 and 0 a score of 1. thus, 51 of those surveyed took this to be an effective factor. Gedge et al. (2008) referred to this strategy.

The SF “Specify airtight junctions and details” scored a mean value of 3.79 (marginally effective) with a S.D. of 0.894, indicating a high level of agreement. 14 architects gave a score of 5 and 41 gave a score of 4 for this factor, so that 55 respondents considered this factor to be effective or very effective. Wright and Frohnsdorff (1985) wrote about the significance of this SF.

The SF “Avoid the use of long roof eaves due to vulnerability to storms” scored a mean value of 3.77 (marginally effective) with a S.D. of 0.826, indicating good agreement. 14 respondents gave a score 5, 36 a score of 4, 22 a score of 3, 5 a score of 2, and 0 a score of 1. In total, 50 respondents took this factor to be effective or very effective. Tran, Tuan Anh et al. (2012) indicated the effectiveness of this strategy.

The SF “Specify glazing ratio of 30-50% for vertical surfaces and 20% for rooflights to provide adequate daylight and avoid overheating” scored a mean value of 3.75 (marginally effective) with a S.D. of 0.797. 14 of 77 respondents gave a score of 5, 33 a score of 4, 27 a score of 3, 3 a score of 2 and 0 a score of 1. 47 respondents chose this factor as being effective. From the literature review, Lomas and Ji (2009) referred to this factor.

The SF “Specify materials that can get wet and dry out without permanent damage” scored a mean value of 3.73 (marginally effective) with a S.D. of 0.868, suggesting good agreement between respondents on the level of effectiveness of this measure. The overall effectiveness score of this SF is among the lowest of those included in the survey. By contrast, Di Girolamo et al. (2013) indicate this to be a significant resilient strategy.

The SF “Use double façades for natural ventilation as an outlet or inlet path” scored a mean value of 3.71 (marginally effective) with a S.D. of 0.792. Roders et al. (2013) referred to this factor.

The SF “Use fenestration high on walls or roofs to bring daylight deep into rooms” scored a mean value of 3.71 (marginally effective) with a S.D. of 0.776. 11 participants gave a score of 5 and 37 gave a score of 4. However, although the majority of respondents’ scored 4 or 5, this factor was among the lower ranked ones. In the literature review, it was referred to by NASA (2008).

The SF “Avoid the use of long rectangular plans with the ratio between the length and width over 2.5 (a ratio over 2.5 creates vulnerability to storms)” scored a mean value of 3.66 (marginally effective) with a S.D. of 0.771. A total of 9 respondents gave a score of 5 and 37 a score 4 to this SF – a total of 42 regarding it as effective or very effective. This factor was included because of the reference by Tran, Tuan Anh et al. (2012).

The SF “Specify smaller windows for spaces to the north of the building to minimize heat loss” scored a mean value of 3.61 (marginally effective) with a S.D of 0.781. Out of 77 designers, 9 gave a score of 5 and 34 a score of 4 to this factor; in other words, 43 of the respondents believe that this SF is effective or very effective, although its overall effectiveness places it among the lower ranked SFs according to the respondents. Lomas and Ji referred to this factor.

The SF “Specify window film to prevent injuries from shattered glass” scored a mean value of 3.55 (marginally effective) with a S.D. of 0.867. 8 respondents gave it a score of 5, 35 a score of 4, 27 a score of 3, 5 a score of 2 and 2 a score of 1. Overall, 43 respondents indicated this SF to be effective or very effective, although its mean value is among the lower ones in the survey. In the literature review, This resilience strategy was indicated by Newman et al. (2003).

The SF “Specify forms that follow many future functions” scored a mean value of 3.53 (marginally effective) with a S.D. of 0.897. Of the respondents, 9 gave it a score of 5, 33 a score of 4 and 27 a score of 3; in other words, 42 indicated it to be effective, although overall the mean value was relatively low. Table 7 shows that the majority of the respondents’ scores were concentrated between 3 and 4 scores. Slaughter (2011) referred to this strategy

The SF “Avoid the use of forms shapes that create a wind-suction bag effect during storms” scored a mean value of 3.53 (marginally effective) with a S.D. of 1.008. 12 designers gave a score of 5, 30 a score of 4 and 26 a score of 3. Tran, Tuan Anh et al. (2012) discussed this strategy.

The SF "Use openings in the envelope to ensure that floodwaters enter and exit" scored a mean value of 3.53 (marginally effective) with a S.D of 0.882. Among the respondents, 10 gave a score 5 and 31 a score of 4 (very effective or effective); however, this factor ranked relatively lowly. By contrast, Newman et al. (2013) include this as a significant resilient factor.

The SF "Specify dry flood-proofing e.g., watertight structure using sealants, flood shields, etc. to protect against floods" scored a mean value of 3.53 (marginally effective) with a S.D. of 0.926. 12 architects gave a score of 5, 27 a score of 4, 29 a score of 3, 8 a score of 2, and 1 a score of 1. Shaw, et al, (2007) advocated this resilience factor.

The SF "Use green roofs to reduce the heat island effect in urban settings" scored a mean value of 3.51 with a S.D. of 0.883. For this factor, 10 designers selected a score of 5, 28 a score of 4, 31 a score of 3, 7 a score of 2 and 1 a score of 1. The Ministry for the Environment (2008) referred the significance of this factor.

The SF "Oversize anchors for roof-/wall-mounted heating, ventilation, and air conditioning units" scored a mean value of 3.42 (neutral) with a S.D of 0.879. For this factor, only 6 respondents gave a score of 5, 32 a score of 4, 29 a score of 3, 8 a score of 2 and 2 a score of 1. Newman et al. (2013) point to this factor; however, respondents to the survey overall ranked this as one of the least important proposed strategies.

The SF "Specify roofs' shape and orientation to strengthen the natural driving forces" scored a mean value of 3.26 (neutral) with a S.D. of 0.834. Among those in the survey, 6 gave a score of 5, 20 a score of 4, 40 a score of 3, 10 a score of 2 and 1 a score of 1. Tran, Tuan Anh, et al (2012) referred to this strategy but it was not highly rated by the survey respondents.

The SF "Specify roofs sloping upward towards the outlet to lead the ventilation air to the outlet" scored a mean value of 3.26 (neutral) with a S.D of 0.818. 6 architects gave a score of 5, 20 a score of 4, and 39 a score of 3. Again this was one of the lowest rankings of resilience factors by the surveyed architects.

Table 9-7: Envelope design resilience strategies (part 1).

| Code | **Envelope design resilience strategies** | Total no. | Frequency of scores | | | | | Mean | Std-deviation | Ranking |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | 4 | 5 | | | |
| ES1 | Use appropriate insulation systems to reduce conduction through the thermal envelope | 77 | 1 | 1 | 4 | 31 | 40 | 4.40 | .765 | 2 |
| ES2 | Provide expansion joints within the materials on vulnerability to expansion | 77 | 0 | 3 | 10 | 45 | 19 | 4.04 | .733 | 9 |
| ES3 | Use a high solar reflectance to reflect sunlight and heat away from a building | 77 | 1 | 7 | 12 | 25 | 32 | 4.04 | 1.032 | 8 |
| ES4 | Use appropriate materials to prevent the effects of flooding | 77 | 0 | 5 | 17 | 33 | 22 | 3.94 | .879 | 11 |
| ES5 | Use an appropriate shape and angle of the roof to optimize ventilation and thermal comfort, as well as, to resist storms | 77 | 0 | 3 | 14 | 33 | 27 | 4.09 | .830 | 6 |
| ES6 | Use energy-efficient windows and shading devices to reduce energy use | 77 | 1 | 2 | 5 | 24 | 45 | 4.43 | .834 | 1 |
| ES7 | Specify window film to prevent injuries from shattered glass | 77 | 2 | 5 | 27 | 35 | 8 | 3.55 | .867 | 24 |
| ES8 | Use advanced wall and framing techniques to reduce energy loss | 77 | 1 | 3 | 10 | 39 | 24 | 4.06 | .848 | 7 |
| ES9 | Specify windows, doors, and openings to withstand wind loads and windblown debris | 77 | 0 | 2 | 8 | 35 | 32 | 4.26 | .750 | 3 |
| ES10 | Oversize framing and bracing to increase redundancy | 77 | 0 | 1 | 10 | 35 | 31 | 4.25 | .728 | 4 |
| ES11 | Oversize anchors for roof-/wall-mounted heating, ventilation, and air conditioning units | 77 | 2 | 8 | 29 | 32 | 6 | 3.42 | .879 | 30 |
| ES12 | Use green roofs to reduce the heat island effect in urban settings | 77 | 1 | 7 | 31 | 28 | 10 | 3.51 | .883 | 29 |
| ES13 | Use green roofs to minimize runoff rainwater | 77 | 0 | 5 | 21 | 35 | 16 | 3.81 | .844 | 15 |

Table 9-8: Envelope design resilience strategies (part 2)

| Code | **Envelope design resilience strategies** | Total no. | Frequency of scores | | | | | Mean | Std-deviation | Ranking |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | 4 | 5 | | | |
| ES14 | Use appropriate exterior shading to reduce vulnerability to overheating | 77 | 1 | 3 | 9 | 33 | 31 | 4.17 | .880 | 5 |
| ES15 | Use openings in the envelope to ensure that floodwaters enter and exit | 77 | 0 | 10 | 26 | 31 | 10 | 3.53 | .882 | 27 |
| ES16 | Use light shelves or specially-designed reflective-louvered blinds to reflect light deep into rooms | 77 | 0 | 5 | 13 | 48 | 11 | 3.84 | .745 | 14 |
| ES17 | Specify materials that can get wet and dry out without permanent damage | 77 | 1 | 2 | 30 | 28 | 16 | 3.73 | .868 | 19 |
| ES18 | Specify airtight junctions and details | 77 | 2 | 4 | 16 | 41 | 14 | 3.79 | .894 | 16 |
| ES19 | Specify light paint colours for interior ceilings and walls to improve internal distribution of daylight | 77 | 0 | 3 | 18 | 37 | 19 | 3.94 | .800 | 10 |
| ES20 | Use fenestration high on walls or roofs to bring daylight deep into rooms | 77 | 0 | 4 | 25 | 37 | 11 | 3.71 | .776 | 21 |
| ES21 | Specify dry flood-proofing e.g., watertight structure using sealants, flood shields, etc. to protect against floods | 77 | 1 | 8 | 29 | 27 | 12 | 3.53 | .926 | 28 |
| ES22 | Avoid the use of forms shapes that create a wind-suction bag effect during storms | 77 | 4 | 5 | 26 | 30 | 12 | 3.53 | 1.008 | 26 |
| ES23 | Avoid the use of long rectangular plans with the ratio between the length and width over 2.5 (a ratio over 2.5 creates vulnerability to storms) | 77 | 1 | 2 | 28 | 37 | 9 | 3.66 | .771 | 22 |
| ES24 | Avoid the use of long roof eaves due to vulnerability to storms | 77 | 0 | 5 | 22 | 36 | 14 | 3.77 | .826 | 17 |
| ES25 | Use double façades for natural ventilation as an outlet or inlet path | 77 | 0 | 4 | 26 | 35 | 12 | 3.71 | .792 | 20 |
| ES26 | Specify roofs' shape and orientation to strengthen the natural driving forces | 77 | 1 | 10 | 40 | 20 | 6 | 3.26 | .834 | 31 |
| ES27 | Specify roofs sloping upward towards the outlet to lead the ventilation air to the outlet | 77 | 0 | 12 | 39 | 20 | 6 | 3.26 | .818 | 32 |
| ES28 | Specify smaller windows for spaces to the north of the building to minimize heat loss | 77 | 0 | 5 | 29 | 34 | 9 | 3.61 | .781 | 23 |
| ES29 | Specify glazing ratio of 30-50% for vertical surfaces and 20% for rooflights to provide adequate daylight and avoid overheating | 77 | 0 | 3 | 27 | 33 | 14 | 3.75 | .797 | 18 |
| ES30 | Specify buffer spaces such as earth sheltering and conservatories to reduce heat losses or increase heat gains | 77 | 1 | 5 | 11 | 42 | 18 | 3.92 | .870 | 13 |
| ES31 | Specify forms that follow many future functions | 77 | 2 | 6 | 27 | 33 | 9 | 3.53 | .897 | 25 |
| ES32 | Use mass construction with suitable insulation to moderate the effects of high external temperatures | 77 | 1 | 2 | 20 | 33 | 21 | 3.92 | .870 | 12 |

#### *9.3.6.5 System design resilience strategies*

Table 9-9 illustrates respondents’ scores for each SF of the aspect. This category includes 16 proposed resilience strategies.

The SF “Build a permanent water-resistant barrier around HVAC equipment to protect from flooding” scored a mean value of 4.14 (effective) with a S.D. of 0.838. The majority of architects participating in the survey judged this to be an effective or very effective factor. Newman et al. (2013) is among those references from the literature review that consider this to be a significant resilience factor.

The SF “Provide protection for the main electrical system from flooding” scored a mean value of 4.10 (effective) with a standard deviation of 0.836. Newman et al. (2013) stressed the importance of this strategy.

The SF “Specify cogeneration and solar power to run during blackouts” scored a mean value of 4.04 with S.D. of 0.785. Keung (2010) and Newman et al. (2013) referred to the importance of these alternative power sources as a resilience factor. There is an agreement between the literature review and participants' perspectives.

The SF “Size drainage system to vulnerability to high level of rain” scored a mean value of 4.01 (effective) with a S.D. of 0.851. . In the survey, 20 architects gave a score of 5, and 44 gave a score of 4 for this SF; in other words, 64 designers considered this to be an effective or very effective SF. Turnbull, Sterrett and Hilleboe (2013), Hertfordshire County Council (2013) and Ross, Saunders and Novakovic (2007) all refer to the significance of this strategy.

The SF “Size drainage system to vulnerability to high level of rain” scored a mean value of 4.01 with S.D. of 0.851, and was considered to be an effective factor among respondets.

Marilise Turnbull, Charlotte L. Sterrett, Amy Hilleboe (2013), Hertfordshire County Council (2013), Ross K, Saunders G, Novakovic O (2007) refer to this importance of this strategy.

The SF “Specify heat and cold storage in the ground to protect against power shutdown” scored a mean value 3.94 (effective) with a S.D. of 0.848. 20 respondents gave a score of 5, 37 a score of 4, 15 a score of 3 and 5 a score of 2 to this SF. 57 respondents out of 77 believe that this SF is effective, while 15 believe it is possible SF. Hertin et al. (2003) indicated this possible resilience strategy.

The SF “Specify water-efficient fittings and devices to ensure the continuity of operation of the building” scored a mean value of 3.92 (effective) with a S.D. of 0.885. . 16 participants gave a score of 5 and 44 gave a score of 4. Hertfordshire County Council (2013) referred to the significance of this factor.

The SF “Specify ductile-utility connectors to reduce breakage during disturbance events” scored a mean value of 3.91 with a S.D. of 0.846. 14 of the architects gave a score of 5 and 47 a score 4 to this SF. In total, it was selected as effective by 61 respondents. Newman et al. (2013) referred to the significance of this factor.

The SF “Use multiple lighting resources to avoid electricity shutdown” scored a mean value of 3.88 (effective) with a S.D. of 0.843. BIM (2011) cited the significance of this factor.

The SF “Separate electrical circuits between levels under and above expected flooded levels” scored a mean value of 3.79 (effective) with a S.D of 0.894. Newman et al. (2013) referred to this importance of this strategy.

The SF “Specify backup power to avoid electricity shutdown” scored a mean value of 3.70 (marginally effective) with a S.D. of 0.812. 17 respondents gave a score of 5 and 33 a score of 4. Newman et al. (2013) cited this factor as being significant.

The SF “Separate the power system from the roof and walls to facilitate the process of replacement and maintenance” scored a mean value of 3.65 (marginally effective) with a S.D. of 0.774. Of those taking part in the survey, 9 gave a score of 5, 37 a score of 4 and 26 a score of 3. 46 respondents out of 77 agreed on selecting this SF as an effective, whereas 26 of them agreed to accept is as a possible SF. As can be seen in Table 8, the majority of the respondents were concentrated between scores 3 and 4. Ross, Saunders and Novakovic (2007) pointed to the significance of this strategy.

The SF “Raise electrical service above expected flood levels (system)” scored a mean value of 3.61 (marginally effective) with a S.D. of 1.015. 14 designers gave a score of 5, 31 a score of 4 and 24 a score of 3. Newman et al. (2013) referred to this factor.

The SF “Provide on-site renewables to protect against power shutdown and create redundant sources of energy” scored a mean value of 3.49 (neutral) with a S.D. of 0.883. By contrast, the Committee on Climate Change (2010) pointed to this as an important resilience factor.

The SF “Specify water features in an atrium to provide evaporative cooling” scored a mean value 3.44 (neutral) with a S.D of 0.866. Among those surveyed, 8 designers scored 5 and 28 scored 4, i.e. effective or very effective; overall, however, it emerged with a score close to neutral. In contrast, Bowman et al. (2001) cited this as a significant factor.

The SF “Ensure the provision of HVAC systems redundancy or overcapacity to cope with unexpected load” scored a mean value of 3.43 (neutral) with a S.D. of 0.992. 10 respondents gave a score of 5, 29 a score of 4, 24 a score of 3, 12 a score of 2 and 2 a score of 1; overall, 24 respondents out of 77 disagreed on selecting this factor as an SF. Los Alamos (2013) and Kane (2009) referred to the importance of this resilience factor.

The SF "Specify spray systems on roofs and terraces for evaporative cooling" scored a mean value of 3.40 (neutral) with a S.D. of 0.907. 44 respondents out of 77 scored this factor as either natural or ineffective. Newman et al. (2013) referred to this factor. Based on the results of the survey, it is not considered as a possible SF.

Table 99-: System design resilience strategies.

| Code | **System design resilience strategies** | Total no. | Frequency of scores | | | | | Mean | Std-deviation | Ranking |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | 4 | 5 | | | |
| YS1 | Ensure the provision of HVAC systems redundancy or overcapacity to cope with unexpected load | 77 | 2 | 12 | 24 | 29 | 10 | 3.43 | .992 | 15 |
| YS2 | Provide protection for the main electrical system from flooding | 77 | 1 | 2 | 11 | 37 | 26 | 4.10 | .836 | 2 |
| YS3 | Specify cogeneration and solar power to run during blackouts | 77 | 1 | 2 | 10 | 44 | 20 | 4.04 | .785 | 3 |
| YS4 | Size drainage system to vulnerability to high level of rain | 77 | 0 | 5 | 12 | 37 | 23 | 4.01 | .851 | 4 |
| YS5 | Separate the power system from the roof and walls to facilitate the process of replacement and maintenance | 77 | 0 | 5 | 26 | 37 | 9 | 3.65 | .774 | 11 |
| YS6 | Specify water-efficient fittings and devices to ensure the continuity of operation of the building | 77 | 0 | 5 | 18 | 32 | 22 | 3.92 | .885 | 6 |
| YS7 | Specify ductile-utility connectors to reduce breakage during disturbance events | 77 | 2 | 2 | 13 | 44 | 16 | 3.91 | .846 | 7 |
| YS8 | Build a permanent water-resistant barrier around HVAC equipment to protect from flooding | 77 | 2 | 1 | 7 | 41 | 26 | 4.14 | .838 | 1 |
| YS9 | Separate electrical circuits between levels under and above expected flooded levels | 77 | 1 | 4 | 22 | 33 | 17 | 3.79 | .894 | 9 |
| YS10 | Use multiple lighting resources to avoid electricity shutdown | 77 | 2 | 3 | 11 | 47 | 14 | 3.88 | .843 | 8 |
| YS11 | Raise electrical service above expected flood levels (system) | 77 | 4 | 4 | 24 | 31 | 14 | 3.61 | 1.015 | 12 |
| YS12 | Specify backup power to avoid electricity shutdown | 77 | 2 | 1 | 25 | 39 | 10 | 3.70 | .812 | 10 |
| YS13 | Provide onsite renewables to protect against power shutdown and create redundant sources of energy | 77 | 1 | 6 | 35 | 24 | 11 | 3.49 | .883 | 13 |
| YS14 | Specify heat and cold storage in the ground to protect against power shutdown | 77 | 0 | 5 | 15 | 37 | 20 | 3.94 | .848 | 5 |
| YS15 | Specify spray systems on roofs and terraces for evaporative cooling | 77 | 2 | 7 | 35 | 24 | 9 | 3.40 | .907 | 16 |
| YS16 | Specify water features in an atrium to provide evaporative cooling | 77 | 1 | 8 | 32 | 28 | 8 | 3.44 | .866 | 14 |

#### *9.3.6.6 Operation design resilience strategies*

Table 9-11 illustrates respondents' evaluations for each SF of this aspect, which includes four proposed resilience strategies.

The SF "Secure interior furnishings and equipment to ensure continuity of operation" scored a mean value of 3.25 (neutral) with a S.D. of 0.876. Newman et al. (2013) included this a significant resilience factor. Yet, overall, the respondents scored this as a non-effective factor; therefore it is not accepted as an SF.

The SF "Specify temperature controls to cater for different needs of occupants scored a mean value of 2.79 (between ineffective and neutral) with a S.D. of 1.043. The result shows that respondents do not accept this as an effective resilience strategy. This is in contradiction to Zachary et al. (2010) and Thomas and Baird (2006) in the literature review, who discussed this as a significant SF.

The SF "Specify early warning systems, to alert vulnerable building occupants" scored a mean value of 2.69 (between ineffective and neutral) with a S.D. of 1.139. Only 7 designers selected a score of 5 and 11 a score of 4; 40 respondents indicated that this SF is ineffective and should not be included in considerations of building resilience design. This is in disagreement with Turnbull, et al, (2013) who discussed it as a resilience factor. This factor had a low of score from respondents, while literary studies confirmed that it is an important factor. This contrast may be comes from a lack of knowledge, where this is new field.

The SF "Design for emergency repairs to ensure readiness for any risks and ensure continuity of operation" scored a mean value of 2.62 (between ineffective and neutrl) with a S.D. of 1.136. 5 respondents out of 77 gave a score of 5 and 13 a score of 4; on the other hand, 40 respondents rejected this SF as being effective. This contrasts with the findings of Newman et al. (2013) who referred to its importance.

Table 9-11: Operation design resilience strategies.

| Code | **Operation design resilience strategy** | Total no. | Frequency of scores | | | | | Mean | Std-deviation | Ranking |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | 4 | 5 | | | |
| OS1 | Specify early warning systems, to alert vulnerable building occupants | 77 | 9 | 31 | 19 | 11 | 7 | 2.69 | 1.139 | 3 |
| OS2 | Secure interior furnishings and equipment to ensure continuity of operation | 77 | 1 | 13 | 35 | 22 | 6 | 3.25 | .876 | 1 |
| OS3 | Design for emergency repairs to ensure readiness for any risks and ensure continuity of operation | 77 | 12 | 28 | 19 | 13 | 5 | 2.62 | 1.136 | 4 |
| OS4 | Specify temperature controls to cater for different needs of occupants | 77 | 6 | 28 | 24 | 14 | 5 | 2.79 | 1.043 | 2 |

## 9.4 Summary of this Chapter

The results from the survey of architects concerning what they regard as the most effective resilience factors included in the questionnaire, and how their responses compare with the outcome of the literature review, have been described and discussed. The data from the 77 respondents, who have different professional capacities and levels of experience have been analysed. As a result, the most effective SFs have been identified for use in development of the Resilience Building Design model. In the following chapters, techniques such as data ranking and test hypothesis will be used on the findings from this chapter, in order to develop the research model.

# Chapter 10: Ranking the Findings

## 10.1 Introduction

Building resilience design requires consideration of a wide variety of resilience factors (SFs). In the previous chapter, the results of a survey of architects who were asked to assess the relative effectiveness of 85 different resilience factors were presented. In this chapter, the ranking of these factors will be examined based on the respondents' experience and professional role. The ranking of the SFs will be based on a determination of the following statistical measures: mean value, standard deviation, coefficient of variance and severity indices.

## 10.2 Methodology

As a result of the literature review, 85 SFs were extracted. These were then classified into six main building aspects and included in the questionnaire sent out to a large sample of architects of differing capacity and level of experience. The SFs were then ranked based on a statistical analysis of the survey results. The overall scheme of the methodology is shown in Figure 10-1.

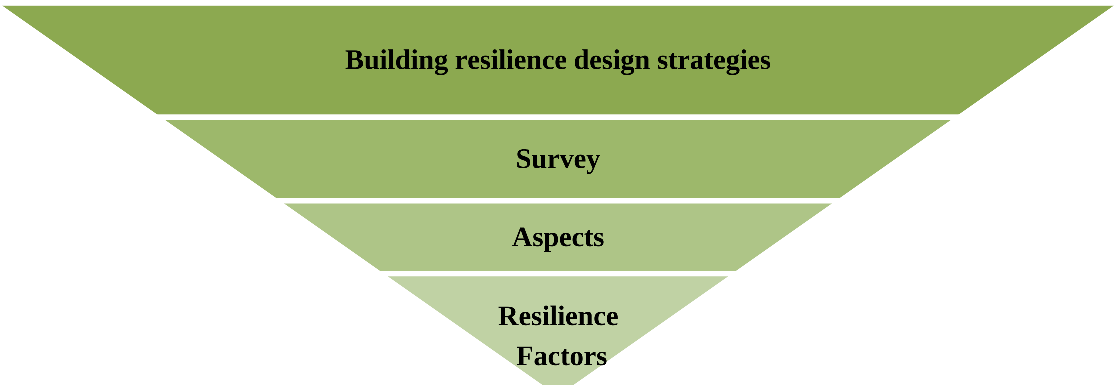


Figure 10-1: The survey hierarchy

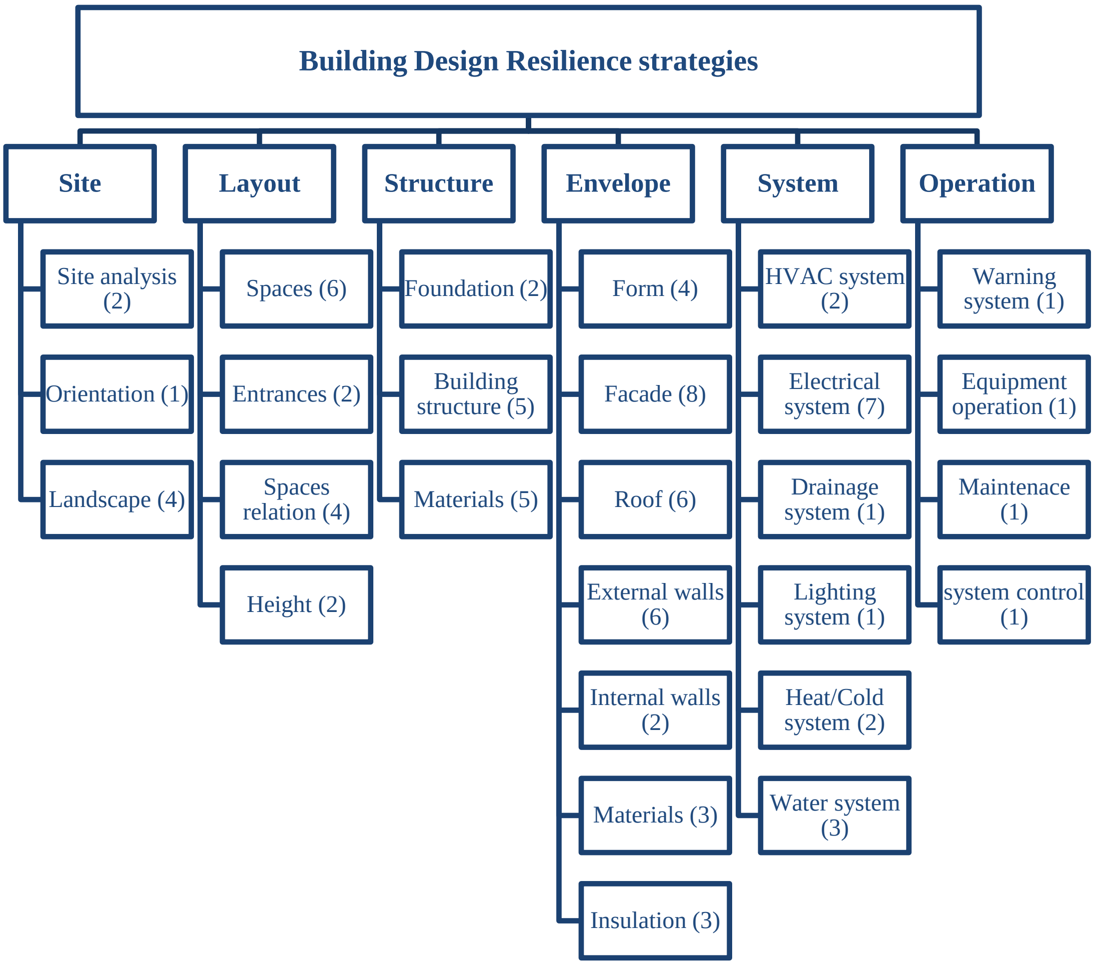


Figure 10-2: Resilience building design aspects and sub-aspects

Figure 10-2 illustrates the number of SFs for each sub-aspect. The building resilience design incorporates six main aspects (site, layout, structure, envelope, system and operation), 27 sub-aspects and 85 SFs. The site aspect (SDS) includes 3 sub-aspects with a total of 7 SFs. The layout aspect (SDL) contains the sub-aspects spaces, entrances, spaces relation and height, with 6, 2, 4 and 2 SFs respectively. The structure aspect (SDT) has 3 sub-aspects, foundation, building structure and materials, with 12 SFs. The envelope aspect (SDE) incorporates 7 sub-aspects and 32 SFs. The system aspect has which 6 sub-aspects and 15 SFs, while the operation aspect (SDO) has 4 sub-aspects with one SF.

A scoring system of 1 to 5 has been adopted to assess the effectiveness of each SF: 1 (very ineffective), 2 (ineffective), 3 (neutral), 4 (effective) and 5 (very effective).

## 10.3 Ranking and analysis of building resilience design factors

Various methods are available for analysing the findings of the questionnaire. Vakili-Ardebili (2004) referred to 4 possible methods for ranking indicators, namely: mean weighted equation, severity index, coefficient of variation and Kendall's coefficient of concordance. The first three of these methods were applied by the researcher, and SPSS and Excel software used to organise the data and perform the calculations.

The **mean weighted equation** enables the mean value to be calculated, thus:

$$\textbf{Mean} = (\sum \boldsymbol{R} \times \boldsymbol{F})\ /\boldsymbol{n}, \ldots\ldots(10.1)$$

where *R* (rating) is a value from 1 to 5 (3 the neutral point), *F* is the frequency of responses, and *n* is the total number of respondents = 77.

**Severity index (S.I.)** provides a measure of the significance of each resilience factor. It is given by the formula:

$$\textbf{S.I} = [(\sum \boldsymbol{W} \times \boldsymbol{F})\ /\boldsymbol{n}] \times \mathbf{100\%}, \ldots\ldots(10.2)$$

Where *W* is the weight for each rating (1, 2, 3, 4, 5), *F* is the frequency of responses, and *n* = 77. In this study the severity index equation becomes:

$$\textbf{S.I.} = [(\mathbf{WR1}\times\mathbf{0.2} + \mathbf{WR2}\times\mathbf{0.4}+\mathbf{WR3}\times\mathbf{0.6} + \mathbf{WR4}\times\mathbf{0.8} + \mathbf{WR5}\times\mathbf{1})/\mathbf{77}]\times\mathbf{100\%} \ldots(10.3)$$

The **coefficient of variation (COV)** is useful when comparing data received from various respondents. It is given by the formula:

$$\textbf{COV} = (\boldsymbol{S}\ /\ \boldsymbol{M}) \times\mathbf{100\%}, \ldots\ldots(10.4)$$

Where *S* is the standard deviation and *M* is the weighted mean.

The calculated values of weighted mean, severity index and coefficient of variation are presented in Tables 1 to 7.

## 10.4 Ranking data based on experience and professional role

The ranking of building resilience design strategies as a result of the statistical analysis of the survey results will be presented in what follows. In Tables 1 to 7, SFs are ranked according to the mean values and standard deviations. Each table presents the sub-aspect, aspect and overall ranking. The ranking of these is based on severity indices. A discussion of the results and the rankings is provided in the following sections.

### 10.4.1 Site design resilience strategies

This aspect (SS) has seven associated SFs. The five most effective of these, SS2, SS3, SS5, SS6, and SS7, based on the overall rankings, are highlighted in red in Table 1.

There are three sub-aspects, the mean value of which varies from 3.84 to 4.34.

SS5 (Prepare site landscape and landforms for high wind conditions as well as to reduce the noise, pollution, energy consumption, temperature degree and relative humidity) ranks first of the seven SFs with a severity index is 86.75%, a coefficient of variation of 19.29, a standard deviation is 0.837 and a mean value of 4.34. The overall ranking of the SS5 is 5 out of 85 SFs. Table 1 shows that the mean values for all SFs are above the neutral point (3), which qualifies them all as effective resilience factors.

The rankings take into account the professional capacity and level of experience of the respondents. Rankings of individual SFs varied between these different groups of architects. For instance, SDS SS2 (“Direct runoff of water to a catch basin or holding area to reduce erosion”) was ranked 14 by practising architects, but was ranked 25 and 41 by the other two groups based on professional capacity (see Table 1). There were also discrepancies between the assessments of respondents and those found in the literature review. For example, SS7 (“Use permeable surfaces in landscaping against vulnerability to flooding”) was ranked 35 by architects in the survey with between 5 and 10 years' experience, making it is one of the lowest effective SFs. Yet, this resilience factor was extracted based on a particular reference, i.e. Hertfordshire County Council (2013), which argued in favour of permeable surfaces as a resilience factor against flooding. The rankings of the other SFs varied between 5 and 49, as shown in Table 10-1.

Table 10-1: Resilience building design strategies: resilience design site.

A: Ranking based on attribute, O: Overall ranking, and N: Total response.

| Code | N | Mean | Std. deviation | Coefficient of variation | Severity index | General Overall ranking | | academic & practicing Overall ranking | | academic Overall ranking | | practicing Overall ranking | | 0-5 Overall ranking | | 5-10 Overall ranking | | More than 10 Overall ranking | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | A | O | A | O | A | O | A | O | A | O | A | O | A | O |
| SS1 | 77 | 3.84 | .904 | 23.54 | 76.88 | 7 | 41 | 7 | 41 | 5 | 29 | 7 | 56 | 4 | 27 | 6 | 39 | 7 | 47 |
| SS2 | 77 | 3.96 | .880 | 22.22 | 79.22 | 5 | 28 | 6 | 32 | 6 | 41 | 3 | 14 | 5 | 35 | 4 | 33 | 4 | 25 |
| SS3 | 77 | 4.08 | .623 | 15.27 | 81.56 | 2 | 15 | 4 | 29 | 2 | 16 | 2 | 12 | 1 | 5 | 3 | 14 | 5 | 29 |
| SS4 | 77 | 3.91 | .781 | 19.97 | 78.18 | 6 | 36 | 5 | 30 | 7 | 51 | 5 | 28 | 2 | 10 | 7 | 45 | 6 | 40 |
| SS5 | 77 | 4.34 | .837 | 19.29 | 86.75 | 1 | 5 | 1 | 8 | 1 | 6 | 1 | 4 | 3 | 17 | 1 | 2 | 1 | 7 |
| SS6 | 77 | 4.05 | .826 | 20.40 | 81.04 | 3 | 18 | 2 | 21 | 3 | 21 | 4 | 26 | 7 | 49 | 2 | 12 | 3 | 22 |
| SS7 | 77 | 4.01 | .786 | 19.60 | 80.26 | 4 | 26 | 3 | 24 | 4 | 24 | 6 | 33 | 6 | 44 | 5 | 35 | 2 | 17 |

### 10.4.2 Layout design resilience strategies

This aspect, LS, includes 4 sub-aspects with 14 SFs. The sub-aspects are: spaces, entrances, spaces relation, and height. Table 10-1 presents the statistical result of this aspect and ranking for each SF. As the table shows, the range of mean values varies from 2.97 to 4.36, so that, with the exception of LS6, all are above the neutral. Their severity indexes are between 59.48 and 87.27. The highest ranked factors turn out to be LS8 (Use secure cross-ventilation for passive cooling and occupants' comfort) and LS5 (Use appropriate floor height to allow for future modification), which have severity indices of 87.27 and 87.01 and coefficients of variation of 20.34 and 17.79. Their overall ranks are 3 and 4 respectively out of 85 SFs. Both of them are ranked 1 and 2 in terms of this aspect.

Overall, within this category of strategy, no clear differences were found between the rankings of respondents in terms of either their professional capacity or level of experience.

Table 10-2: Resilience building design strategies: resilience design layout.

A: Ranking based on attribute, O: Overall ranking and N: Total response.

| **Code** | **N** | **Mean** | **Std-deviation** | **Coefficient of variation** | **Severity index** | General **Overall ranking** | | academic & practicing **Overall ranking** | | academic **Overall ranking** | | practicing **Overall ranking** | | 0-5 **Overall ranking** | | 5-10 **Overall ranking** | | More than 10 **Overall ranking** | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | **A** | **O** | **A** | **O** | **A** | **O** | **A** | **O** | **A** | **O** | **A** | **O** | **A** | **O** |
| LS1 | 77 | 3.79 | .879 | 23.19 | 75.84 | 8 | 45 | 7 | 46 | 9 | 63 | 4 | 23 | 9 | 61 | 5 | 27 | 9 | 48 |
| LS2 | 77 | 3.58 | .879 | 24.55 | 71.69 | 11 | 62 | 11 | 70 | 12 | 71 | 8 | 43 | 7 | 48 | 7 | 38 | 11 | 70 |
| LS3 | 77 | 3.44 | .866 | 25.17 | 68.83117 | 13 | 74 | 12 | 74 | 13 | 77 | 11 | 55 | 11 | 67 | 12 | 72 | 12 | 72 |
| LS4 | 77 | 4.03 | .794 | 19.70 | 80.52 | 4 | 23 | 4 | 20 | 5 | 20 | 7 | 39 | 2 | 16 | 3 | 7 | 7 | 39 |
| LS5 | 77 | 4.35 | .774 | 17.79 | 87.01 | 2 | 4 | 2 | 6 | 2 | 2 | 1 | 5 | 4 | 34 | 1 | 1 | 1 | 2 |
| LS6 | 77 | 2.97 | .778 | 26.20 | 59.48 | 14 | 82 | 14 | 82 | 14 | 82 | 14 | 81 | 14 | 85 | 14 | 81 | 14 | 82 |
| LS7 | 77 | 3.44 | .966 | 28.08 | 68.83 | 12 | 73 | 13 | 77 | 11 | 68 | 12 | 71 | 10 | 66 | 11 | 70 | 13 | 73 |
| LS8 | 77 | 4.36 | .887 | 20.34 | 87.27 | 1 | 3 | 1 | 4 | 1 | 1 | 2 | 8 | 1 | 4 | 2 | 3 | 2 | 9 |
| LS9 | 77 | 3.86 | .823 | 21.32 | 77.14 | 7 | 39 | 9 | 48 | 3 | 15 | 10 | 48 | 6 | 43 | 10 | 52 | 5 | 33 |
| LS10 | 77 | 3.68 | .818 | 22.23 | 73.50 | 9 | 54 | 10 | 56 | 8 | 62 | 9 | 47 | 12 | 71 | 8 | 40 | 10 | 55 |
| LS11 | 77 | 3.90 | .897 | 23 | 77.92 | 6 | 37 | 6 | 38 | 7 | 39 | 6 | 34 | 3 | 26 | 9 | 44 | 6 | 37 |
| LS12 | 77 | 4.01 | .678 | 16.91 | 80.26 | 5 | 25 | 5 | 31 | 6 | 28 | 3 | 11 | 8 | 57 | 4 | 19 | 4 | 21 |
| LS13 | 77 | 4.05 | .887 | 21.90 | 81.04 | 3 | 19 | 3 | 19 | 4 | 18 | 5 | 30 | 5 | 38 | 6 | 32 | 3 | 18 |
| LS14 | 77 | 3.64 | .986 | 27.09 | 72.73 | 10 | 58 | 8 | 47 | 10 | 67 | 13 | 73 | 13 | 80 | 13 | 75 | 8 | 46 |

### 10.4.3 Structure design resilience strategies

This aspect consists of three main sub-aspects – foundation, materials and building structure – which include 12 SFs. Table 10-3 highlights the 5 SFs with the highest ranking for this aspect. The mean value of TS5 (Increase structure bracing to create strength redundancy to wind and snow loads) is 4.32 and it has a severity index is 86.49 and a coefficient of variation of 19.31. It ranks first in this particular aspect and 6th of all SFs.

As far as structural design strategies go, the rankings of resilience factors given by the different groups of architects are, in general, quite similar. TS9 ("Construct masonry chimneys with continuous reinforced steel bracing to increase the resistance"), cited as a significant resilience factor by Newman et al. (2013), emerged as with a rank of 1 by practicing architects, as shown in Table 10-3. The rest of the factors vary in ranking between 8 and 14.

Table 10-3: Resilience building design strategies: resilience design structure.

A: Ranking based on attribute, O: Overall ranking and N: Total response.

| Code | N | Mean | Std. deviation | Coefficient of variation | Severity index | General Overall ranking | | academic & practicing Overall ranking | | academic Overall ranking | | practicing Overall ranking | | 0-5 Overall ranking | | 5-10 Overall ranking | | More that 10 Overall ranking | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | A | O | A | O | A | O | A | O | A | O | A | O | A | O |
| TS1 | 77 | 3.62 | .904 | 24.97 | 72.47 | 9 | 59 | 4 | 63 | 9 | 48 | 8 | 58 | 8 | 55 | 8 | 63 | 10 | 60 |
| TS2 | 77 | 3.79 | .848 | 22.37 | 75.84 | 7 | 47 | 6 | 49 | 7 | 33 | 7 | 53 | 10 | 62 | 9 | 65 | 6 | 35 |
| TS3 | 77 | 3.52 | .898 | 25.51 | 70.39 | 11 | 69 | 2 | 72 | 11 | 72 | 6 | 52 | 11 | 75 | 12 | 79 | 9 | 57 |
| TS4 | 77 | 3.97 | .760 | 19.14 | 79.48 | 5 | 27 | 8 | 34 | 4 | 12 | 5 | 37 | 4 | 13 | 4 | 31 | 5 | 31 |
| TS5 | 77 | 4.32 | .834 | 19.31 | 86.49 | 1 | 6 | 12 | 2 | 2 | 9 | 3 | 7 | 1 | 2 | 3 | 11 | 1 | 4 |
| TS6 | 77 | 3.81 | .795 | 20.87 | 76.1 | 6 | 43 | 7 | 37 | 6 | 32 | 11 | 67 | 5 | 15 | 7 | 62 | 7 | 45 |
| TS7 | 77 | 4.06 | .848 | 20.89 | 81.30 | 4 | 16 | 9 | 15 | 5 | 23 | 4 | 27 | 7 | 25 | 5 | 37 | 3 | 12 |
| TS8 | 77 | 4.18 | .869 | 20.79 | 83.64 | 3 | 10 | 11 | 12 | 3 | 11 | 2 | 6 | 3 | 8 | 2 | 8 | 4 | 20 |
| TS9 | 77 | 4.29 | .792 | 18.46 | 85.71 | 2 | 7 | 10 | 14 | 1 | 8 | 1 | 1 | 2 | 7 | 1 | 5 | 2 | 10 |
| TS10 | 77 | 3.32 | .802 | 24.16 | 66.49 | 12 | 78 | 1 | 76 | 12 | 78 | 12 | 76 | 12 | 79 | 11 | 74 | 12 | 76 |
| TS11 | 77 | 3.58 | .937 | 26.17 | 71.69 | 10 | 63 | 3 | 66 | 8 | 47 | 9 | 60 | 6 | 24 | 6 | 60 | 11 | 68 |
| TS12 | 77 | 3.66 | .852 | 23.28 | 73.25 | 8 | 55 | 5 | 52 | 10 | 58 | 10 | 63 | 9 | 60 | 10 | 69 | 8 | 51 |

### 10.4.4 Envelope design resilience strategies

This aspect includes seven sub-aspects – form, façade, roof, external walls, internal walls, materials and insulation – and 32 SFs. Table 10-4 illustrated the ranking the SFs. These have mean values between 3.26 and 4.43, so that all qualify as effective. Their severity indexes vary from 65.19 to 88.57. The highest ranked SF in this aspect is ES6 (Use energy-efficient windows and shading devices to reduce energy use), with a severity index of 88.57 and coefficient of variation of 18.83. It ranks first out of 32 SFs in this aspect and first out of 85 overall.

As shown in Table 10-4, there is a not big difference between the various rankings, with the exception of a few SFs which are highlighted in red. For instance, the ES1 (Use appropriate insulation systems to reduce conduction through the thermal envelope) SF is ranked 3 by the participants, whereas the other ranking from participants based on their experience and professional role fluctuated between 1 and 6. This could reflect the awareness of the significance of this SF by architects who have 5-10 years' experience.

Table 10-4: Resilience building design strategies: resilience design envelope.

A: Ranking based on Attribute, O: Overall ranking and N: Total response.

| Code | N | Mean | Std. deviation | Coefficient of variation | Severity Index | General Overall ranking | | academic & practicing overall ranking | | academic Overall ranking | | practicing Overall ranking | | 0-5 Overall ranking | | 5-10 Overall ranking | | More than 10 Overall ranking | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | A | O | A | O | A | O | A | O | A | O | A | O | A | O |
| ES1 | 77 | 4.40 | .765 | 17.39 | 88.05 | 2 | 2 | 2 | 3 | 1 | 3 | 2 | 3 | 2 | 3 | 2 | 6 | 1 | 1 |
| ES2 | 77 | 4.04 | .733 | 18.14 | 80.78 | 9 | 22 | 8 | 23 | 11 | 30 | 4 | 10 | 9 | 33 | 12 | 28 | 9 | 16 |
| ES3 | 77 | 4.04 | 1.032 | 25.54 | 80.78 | 8 | 20 | 7 | 17 | 12 | 34 | 10 | 21 | 20 | 54 | 10 | 24 | 6 | 13 |
| ES4 | 77 | 3.94 | .879 | 22.31 | 78.70 | 11 | 31 | 9 | 26 | 15 | 38 | 15 | 36 | 8 | 32 | 17 | 48 | 10 | 23 |
| ES5 | 77 | 4.09 | .830 | 20.29 | 81.82 | 6 | 14 | 6 | 13 | 5 | 10 | 14 | 32 | 7 | 31 | 7 | 18 | 7 | 14 |
| ES6 | 77 | 4.43 | .834 | 18.83 | 88.57 | 1 | 1 | 1 | 1 | 2 | 4 | 1 | 2 | 1 | 1 | 1 | 4 | 2 | 3 |
| ES7 | 77 | 3.55 | .867 | 24.42 | 70.91 | 24 | 64 | 24 | 61 | 20 | 50 | 29 | 77 | 29 | 74 | 27 | 71 | 22 | 56 |
| ES8 | 77 | 4.06 | .848 | 20.89 | 81.30 | 7 | 17 | 10 | 28 | 6 | 14 | 5 | 13 | 11 | 39 | 9 | 23 | 8 | 15 |
| ES9 | 77 | 4.26 | .750 | 17.61 | 85.19 | 3 | 8 | 5 | 10 | 3 | 5 | 3 | 9 | 3 | 14 | 4 | 10 | 3 | 5 |
| ES10 | 77 | 4.25 | .728 | 17.13 | 84.94 | 4 | 9 | 3 | 5 | 4 | 7 | 8 | 18 | 5 | 28 | 3 | 9 | 4 | 6 |
| ES11 | 77 | 3.42 | .879 | 25.70 | 68.31 | 30 | 76 | 29 | 73 | 28 | 66 | 30 | 78 | 30 | 76 | 31 | 78 | 29 | 67 |
| ES12 | 77 | 3.51 | .883 | 25.16 | 70.13 | 29 | 70 | 23 | 60 | 24 | 57 | 32 | 80 | 24 | 65 | 29 | 76 | 23 | 61 |
| ES13 | 77 | 3.81 | .844 | 22.15 | 76.10 | 15 | 42 | 16 | 44 | 8 | 19 | 26 | 70 | 12 | 40 | 23 | 59 | 16 | 43 |
| ES14 | 77 | 4.17 | .880 | 21.10 | 83.38 | 5 | 11 | 4 | 9 | 7 | 17 | 9 | 20 | 13 | 42 | 6 | 17 | 5 | 8 |
| ES15 | 77 | 3.53 | .882 | 24.99 | 70.65 | 27 | 67 | 28 | 68 | 27 | 65 | 21 | 54 | 14 | 45 | 26 | 68 | 28 | 66 |
| ES16 | 77 | 3.84 | .745 | 19.40 | 76.88 | 14 | 40 | 18 | 51 | 10 | 27 | 13 | 29 | 17 | 51 | 15 | 46 | 13 | 34 |
| ES17 | 77 | 3.73 | .868 | 23.27 | 74.55 | 19 | 50 | 25 | 64 | 19 | 46 | 6 | 15 | 16 | 47 | 16 | 47 | 19 | 50 |
| ES18 | 77 | 3.79 | .894 | 23.59 | 75.84 | 16 | 46 | 20 | 55 | 13 | 35 | 17 | 42 | 22 | 59 | 11 | 26 | 18 | 49 |
| ES19 | 77 | 3.94 | .800 | 20.30 | 78.70 | 10 | 30 | 11 | 36 | 14 | 37 | 11 | 22 | 4 | 20 | 14 | 36 | 11 | 28 |
| ES20 | 77 | 3.71 | .776 | 20.92 | 74.29 | 21 | 52 | 21 | 57 | 21 | 52 | 18 | 45 | 19 | 53 | 20 | 54 | 20 | 52 |
| ES21 | 77 | 3.53 | .926 | 26.23 | 70.65 | 28 | 68 | 22 | 59 | 29 | 70 | 28 | 75 | 26 | 70 | 25 | 67 | 27 | 65 |
| ES22 | 77 | 3.53 | 1.008 | 28.56 | 70.65 | 26 | 66 | 30 | 75 | 26 | 61 | 19 | 46 | 21 | 58 | 19 | 53 | 30 | 71 |
| ES23 | 77 | 3.66 | .771 | 21.07 | 73.25 | 22 | 23 | 17 | 50 | 22 | 54 | 24 | 65 | 25 | 69 | 22 | 58 | 21 | 54 |
| ES24 | 77 | 3.77 | .826 | 21.91 | 75.32 | 17 | 48 | 13 | 40 | 17 | 44 | 23 | 64 | 28 | 73 | 18 | 50 | 15 | 42 |
| ES25 | 77 | 3.71 | .792 | 21.35 | 74.29 | 20 | 51 | 12 | 39 | 25 | 59 | 25 | 66 | 32 | 82 | 21 | 56 | 17 | 44 |
| ES26 | 77 | 3.26 | .834 | 25.58 | 65.19 | 31 | 79 | 31 | 78 | 32 | 81 | 31 | 79 | 31 | 78 | 30 | 77 | 31 | 79 |
| ES27 | 77 | 3.26 | .818 | 25.09 | 65.19 | 32 | 80 | 32 | 81 | 31 | 75 | 27 | 72 | 27 | 72 | 32 | 80 | 32 | 80 |
| ES28 | 77 | 3.61 | .781 | 21.63 | 72.21 | 23 | 61 | 26 | 65 | 23 | 56 | 20 | 50 | 18 | 52 | 24 | 61 | 24 | 62 |
| ES29 | 77 | 3.75 | .797 | 21.25 | 75.06 | 18 | 49 | 19 | 54 | 18 | 45 | 16 | 41 | 10 | 37 | 5 | 13 | 26 | 64 |
| ES30 | 77 | 3.92 | .870 | 22.19 | 78.44 | 13 | 34 | 15 | 43 | 16 | 40 | 7 | 17 | 15 | 46 | 13 | 29 | 12 | 30 |
| ES31 | 77 | 3.53 | .897 | 25.41 | 70.65 | 25 | 65 | 27 | 67 | 30 | 73 | 22 | 62 | 23 | 64 | 28 | 73 | 25 | 63 |
| ES32 | 77 | 3.92 | .870 | 22.19 | 78.44 | 12 | 33 | 14 | 42 | 9 | 26 | 12 | 24 | 6 | 30 | 8 | 21 | 14 | 36 |

### 10.4.5 System design resilience strategies

This aspect includes 6 sub-aspects – HVAC system, electrical system, drainage system, lighting system, heat/cold system and water system – and 16 SFs. The ranking result shows that there are 4 SFs with mean values above 4 (effective), the highest of all being YS8 (Build a permanent water-resistant barrier around HVAC equipment to protect from flooding) with a mean value of 4.14, severity index of 82.86 and coefficient of variation of 20.24. Its overall ranking is 12 out of 85 SFs, as shown in Table 10-5.

In ranking, the YS15 (Specify spray systems on roofs and terraces for evaporative cooling) SF factor was ranked 80 by academic architects as from the lowest effective SF, even though one of the references in the literature review, Newman et al. (2013), pointed this out as a significant resilience factor. This result could be because these respondents are furthest from practicing architecture, whereas, the professional role respondents ranked this SF between 68 and 69. The classification based on data from architects with 5-10 years of experience is 55. Also, YS2 (Provide protection for the main electrical system from flooding) SF was ranked 19$^{th}$ by the participants with more than 10 years' experience. This shows how experience might have an impact on the architects’ rankings.

Table 10-5: Resilience building design strategies: resilience design system.

A: Ranking based on attribute, O: Overall ranking and N: Total Response.

| Code | N | Mean | Std. deviation | Coefficient of variation | Severity index | General Overall ranking | | academic & practicing Overall ranking | | academic Overall ranking | | practicing Overall ranking | | 0-5 Overall ranking | | 5-10 Overall ranking | | More than 10 Overall ranking | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | A | O | A | O | A | O | A | O | A | O | A | O | A | O |
| YS1 | 77 | 3.43 | .992 | 28.92 | 68.57 | 15 | 75 | 16 | 79 | 14 | 76 | 10 | 51 | 9 | 23 | 10 | 43 | 16 | 81 |
| YS2 | 77 | 4.10 | .836 | 20.39 | 82.08 | 2 | 13 | 3 | 16 | 1 | 13 | 1 | 16 | 1 | 6 | 5 | 25 | 2 | 19 |
| YS3 | 77 | 4.04 | .785 | 19.43 | 80.78 | 3 | 21 | 2 | 11 | 5 | 37 | 5 | 35 | 4 | 12 | 2 | 16 | 5 | 27 |
| YS4 | 77 | 4.01 | .851 | 21.22 | 80.26 | 4 | 24 | 7 | 27 | 3 | 25 | 2 | 19 | 2 | 9 | 6 | 30 | 4 | 26 |
| YS5 | 77 | 3.65 | .774 | 21.20 | 72.99 | 11 | 57 | 12 | 58 | 11 | 60 | 9 | 49 | 12 | 41 | 14 | 57 | 10 | 58 |
| YS6 | 77 | 3.92 | .885 | 22.58 | 78.44 | 6 | 32 | 6 | 25 | 7 | 43 | 6 | 38 | 10 | 29 | 3 | 20 | 8 | 41 |
| YS7 | 77 | 3.91 | .846 | 21.64 | 78.18 | 7 | 35 | 9 | 35 | 4 | 31 | 7 | 40 | 8 | 22 | 15 | 64 | 3 | 24 |
| YS8 | 77 | 4.14 | .838 | 20.24 | 82.86 | 1 | 12 | 1 | 7 | 2 | 22 | 4 | 31 | 7 | 21 | 4 | 22 | 1 | 11 |
| YS9 | 77 | 3.79 | .894 | 23.59 | 75.84 | 9 | 44 | 8 | 33 | 12 | 69 | 8 | 44 | 3 | 11 | 11 | 49 | 9 | 53 |
| YS10 | 77 | 3.88 | .843 | 21.73 | 77.66 | 8 | 38 | 4 | 18 | 6 | 42 | 11 | 57 | 11 | 36 | 7 | 34 | 7 | 38 |
| YS11 | 77 | 3.61 | 1.015 | 28.11 | 72.21 | 12 | 60 | 11 | 53 | 9 | 53 | 16 | 74 | 6 | 19 | 8 | 41 | 12 | 69 |
| YS12 | 77 | 3.70 | .812 | 21.95 | 74.03 | 10 | 53 | 10 | 45 | 10 | 55 | 13 | 61 | 5 | 18 | 9 | 42 | 11 | 59 |
| YS13 | 77 | 3.49 | .883 | 25.30 | 69.87 | 13 | 71 | 13 | 62 | 13 | 74 | 15 | 69 | 13 | 50 | 13 | 55 | 14 | 75 |
| YS14 | 77 | 3.94 | .848 | 21.52 | 78.70 | 5 | 29 | 5 | 22 | 8 | 49 | 3 | 25 | 14 | 56 | 1 | 15 | 6 | 32 |
| YS15 | 77 | 3.40 | .907 | 26.68 | 68.05 | 16 | 77 | 14 | 69 | 16 | 80 | 14 | 68 | 16 | 77 | 12 | 51 | 15 | 77 |
| YS16 | 77 | 3.44 | .866 | 25.17 | 68.83 | 14 | 14 | 15 | 71 | 15 | 79 | 12 | 59 | 15 | 68 | 16 | 66 | 13 | 74 |

### 10.4.6 Operation design resilience strategies

The aspect includes 4 SFs. All are among the lowest range of all the SFs considered in this research, as shown in Table 10-6. OS2 (Secure interior furnishings and equipment to ensure continuity of operation) is ranked 1st in the aspect by all respondent groups. All the SFs were ranked close to each other, and there are no clear differences between them.

Table 10-6: Resilience building design factors: resilience design operation.

A: Ranking based on attribute, O: Overall ranking and N: Total response.

| Code | N | Mean | Std. deviation | Coefficient of variation | Severity index | General Overall ranking | | academic & practicing Overall ranking | | academic Overall ranking | | practicing Overall ranking | | 0-5 Overall ranking | | 5-10 Overall ranking | | More that 10 Overall ranking | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | A | O | A | O | A | O | A | O | A | O | A | O | A | O |
| OS1 | 77 | 2.69 | 1.139 | 42.34 | 53.77 | 3 | 84 | 4 | 85 | 2 | 83 | 2 | 83 | 2 | 81 | 4 | 85 | 3 | 84 |
| OS2 | 77 | 3.25 | .876 | 26.95 | 64.94 | 1 | 81 | 1 | 30 | 1 | 64 | 1 | 82 | 1 | 63 | 1 | 82 | 1 | 78 |
| OS3 | 77 | 2.62 | 1.136 | 43.36 | 52.47 | 4 | 85 | 3 | 84 | 4 | 85 | 4 | 85 | 3 | 83 | 2 | 84 | 4 | 85 |
| OS4 | 77 | 2.79 | 1.043 | 37.38 | 55.84 | 2 | 83 | 2 | 83 | 3 | 84 | 3 | 84 | 4 | 84 | 3 | 83 | 2 | 83 |

## 10.5 Conclusion of overall ranking

Table 10-7 displays the most effective resilience factors that have been extracted as a result of the statistical analysis of the questionnaire data. These SFs, of which there are 28, are listed in order of overall ranking, taking into account the values for the mean value, standard deviation, and severity. The mean of all the extracted SFs is greater than 3, which is the neutral score.

Table 10-7: Most effective ranked resilience factors extracted for resilience building design.

| Code | Resilience building design factors (SF) | N | Mean | Std. deviation | Coefficient of variation | Severity index | General Overall ranking | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | A | O |
| ES6 | Use energy-efficient windows and shading devices to reduce energy use | 77 | 4.43 | .834 | 18.83 | 88.57 | 1 | 1 |
| ES1 | Use appropriate insulation systems to reduce conduction through the thermal envelope | 77 | 4.40 | .765 | 17.39 | 88.05 | 2 | 2 |
| LS8 | Use secure cross-ventilation for passive cooling and occupants' comfort | 77 | 4.36 | .887 | 20.34 | 87.27 | 1 | 3 |
| LS5 | Use appropriate floor height to allow for future modification | 77 | 4.35 | .774 | 17.79 | 87.01 | 2 | 4 |
| SS5 | Prepare site landscape and landforms for high wind conditions as well as to reduce the noise, pollution, energy consumption, temperature degree and relative humidity | 77 | 4.34 | .837 | 19.29 | 86.75 | 1 | 5 |
| TS5 | Increase structure bracing to create strength redundancy to wind and snow loads | 77 | 4.32 | .834 | 19.31 | 86.49 | 1 | 6 |
| TS9 | Construct masonry chimneys with continuous reinforced steel bracing to increase the resistance | 77 | 4.29 | .792 | 18.46 | 85.71 | 2 | 7 |
| ES9 | Specify windows, doors, and openings to withstand wind loads and windblown debris | 77 | 4.26 | .750 | 17.61 | 85.19 | 3 | 8 |
| ES10 | Oversize framing and bracing to increase redundancy | 77 | 4.25 | .728 | 17.13 | 84.94 | 4 | 9 |
| TS8 | Use structure materials that are more resistant to pests to mitigate high temperature | 77 | 4.18 | .869 | 20.79 | 83.64 | 3 | 10 |
| ES14 | Use appropriate exterior shading to reduce vulnerability to overheating | 77 | 4.17 | .880 | 21.10 | 83.38 | 5 | 11 |
| YS8 | Build a permanent water-resistant barrier around HVAC equipment to protect from flooding | 77 | 4.14 | .838 | 20.24 | 82.86 | 1 | 12 |
| YS2 | Provide protection for the main electrical system from flooding | 77 | 4.10 | .836 | 20.39 | 82.08 | 2 | 13 |
| ES5 | Use an appropriate shape and angle of the roof to optimize ventilation and thermal comfort, as well as, to resist storms | 77 | 4.09 | .830 | 20.2934 | 81.82 | 6 | 14 |
| SS3 | Plant mature trees to assist in dissipation of the wind force | 77 | 4.08 | .623 | 15.27 | 81.56 | 2 | 15 |
| TS7 | Provide anchorage between superstructure and substructure to increase resistance to high winds | 77 | 4.06 | .848 | 20.89 | 81.30 | 4 | 16 |
| ES8 | Use advanced wall and framing techniques to reduce energy loss | 77 | 4.06 | .848 | 20.89 | 81.30 | 7 | 17 |
| SS6 | Use optimum building orientation to improve resilience to high/low temperature | 77 | 4.05 | .826 | 20.40 | 81.04 | 3 | 18 |
| LS13 | Specify thermal zones, by facing rooms of high energy demand on the south and putting rooms such as cellars, stairs, garages and laundry rooms on the north to act as buffer space | 77 | 4.05 | .887 | 21.90 | 81.03 | 3 | 19 |
| ES3 | Use a high solar reflectance to reflect sunlight and heat away from a building | 77 | 4.04 | 1.032 | 25.54 | 80.780 | 8 | 20 |
| YS3 | Specify cogeneration and solar power to run during blackouts | 77 | 4.04 | .785 | 19.43 | 80.78 | 3 | 21 |
| ES2 | Provide expansion joints within the materials on vulnerability to expansion | 77 | 4.04 | .733 | 18.14 | 80.78 | 9 | 22 |
| LS4 | Use appropriate floor height to enhance and optimize thermal and ventilation processes | 77 | 4.03 | .794 | 19.70 | 80.52 | 4 | 23 |
| YS4 | Size drainage system to vulnerability to high level of rain | 77 | 4.01 | .851 | 21.22 | 80.26 | 4 | 24 |
| LS12 | Specify the layout of rooms, corridors, stairwells etc. in a way that upholds a low-resistance airflow path through the building (both in plan and section) to thermal comfort | 77 | 4.01 | .678 | 16.91 | 80.26 | 5 | 25 |
| SS7 | Use permeable surfaces in landscaping against vulnerability to flooding | 77 | 4.01 | .786 | 19.60 | 80.26 | 4 | 26 |
| TS4 | Oversize roof covering fixings to reduce windblown debris | 77 | 3.97 | .760 | 19.14 | 79.48 | 5 | 27 |
| SS2 | Direct runoff of water to a catch basin or holding area to reduce erosion | 77 | 3.96 | .880 | 22.22 | 79.22 | 5 | 28 |

## 10.6 Average severity indices of resilience building design aspects

The calculated values of the severity index, given as a percentage, have been used in the ranking of resilience strategies. In Figure 10-3, the numbers from 1 to 6 relate to the various aspects of the design (1 = resilience design site, 2 = resilience design layout, 3 = resilience design structure, 4 = resilience design envelope, 5 = resilience design system and 6 = resilience design operation). The highest severity index was scored by SDS with 80.55%, the lowest by SDO with 56.75%, with the others varying between 75.58% and 76.90%. Generally, in resilience building design all aspects are deemed effective and significant except the operation aspect. SDO is the lowest ranking. This could be because of the lack of consideration given to this aspect or of understanding that its SFs can lead to improvements the reliance design in current and future practice.

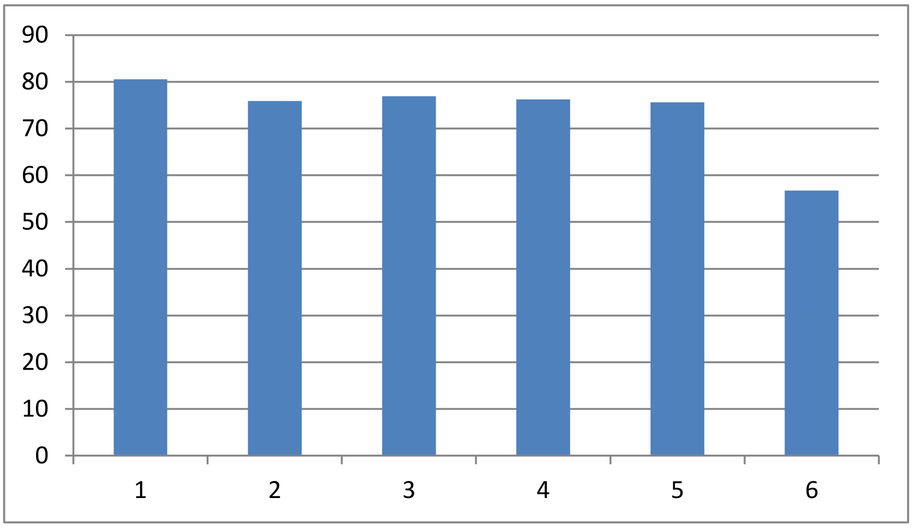


Figure 10-3: Average severity indices of resilience building design aspects: 1 = resilience design site, 2 = resilience design layout, 3 = resilience design structure, 4 = resilience design envelope, 5 = resilience design system and 6 = resilience design operation

## 10.7 Summary

In this chapter, a combination of the mean value, standard deviation, and severity index has been used to rank the effectiveness of each SF for each aspect of a building. The outcome of this ranking, aspect by aspect, is presented in Tables 10-1 to 10-6. An overall ranking of the 28 most effective resilience factors, all with mean values significantly greater than 3 (the neutral score) is shown in Table 10-7. A further analysis and discussion of these 28 extracted SFs follows in the next two chapters. A reliability analysis and an analysis of variance (ANOVA) is conducted in chapter 12 in order to compare the architects' views based on both their professional capacities and levels of experience. Chapter 13 will include a data analysis to ascertain some clusters for developing the new conceptual model.

# Chapter 11: Hypothesis and Reliability Testing

## 11.1 Introduction

In Chapter 9 a statistical analysis of the questionnaire-based survey, together with a ranking of resilience factors extracted as a result, were presented. Differences were found between the rankings of respondents, depending upon their professional role and level of experience. In this chapter, the hypotheses of resilience building design strategies with respect to the category of respondents will be tested using the analysis of variance (ANOVA) method. An analysis will be carried out for each SF and the outcomes of the testing presented and discussed in the sections that follow.

## 11.2 Method

Two methodologies were used to compare the response of participants based on their professional roles and experience. An ANOVA one-way analysis will be used to determine if, and to what extent, there are significant differences between the assessments of the different categories of respondent.

The ANOVA one-way analysis produces *p*-values and *F* statistics (or *F*-values). These statistical measures have the following meanings.

The *p*-value is understood as the probability of obtaining the sample results when the null hypothesis is true. For the purposes of this research a significance level of 5% will be assumed, which means that if the *p*-value is such that $p \leq 0.05$ the suggestion is that the observed data is not consistent with the assumption that the null hypothesis is true, in this case the null hypothesis must be disregarded and the other hypothesis is accepted as true. Therefore, the *p*-value is the probability of obtaining a result at least as extreme as the one that was actually observed, As a result, it can be assumed that the the null hypothesis is true (Dallal, 2007).

The *F*-value, or *F* statistic, is the test statistic. It is given by:

*F* = variance of the group means / mean of the within-group variances.

Thus, the *p*-value is a probability where *F* is a measure of the value of a test.

## 11.3 Analysis of participants' responses based on their professional role

The professional role of each respondent to the questionnaire was considered to fall within one of three categories (see Table 11-1) – architects who are both academic and practicing, those who are exclusively academic, and those who are exclusively practicing architects. The number of respondents in each category, and the percentage they represent of the total, is shown in Table 11-1.

Table 11-1: Respondents' classification based on their professional role

| academics and practicing architects | | academics architects | | practicing architects | | Total | |
|---|---|---|---|---|---|---|---|
| No. | Percentage | No. | Percentage | No. | Percentage | No. | Percentage |
| 36 | 46.75% | 20 | 25.97 | 21 | 27.27% | 77 | 100% |

The highest percentage (46.75%) of respondents is in the case of those who are both academics and practicing architects.

### ANOVA ratings based on architects' professional role

The statistics are reported in (Appendix D) Tables 19-1 to 19-13. The ANOVA method is used to analyse the group responses through testing the following hypotheses:

$A_0(p > 0.05)$: There is no statistically significant difference between the respondents' perceptions on the effectiveness of resilience factors, based on their professional role.

$A_{01}(p < 0.05)$: There is a statistically significant difference between the respondents' perceptions on the effectiveness of resilience factors, based on their professional role.

### 11.3.1 Site design resilience strategies

The results from the statistical analysis of this aspect of building resilience are shown in Appendix D Table 3. The rankings, derived for each group of respondents, are very similar. Consequently, the analysis of variance method was used to justify the responses of the different groups through testing the hypotheses concerning the site design resilience strategies.

The results of the ANOVA for each resilience factor in the site design category are shown presented in Appendix D Table 3. No significant difference was found between the evaluations of architects in the various groups for each SF; $p > 0.05$ in each case, confirming the null hypothesis.

Based on the F values from the analysis of variance, the top ranked SFs are SS1, SS6 and SS7 (see Table 11-2).

Table 11-2: The top resilience factors of Site based on the F-value.

| Code | Resilience design factors |
|---|---|
| SS1 | Use site stabilization techniques to prevent erosion |
| SS6 | Use optimum building orientation to improve resilience to high/low temperature |
| SS7 | Use permeable surfaces in landscaping against vulnerability to flooding |

### 11.3.2 Layout design resilience strategies

The rankings presented in the previous chapters point to some differences between the estimates from the various architect groups. Again, ANOVA was used to test the responses from the groups for this building aspect.

Each of the layout design resilience factors was analysed by the ANOVA technique. The results are presented in Appendix Table 11-5. One SF out of the 14 for this building aspect, LS9 (“Oversize space to reduce occupants’ stress”) showed a significantly different response rom one the architect groups. In other words, for LS9, $p < 0.05$, and the null hypothesis is rejected.

The highest rated SFs were LS4, LS5, LS8, LS9, LS13 and LS14 as shown in Table 11-3. The previous SFs were expected to be in the top rank because all of them had been selected based on the literature review.

Table 11-3: The top resilience factors of layout based on the F-value.

| Code | Resilience design factors |
|---|---|
| LS4 | Use appropriate floor height to enhance and optimize thermal and ventilation processes |
| LS5 | Use appropriate floor height to allow for future modification |
| LS8 | Use secure cross-ventilation for passive cooling and occupants' comfort |
| LS9 | Oversize space to reduce occupants' stress |
| LS13 | Specify thermal zones, by facing rooms of high energy demand on the south and putting rooms such as cellars, stairs, garages and laundry rooms on the north to act as buffer space |
| LS14 | Provide 'safe spaces' in the building to protect the occupants from extreme events |

Hansen et al (2005) referred to how limitations of space can have an impact on the stress level of the occupants. The different views between respondents from the different professional roles could be a reflection of their particular interest or lack of knowledge or practices. For example, this could be a more important factor for architects who are practicing as a result of interactions with actual designs than it is in the case of academic architects. Also, dealing with customers at some stage could make a clear difference between them.

### 11.3.3 Structure design resilience strategies

The results from the statistical analysis of the structure design aspect are shown in Appendix Table 7. The rankings, derived for each group of respondents, are very similar.

Consequently, ANOVA was used to justify the responses of the different groups through testing the hypotheses concerning the TS strategies.

The ANOVA analysis shows that there are no statistically significant differences between the top 7 ranked SFs – TS2, TS4, TS5, TS6, TS7, TS11 and TS12. Based on an analysis of the three types of professional roles, only one SF out of the 12 had responses that differed significantly. This SF was TS6 (Oversize walls and roofs to create strength redundancy for wind and snow loads), for which $F = 5.583$ and $p = 0.006$, so for this the null hypothesis is rejected. TS6, along with the other SFs identified in Table 10 were selected based on the critical literature review. These SFs were selected based on the literature review, as shown in Table 11-4. The difference in views between the various professional categories could be due to differences in such factors as their specialties, areas of interest, types of building they design, and their location.

Table 11-4: The top resilience factors of structure based on the F-value.

| Code | Resilience design factors |
|---|---|
| TS2 | Use flexible pipes and joints to resist high wind and other pressures |
| TS4 | Oversize roof covering fixings to reduce windblown debris |
| TS5 | Increase structure bracing to create strength redundancy to wind and snow loads |
| TS6 | Oversize walls and roofs to create strength redundancy for wind and snow loads |
| TS7 | Provide anchorage between superstructure and substructure to increase resistance to high winds |
| TS11 | Use thermal mass on floor/ceiling/walls to moderate internal temperatures and reduce electricity demand |
| TS12 | Specify durable and robust materials and construction methods to resist the increasing number of significant extreme weather events |

### 11.3.4 Envelope design resilience strategies

The rankings presented in the previous chapters point to some differences between the estimates from the various architect groups. For this reason, ANOVA was used to test the responses from the groups for this building aspect.

Each SF in the aspect was analysed using ANOVA. The results of the analysis are shown in Appendix Table 11-9. The highest ranked SFs were ES4, ES5, ES6, ES7, ES9, ES10, ES11, ES12, ES13, ES14, ES16, ES17, ES21, ES23, ES24, ES25 and ES26. A description of these is given in Table 11-5. Based on analysis of the responses of from the three different groupings of architect by professional role, for only 6 SFs out of the 32 in this aspect did the responses differ significantly; these were ES7, ES10, ES12, ES13, ES24 and ES25. In this case, the null hypothesis is rejected. The *p*-values of SFs ES7, ES10, ES12, ES13, ES24 and ES25 are 0.033, 0.018, 0.010, 0.002, 0.025 and 0.022, respectively. The *F* statistics for these factors are 3.560, 4.268, 4.925, 6.905, 3.895 and 4.014, respectively.

Table 11-5: The top resilience factors of envelope-based on the F-value.

| Code | Resilience design factors |
|---|---|
| ES4 | Use appropriate materials to prevent the effects of flooding |
| ES5 | Use an appropriate shape and angle of the roof to optimize ventilation and thermal comfort, as well as, to resist storms |
| ES6 | Use energy-efficient windows and shading devices to reduce energy use |
| ES7 | Specify window film to prevent injuries from shattered glass |
| ES9 | Specify windows, doors, and openings to withstand wind loads and windblown debris |
| ES10 | Oversize framing and bracing to increase redundancy |
| ES11 | Oversize anchors for roof-/wall-mounted heating, ventilation, and air conditioning units |
| ES12 | Use green roofs to reduce the heat island effect in urban settings |
| ES13 | Use green roofs to minimise runoff rainwater |
| ES14 | Use appropriate exterior shading to reduce vulnerability to overheating |
| ES16 | Use light shelves or specially-designed reflective-louvered blinds to reflect light deep into rooms |
| ES17 | Specify materials that can get wet and dry out without permanent damage |
| ES21 | Specify dry flood-proofing e.g., watertight structure using sealants, flood shields, etc. to protect against floods |
| ES23 | Avoid the use of long rectangular plans with the ratio between the length and width over 2.5 (a ratio over 2.5 creates vulnerability to storms) |
| ES24 | Avoid the use of long roof eaves due to vulnerability to storms |
| ES25 | Use double façades for natural ventilation as an outlet or inlet path |
| ES26 | Specify roofs’ shape and orientation to strengthen the natural driving forces |

### 11.3.5 System design resilience strategies

The rankings presented in the previous chapters point to some differences between the estimates from the various architect groups. For this reason, ANOVA was used to test the responses from the groups for this building aspect.

The result of the ANOVA analysis is shown in Appendix D Table 11-6. Based on the analysis, in the case of three out of the 16 SFs – YS3, YS8 and YS10 – in this aspect the responses differed significantly. Respondents from one of the professional roles rated these SFs significantly different than respondents from the other groups did, so that the null hypothesis is rejected. The highest rated SFs were YS2, YS3, YS6, YS7, YS8, YS9, YS10, YS11, YS12 and YS14. These SFs were selected based on the literature review, as shown in Table 11-6. The difference in views between the various professional categories could be due to differences in such factors as their specialties, areas of interest, types of building they design, and their location.

Table 11-6: The top resilience factors of system based on the F-value.

| Code | Resilience design factors |
|---|---|
| YS2 | Provide protection for the main electrical system from flooding |
| YS3 | Specify cogeneration and solar power to run during blackouts |
| YS6 | Specify water-efficient fittings and devices to ensure the continuity of operation of the building |
| YS7 | Specify ductile-utility connectors to reduce breakage during disturbance events |
| YS8 | Build a permanent water-resistant barrier around HVAC equipment to protect from flooding |
| YS9 | Separate electrical circuits between levels under and above expected flooded levels |
| YS10 | Use multiple lighting resources to avoid electricity shutdown |
| YS11 | Raise electrical service above expected flood levels (system) |
| YS12 | Specify backup power to avoid electricity shutdown |
| YS14 | Specify heat and cold storage in the ground to protect against power shutdown |

### 11.3.6 Operation design resilience strategies

The outcome of ranking for each group showed that there were little or no significant differences between the different groups of respondents. The results of the ANOVA analysis for the SFs in this SO are shown in Appendix D Table 11-13. One out of the 4 SFs in this aspect, OS2 (Secure interior furnishings and equipment to ensure continuity of operation), received responses that differed significantly, so that the null hypothesis is rejected. For OS2, $F = 4.218$ and $p = 0.018$. These SFs were selected based on the literature review, as shown in Table 10. The difference in views between the various professional categories could be due to differences in such factors as their specialties, areas of interest, types of building they design, and their location. The top ranked SFs in this aspect were OS1 and OS2 (as shown in Table 11-7).

Table 11-7: The top resilience factors of operation based on the F-value.

| Code | Resilience design factors |
|---|---|
| OS1 | Specify early warning systems, to alert vulnerable building occupants |
| OS2 | Secure interior furnishings and equipment to ensure continuity of operation |

## 11.4 Analysis of participants' responses based on their experience

Participants’ experience has been divided into three main categories, i.e. architects with 0–5 years’ experience, those with 5–10 years’ experience, and those with 10 years’ experience (see Table 11-8). Results will be compared based on the average rating, then ranked and the hypothesis subsequently tested.

Table 11-8: Respondents' classification based on their experience.

| 0 - 5 | | 5 – 10 | | More than 10 years | | Total | |
|---|---|---|---|---|---|---|---|
| No. | Percentage | No. | Percentage | No. | Percentage | No. | Percentage |
| 15 | 19.48 | 20 | 25.97 | 42 | 54.54 | 77 | 10% |

**ANOVA testing based on architects' experience**

The statistics are presented in Appendix D Tables 11-16 to 11-26. As a result of the rankings for each group of respondents, it emerged that there was little difference between the groups in this respect. Consequently, ANOVA was used to justify the group responses through testing the following hypotheses:

A_0 ( $p > 0.05$): There is no statistically significant difference between the respondents' perceptions on the effectiveness of resilience factors, based on their level of experience.

A_01 ( $p < 0.05$): There is a statistically significant difference between the respondents' perceptions on the effectiveness of resilience factors, based on their level of experience.

### 11.4.1 Site design resilience strategies

ANOVA was used to test the SFs of this aspect in which the ranking showed some differences between the three architect groups. It was applied in order to justify the group responses by testing the site design resilience strategies hypotheses. (shown Table 11-9).

The highest ranking SFs in this aspect were SS5, SS6 and SS7.

Table 11-9: The top resilience factors of site based on the F-value.

| Code | Resilience design factors |
|---|---|
| SS5 | Prepare site landscape and landforms for high wind conditions as well as to reduce the noise, pollution, energy consumption, temperature degree and relative humidity |
| SS6 | Use optimum building orientation to improve resilience to high/low temperature |
| SS7 | Use permeable surfaces in landscaping against vulnerability to flooding |

### 11.4.2 Layout design resilience strategies

ANOVA was used to test the SFs of this aspect in which the ranking showed some differences between the three architect groups. It was applied in order to justify the group responses by testing the site design resilience strategies hypotheses.

Each SF was analysed using ANOVA. Based on analysis of the three types of years of experience, the responses for only one SF out of the 14 proved to be significantly different. This SF is LS4. One of the categories of architect rated this SF significantly different from the other groups, so that the null hypothesis is rejected. For LS4, $F = 4.053$ and $p = 0.021$. The highest ranked SFs in this aspect are LS4, LS5, LS8, LS9, LS13 and LS14.

Table 11-10: The top resilience factors of layout based on the F-value.

| Code | Resilience design factors |
|---|---|
| LS4 | Use appropriate floor height to enhance and optimize thermal and ventilation processes |
| LS5 | Use appropriate floor height to allow for future modification |
| LS8 | Use secure cross-ventilation for passive cooling and occupants’ comfort |
| LS9 | Oversize space to reduce occupants’ stress |
| LS13 | Specify thermal zones, by facing rooms of high energy demand on the south and putting rooms such as cellars, stairs, garages and laundry rooms on the north to act as buffer space |
| LS14 | Provide ‘safe spaces’ in the building to protect the occupants from extreme events |

### 11.4.3 Structure design resilience strategies

ANOVA was again used to test the SFs of this aspect for which the ranking given in previous chapters showed that there were some differences in evaluation between the different architects’ groups.

The result of the ANOVA analysis is shown in Table 20. Based on analysis of the three types of years of experience, the responses for a number of the SFs differed significantly. The highest rated SFs of this aspect were TS2, TS3 and TS7. (shown Table 11-9).

Table 11-11: The top resilience factors of structure based on the F-value.

| Code | Resilience design factors |
|---|---|
| TS2 | Use flexible pipes and joints to resist high wind and other pressures |
| TS3 | Use an appropriate shape and angle of the roof for optimum ventilation and thermal comfort |
| TS7 | Provide anchorage between superstructure and substructure to increase resistance to high winds |

### 11.4.4 Envelope design resilience strategies

ANOVA was again used to test the SFs of this aspect for which the ranking given in previous chapters showed that there were some differences in evaluation between the different architects' groups.

The result of the ANOVA analysis is shown Appendix D Table 11-21. The highest ratings of this aspect were given to the following factors: ES3, ES5, ES8, ES10, ES17, ES18, ES23, ES24, ES25 and ES29.

Table 11-12: The top resilience factors of envelope based on the F-value.

| Code | Resilience design factors |
|---|---|
| ES3 | Use a high solar reflectance to reflect sunlight and heat away from a building |
| ES5 | Use an appropriate shape and angle of the roof to optimize ventilation and thermal comfort, as well as, to resist storms |
| ES8 | Use advanced wall and framing techniques to reduce energy loss |
| ES10 | Oversize framing and bracing to increase redundancy |
| ES17 | Specify materials that can get wet and dry out without permanent damage |
| ES18 | Specify airtight junctions and details |
| ES23 | Avoid the use of long rectangular plans with the ratio between the length and width over 2.5 (a ratio over 2.5 creates vulnerability to storms) |
| ES24 | Avoid the use of long roof eaves due to vulnerability to storms |
| ES25 | Use double façades for natural ventilation as an outlet or inlet path |
| ES29 | Specify glazing ratio of 30-50% for vertical surfaces and 20% for rooflights to provide adequate daylight and avoid overheating |

### 11.4.5 System design resilience strategies

ANOVA was used to test the SFs of this aspect for which the ranking given in previous chapters showed that there were some differences in assessments between the different architects' groups.

The result of the analysis is shown in Appendix D Table 11-24. The responses for one SF out of the 16 differed significantly based on an analysis of the three categories of architect experience. Specifically, in the case of YS1, the rating given by one of the architect groups differed significantly from the rating of the others, so that the null hypothesis is rejected. It is possible that the difference arose because this resilience factor is related more to the application of a specific technology than to architectural design.

The highest ratings of this aspect were obtained in the case of the following SFs: YS1, YS7, YS11, YS12, YS14 and YS15.

Table 11-13: The top resilience factors of system based on the F-value.

| Code | Resilience design factors |
|---|---|
| YS1 | Ensure the provision of HVAC systems redundancy or overcapacity to cope with unexpected load |
| YS7 | Specify ductile-utility connectors to reduce breakage during disturbance events |
| YS11 | Raise electrical service above expected flood levels (system) |
| YS12 | Specify backup power to avoid electricity shutdown |
| YS14 | Specify heat and cold storage in the ground to protect against power shutdown |
| YS15 | Specify spray systems on roofs and terraces for evaporative cooling |

### 11.4.6 Operation design resilience strategies

ANOVA was used to test the SFs of this aspect for which the ranking given in previous chapters showed that there were some differences in assessments between the different architects' groups.

The results of this analysis are shown in Appendix D Table 11-26. The responses for one SF in this aspect differed significantly based on an analysis of the three categories of architect experience.

Table 11-14: The top resilience factors of operation based on the F-value.

| Code | Resilience design factors |
|---|---|
| OS1 | Specify early warning systems, to alert vulnerable building occupants |
| OS3 | Design for emergency repairs to ensure readiness for any risks and ensure continuity of operation |
| OS4 | Specify temperature controls to cater for different needs of occupants |

## 11.5 Discussion

This chapter has examined the data collected from the questionnaire as to the effectiveness of the SFs of the resilience building design conceptual model. Based on this investigation, it has emerged that there are differences between the architects' views based both on their professional capacities and levels of experience. Table 11-15 presents a summary of the rejected factors.

**Areas of disagreement**

Table 11-15: Summary of SFs rejected after ANOVA analysis of discrepancies between respondents' data based on professional capacity and level of experience.

| aspects | Analysis based on professional role | Analysis based on years of experience |
|---|---|---|
| SS | -- | -- |
| LS | SL9 | SL4 |
| TS | ST6 | -- |
| ES | SE7, SE10, SE12, SE13, SE24, SE25, | -- |
| YS | SY3, SY6, SY10 | SY1 |
| OS | SO2 | -- |

The view between the two groups is different in terms of the highest F-values SFs. Their views agree about the F-values of some SFs and differ about others, as highlighted in Table 28.

Table 11-16: Summary of SFs rejected due to F-values of ANOVA analysis of discrepancies between respondents' data based on professional capacity and level of experience.

| Aspects | Analysis based on professional role | Analysis based on years of experience |
|---|---|---|
| SS | SS1, SS6, SS7 | SS5, SS6, SS7 |
| LS | SL4, SL5, LS8, SL9, SL13, SL14 | SL4, SL5, LS8, SL9, SL13, SL14 |
| TS | ST2, ST4, ST5, ST6, ST7, ST11, ST12 | ST2, ST3, ST7 |
| ES | SE4, SE5, SE6, SE7, SE9, SE10, SE11, SE12, SE13, SE14, SE16, SE17, SE23, SE24, SE25, SE26 | SE3, SE5, SE8, SE10, SE17, SE18, SE23, SE24, SE25, SE29 |
| YS | SY2, SY3, SY6, SY7, SY8, SY9, SY10, SY11, SY12, SY14 | SY1, SY7, SY11, SY12, SY14, SY15 |
| OS | SO1, SO2 | SO1, SO3, SO4 |

As a result of the analysis 14 of the original 84 SFs are rejected. As a result of the analysis, 14 of the original 84 SFs are rejected as shown in table 11-16, which serves as confirmation of the effectiveness of the selected SFs. It reflects, too, on the extent to which the SFs can have a clear influential role during the resilience building design process. In addition, by omitting the rejected SFs the architect is able to meet the resilience needs of the design at the early stage.

## 11.6 Summary

Statistical methods, including analysis of variance, have been applied to test whether there is a significant difference between how the designers who responded to this study's questionnaire, assess the importance of resilience strategies depending on their professional roles and length of experience. The outcomes were used to select the final SFs to be included in the design resilience tool.

# Chapter 12: Design Resilience Strategic Assessment tool

## 12.1 Introduction

In the validation of a new assessment tool to evaluate building resilience design an important stage is the development of a conceptual model, for determining whether the tool achieves the necessary level of resilience. Examining the methodology of existing tools can guide the researcher in the preparation of a new tool. Design resilience indicators and other methods are used to assess the building design, to assess if it is resilient or not. Each of these methods is placed into one of several groups and each group is associated with a set of indicators; each also includes ratings and scores for assessment. The existing tool should be as similar as possible to the structure of the proposed assessment tool. In the following section, the various other assessment tools will be reviewed and some of their ratings and equations adapted if possible.

## 12.2 Review of existing assessment tools

Various resilience assessment tools have been developed and used in different countries. These bring detailed quantitative methods to bear on measuring the resilience of entities such as transport systems and economies. Typically, these tools generate a 'resilience index' that provides a gauge of the ability of the system to continue to function when faced with unusual demands or events (such as those resulting from climate change).

Common features of existing resilience assessment tools are that they seek to (1) assess the extent of failure of the system (if any) due to the impact of an event, (2) calculate how long it takes to return to an adequate level of functionality of the system, and (3) compare the performance of the recovered system as a result of a implementing strategy and the system performance without the strategy incorporated. Serulle (2010) identified several previous analyses carried out, together with the related field and the methodology employed (see Table 12-1).

Table 12-1: Overview of proposed quantitative assessments of resilience (Serulle, 2010).

| **Author** | **Field** | **Proposed methodology** |
|---|---|---|
| Hamad and Kikuchi (2002) | Transportation engineering | A measure of traffic congestion built on travel speed and delay was developed. A fuzzy logic methodology was used to combine travel speed and delay into a single resilience index that ranged from 0 (best condition) to 1 (worst). |
| Brenkert and Malone (2004) | Social studies | Put forward a suite of 17 indicators to enable comparisons between various levels of localities, with regards to their resilience to climate change risks. |
| Mayunga (2007) | Social studies | Resilience factors calculated with a weighted average which includes economic, human, social, and physical capital, to derive a unified community disaster resilience index. |
| Heaslip et al. (2010) | Transportation engineering | A set of 10 variables was adopted to define four basic indices of network performance, including network availability, traveller perception, network accessibility and transportation cost. Fuzzy logic was incorporated within these indices for the purpose of creating an unified resilience index. |

## 12.3 Comparisons

Comparisons between resilience assessment tools can be made based on a number of criteria, including: assessment field, resilience aspects, evaluation method, style of view of the assessment tool and aim of the assessment. Common to many assessment tools are aspects such as site, interior and exterior environment, water, material, land use and transport, health and wellbeing and pollution, each of which incorporates several indicators (Giddings et al., 2013).

The Design Resilience Strategic Assessment Tool to be developed here will use its own unique set of criteria that differ from those of existing assessment tools. Moreover, the tool that is the subject of this research will adopt strategies aimed at a particular application – building resilience needs to cope with climate change issues and events. However, although the criteria may be different, the present tool can make use of some previous methodologies and approaches in its development. Thus some existing assessment tools will be examined next to see what can be learned from them.

The AECOM transport modelling tool incorporates resilience as one of its main principles, in the context of a system that analyses transport networks and movements (National Infrastructure Unit, 2011). The AECOM assessment tool is designed with the aim of measuring the resilience of a transport infrastructure, and can work with both road and rail systems at a variety of scales (Hughes and Healy, 2014). Its methodology involved a three-stage approach shown in Figure 12-1.

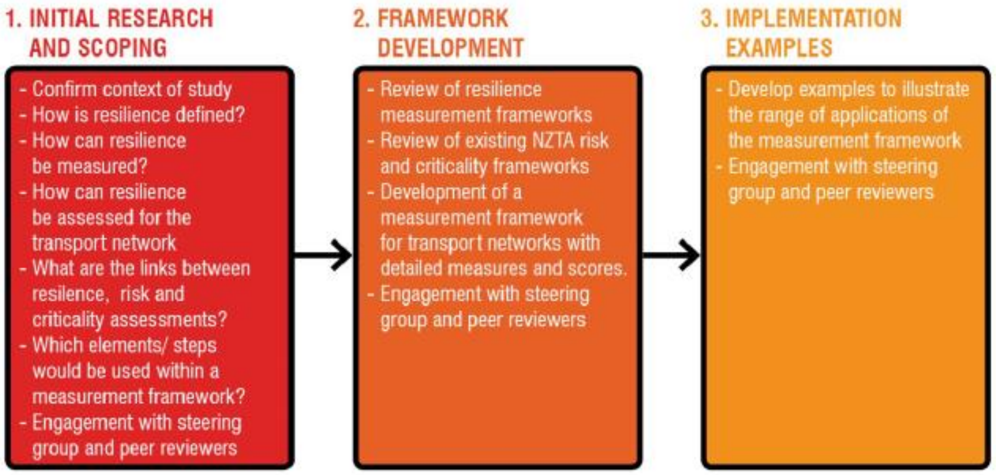


Figure 12-1: Outline of AECOM tool methodology (Hughes and Healy 2014).

The SCEAM assessment tool is intended to investigate the connections between variables which include the quality of life for residents, in addition, the physical environment of nursing homes. Furthermore, the assessment tool includes the level of job satisfaction and the morale of care staff. It is thus applicable only to buildings in use and not to the design of them for resilience (Parker et al., 2004).

The CABE (Commission for Architecture and the Built Environment) tool was devised for use with general-purpose housing and neighbourhoods. Of the 20 criteria it uses only a proportion are connected with the actual design quality of proposals.

Both the CIC (Construction Industry Council) and EVOLVE (Evaluation of Older People's Living Environments) tools were developed to assess a variety of building types. The former was eventually expanded to include five different phases of the building process including design. Scores for the criteria in the model are based on input from a lengthy questionnaire and workshops held for 'stakeholders' in the project (CIC, 2003).

EVOLVE, developed by the University of Sheffield, can evaluate buildings at the design stage and is arranged in six sections: layout, building elements, fittings, environmental design, services and finishes. However, the design assessment only deals with interior issues and the site and location section is limited to a consideration simply of access to local services. Several hundred questions, responses to which are restricted to "yes/no/not in use/not applicable" form the basis for the EVOLVE survey, a sample of which is shown in Figure 12-2.

Generic

| No. | ITEM | yes | no | not in use | n/a |
|---|---|---|---|---|---|
| | **Layout** | | | | |
| 1 | All hinged doors open through a full 90° | ○ | ○ | ○ | ○ |
| | **Building Elements - Doors** *(Does not apply to Living Unit entrance)* | | | | |
| 2 | The colour of doors contrasts with the colour of the surrounding walls | ○ | ○ | ○ | ○ |
| 3 | Doors have a non-reflective satin or matt finish | ○ | ○ | ○ | ○ |
| 4 | The colour of door handles contrasts with the colour of doors | ○ | ○ | ○ | ○ |
| 5 | Door furniture has a non-reflective finish | ○ | ○ | ○ | ○ |
| 6 | Thresholds are flush with general floor level | ○ | ○ | ○ | ○ |
| 7 | Doors are sliding doors, or open into a room and rest with the leading edge against an adjacent wall | ○ | ○ | ○ | ○ |

Figure 12-2: Part of EVOLVE tool (Housing LIN, 2014).

Each of the assessment tools mentioned above has its advantages and disadvantages. The challenge, as far as the research here is concerned, is to provide a tool that is sufficiently flexible that it can be applied to any building, addresses the four principle characteristics of robustness, redundancy, capacity for adaptation and environmental responsiveness, and incorporates the key identified resilience factors with regard to climate change impact. Although the Design Resilience Strategic Assessment Tool does not match closely any of the assessment tools thus described in terms of application, it is possible to adapt some of the features of other assessment tools, such as their scoring systems and rating of results, for use in the present study.

## 12.4 Scoring system of other assessments

Existing assessment tools were examined for the suitability of use of their scoring systems in the present research. It was determined that two scoring systems, those of BREEAM (Building Research Establishment Environmental Assessment Methodology) and LEED (Leadership in Energy and Environmental Design), would be most effective because of the methodology is tested, tried and validated in real projects. As well as the scoring system is robust. A summary of these systems is given in Tables 12-2 and 12-3.

Table 12-2: BREEAM rating (Inbuilt, 2010).

| BREEAM rating | % score |
|---|---|
| Unclassified | <30 |
| Pass | 30 and above |
| Good | 45 and above |
| Very Good | 55 and above |
| Excellent | 70 and above |
| Outstanding | 85 and above |

Table 12-3: LEED rating (Inbuilt, 2010).

| LEED rating | Points |
|---|---|
| Certified | 40-49 |
| Silver | 50-59 |
| Gold | 60-79 |
| Platinum | 80 points and above |

The researcher will adapt these scoring systems for use in the Design Resilience Strategy tool to assess each level of the building resilience, as will be explained later.

## 12.5 Design quality indicator

The design quality indicator (DQI) is a tool developed specifically to assess design quality (Gann et al., 2003). It can be used by the designer to make decisions at various stages in the design process. Development of the DQI was based on existing building assessment methods such as post-occupancy evaluation, BREEAM, LEED, CASBEE, DGN Label and Housing Quality Indicators (Gann et al., 2003).

The conceptual framework of DQI involves three main aspects: functionality, impact and building quality. Each of these is associated with several criteria – these include the use, the access and the space. These include engineering systems, construction and performance; the form and materials; internal environment; social and urban integration; and identity and character (Gann et al., 2003). The makes it similar in broad structure to the model being developed here, in that too involves a cluster of main criteria each of which is associated with a number of strategies.

## 12.6 Data tool

A questionnaire is necessary, for data gathering, to be filled out by stakeholders who participate in the design process. The structure of the questionnaire is based on the division of the framework into three main aspects, as shown in Figure 12-3. The hierarchy of the questionnaire used in the present research is laid out to match the structure of the design resilience strategies.

Build Quality

For sections **N** to **P** please additionally circle the 3 statements within each section that you feel are the most important for your building

| **N PERFORMANCE** | Strongly Disagree | Disagree | Tend to Disagree | Tend to Agree | Agree | Strongly Agree | Not Applicable |
|---|---|---|---|---|---|---|---|
| 01 The building is easy to clean | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 02 The building withstands wear and tear in use | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 03 The building is easily maintained | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 04 The building design has responded to the site microclimate | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 05 The building will weather well | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 06 The building's structure is efficient | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 07 The building's finishes are durable | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 08 There is sufficient daylight in the building | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 09 The artificial lighting levels in the building are sufficient | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 10 The thermal climate in the building is appropriate to its use | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 11 The acoustics quality is appropriate to its use | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 12 The air quality is appropriate to its use | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 13 The building is easy to operate | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 14 The building produces a low number of complaints/faults reported by users | ○ | ○ | ○ | ○ | ○ | ○ | ○ |

Figure 12-3: The details of section of DQI (Gann et al., 2003).

## 12.7 Developing the Design Resilience Strategy Assessment tool

The Design Resilience Strategy Assessment tool is founded upon a critical literature review and subsequent refinement of the resilience factors. The refinement process was described in Chapter 10. The resilience factors were identified and highlighted in each component and displayed in a rankings table. The assessment tool will include a scoring system, the selected resilience factors, and a weighting of these factors based on the case study.

## 12.8 Scoring system

The scoring system of the present tool is based on that of BREEAM and LEED, and the scale is based on that of Vakili-Ardebili (2004), who developed an assessment tool for eco building design. The indicators of Vakili-Ardebili's tool were applied to several case studies and the designers of these projects asked to score it from 0 (not implemented) to 10 (high implementation). The same method has been adopted in this study, as shown in the design resilience strategy sheet. In terms of the equation, each cluster was given a code, as follows: $RO + R + ER + CA$ (where $RO$ = robustness, $R$ = redundancy, $CA$ = capacity for adaptation and *ER* = environmental responsiveness). Each cluster has associated indicators. Designers should score for each indicator a value of 1 to 10, as shown in Figure 4. Because there are 28 resilience factors in the model, the total possible score is 280, which explains the factor in the denominator. The equation is then as follows:

$$\text{Design resilience rating} = \sum \frac{RO + R + CA + ER}{280} \times 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots (12\text{-}1)$$

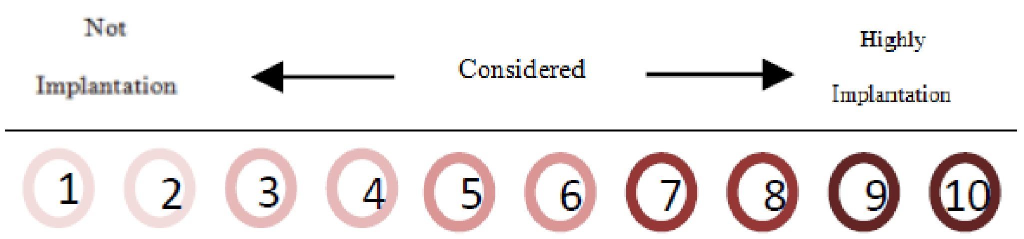


Figure 12-4: Implementation rating of the assessment tool for this research.

Table 12-4: Design resilience strategy rating.

| Design resilience strategy rating | Score without weighting | |
|---|---|---|
| | Points | Percentage |
| Non resilient | 0-112 | < 40% |
| Marginally resilient | 112-140 | 40% and above |
| Moderate resilient | 140-168 | 50% and above |
| Significant resilient | 168-196 | 60% and above |
| Very highly resilient | 196-280 | 70% and above |

Using this formula, the designer can evaluate to what extent the design matches the design resilient building. The case studies are described below (information provided for the projects by Alrkari and Stephen, 2014).

## 12.9 Selection of factors

How the resilience factors (SFs) were chosen was discussed in detail earlier. Extraction of the SFs was based on calculation of the rankings, as explained and displayed in Chapter 10. This was achieved by way of analysing the SFs in addition to the redundant data – the latter being the technique applied to cut down the number of SFs. After this process, 28 SFs remained which were then correlated with the aspects so that the highest effective SFs could be identified (again, as shown in Chapter 10). To calculate resilience scores, the researcher has used an equation of design quality indicators, adapted from those employed by the existing BREEAM and LEED tools.

## 12.10 Model testing

Testing must be carried out in order to demonstrate that the model is valid. In order to do this; three architectural practices were contacted and asked to fill a form, related to one of the projects designed by their practice. The form contained the 28 resilience indicators of the research model, clustered into four categories, as identified from the analysis and ranking in Chapters 10 and 11. On the form, the designers were invited to score their projects as to what extent each resilience factor had been implemented in their project. Figures 12-3, 12-5 and 12-7 and Tables 12-6 to 12-11 present the designers' evaluations and the overall resilience scores. From the resulting scores, the over design building resilience was calculated as percentage value. A diagrammatic representation of the outcomes of the resilience design strategy model are presented in Figures 12-6, 12-8 and 12-10. The nested grey zones, from light in the center to increasingly dark in the outer region indicates the increasing degree of resilience, from inner to outer, along the four dimensions of building characteristic. The blue line shows the actual resilience score of the project for each of these characteristics.

Figure 12-6 illustratesthat project weaknesses are related to CCRs that stem from a failure to implement design resilience strategies. This fact, and the results of the testing with real building projects, supports the researcher's contention that it is important to apply resilience strategies early in the design process.

The building resilience model gives architects the means to identify the weaknesses in their designs in the face of climate change. Moreover, it can supply graphic illustrations of the status of their designs based on scores given to 28 extracted resilience factors.

## 12.11 Case studies

Various case studies were available with which to test this tool; four, each dealing with environmental and sustainable issues, were selected. The tool was delivered to the architects who designed these buildings, in order for them to score each SF, to see if they would be implemented and at what level.

### 12.11.1 Queens Court Project

Queens Court Project is an environmentally-sensitive, affordable housing project consisting of a mix of various sized flats. It also includes car parking, visitor parking, garden and flower areas.


Figure 12-5: Queens Court Project (Arwa Alrkari, 2014).

Table 12-5: Present the designers' evaluations and the overall resilience scores of Queens Court project.

| Project Name: Queens Court | | | | |
|---|---|---|---|---|
| Office Name | Denovo Design Ltd | | | |
| Architect Name | Arwa Alrkari | | | |
| Project Location | Widnes, Runcorn | | | |
| resilient categories | To what extent the following factors are implemented and considered in this design? | .S | T.P | D.P |
| **Robustness (RO)** | SE9: Specify windows, doors, and openings to withstand wind loads and windblown debris | 7 | 18 | 25% |
| | ST4: Oversize roof covering fixings to reduce windblown debris | 1 | | |
| | SY8: Build a permanent water-resistant barrier around HVAC equipment to protect from flooding. | 1 | | |
| | ST7: Provide anchorage between superstructure and substructure to increase resistance to high winds | 3 | | |
| | ST9: Construct masonry chimneys with continuous reinforced steel bracing to increase the resistance | 1 | | |
| | SE10: Oversize framing and bracing to increase redundancy | 4 | | |
| | SY2: Provide protection for the main electrical system from flooding | 1 | | |
| **Redundancy (R)** | SS2: Direct runoff of water to a catch basin or holding area to reduce erosion. | 1 | 14 | 35% |
| | ST5: Increase structure bracing to create strength redundancy to wind and snow loads. | 7 | | |
| | SY3: Specify cogeneration and solar power to run during blackouts. | 1 | | |
| | SY4: Size drainage system to vulnerability to high level of rain. | 5 | | |
| **Capacity for adaptation (CA)** | SS7: Use permeable surfaces in landscaping against vulnerability to flooding | 1 | 35 | 58% |
| | SE2: Provide expansion joints within the materials on vulnerability to expansion | 8 | | |
| | SL5: Use appropriate floor height to allow for future modification. | 7 | | |
| | SS6: Use optimum building orientation to improve resilience to high/low temperature. | 5 | | |
| | SL4: Use appropriate floor height to enhance and optimize thermal and ventilation processes. | 8 | | |
| | ST8: Use structure materials that are more resistant to pests to mitigate high temperature. | 6 | | |
| **Environmental responsiveness (ER)** | SL8: Use secure cross-ventilation for passive cooling and occupants' comfort. | 8 | 67 | 60% |
| | SL12: Specify the layout of rooms, corridors, stairwells etc. in a way that upholds a low-resistance airflow path through the building (both in plan and section) to thermal comfort | 4 | | |
| | SE14: Use appropriate exterior shading to reduce vulnerability to overheating | 7 | | |
| | SL13: Specify thermal zones, by facing rooms of high energy demand on the south and putting rooms such as cellars, stairs, garages and laundry rooms on the north to act as buffer space. | 6 | | |
| | SE6: Use energy-efficient windows and shading devices to reduce energy use | 10 | | |
| | SE1: Use appropriate insulation systems to reduce conduction through the thermal envelope. | 8 | | |
| | SE3: Use a high solar reflectance to reflect sunlight and heat away from a building | 2 | | |
| | SE8: Use advanced wall and framing techniques to reduce energy loss | 10 | | |
| | SS3: Plant mature trees to assist in dissipation of the wind force | 4 | | |
| | SS5: Prepare site landscape and landforms for high wind conditions as well as to reduce the noise, pollution, energy consumption, temperature degree and relative humidity | 7 | | |
| | SE5: Use an appropriate shape and angle of the roof to optimize ventilation and thermal comfort, as well as, to resist storms | 1 | | |
| Result | RBD tool = $\sum \frac{RO+R+CA+ER}{280} * 100$ | RDB tool = $\sum \frac{18+14+35+67}{280} = -*100$ | | |
| | The result = 47% | RDB Rate = Marginally resilient | | |

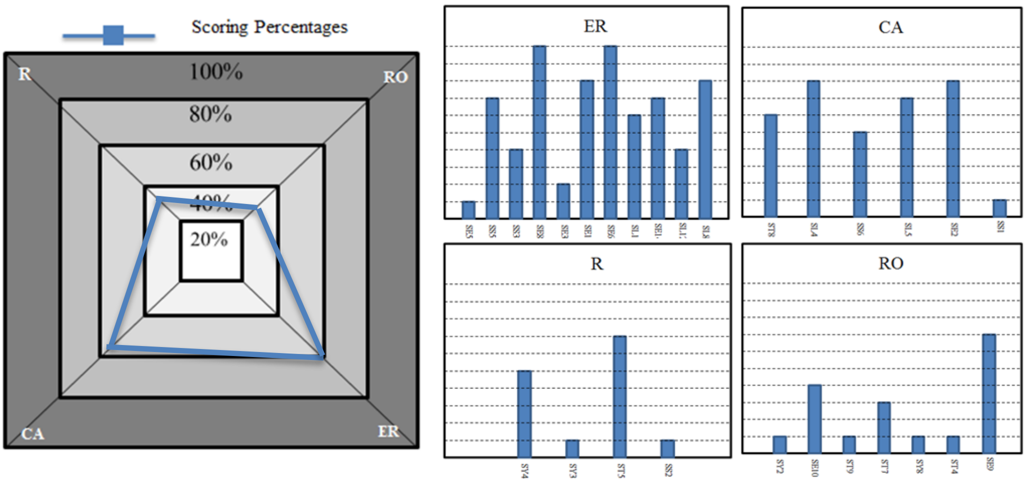


Figure 12-6: Diagram for Queens Court Project.

This project is distinguished by several achievements such as designed to considering green spaces and providing a handbook for the tenants to advise them about the role to enhance achievement of sustainable aims. The result of this project which assess by the designer are shown in the above Table and Figure 12-6. Reducing environmental impact has been achieved through various aspects, as follows:

**Robustness (RO):** The designer scored the resilience factors in this category as follows.

SE9 ("Specify windows, doors, and openings to withstand wind loads and windblown debris"): 7 out of 10. ST4 ("Oversize roof covering fixings to reduce windblown debris"): 1. SY8 ("Build a permanent water-resistant barrier around HVAC equipment to protect from flooding"): 1. ST7 ("Provide anchorage between superstructure and substructure to increase resistance to high winds"): 3. ST9 ("Construct masonry chimneys with continuous reinforced steel bracing to increase the resistance"): 1. SE10 ("Oversize framing and bracing to increase redundancy"): 4. SY2: ("Provide protection for the main electrical system from flooding"): 1.

The total percentage of this aspect is therefore low, at 25%, owing the low scores given to ST4, SY8, ST9 and SY2. More than half of the factors in this aspect were not implemented in this project.

**Redundancy (R):** The lowest scores, of 1, given by the designer in this category was for factors SS2 (“Direct runoff of water to a catch basin or holding area to reduce erosion”) and SY3 (“Specify cogeneration and solar power to run during blackouts”). Without these factors the project would be at threat in case of flood. In addition, the project relied on a single source to provide power, so that in the event of any malfunction of this source there would be an interruption of electric power. In contrast, the project ranked more highly in structural resilience due, for example, to its use of structural bracing to create strength redundancy in case of large wind and snow loads. SY4 was a given a medium score. Overall this category scored 35%.

**Capacity for adaptation (CA):** The highest score in this category was given to the SL4 factor (use expansion joints in the materials that are vulnerable to expansion) and SL5 (use of appropriate floor height to enhance and optimise thermal and ventilation processes). Factors SL7, SS6 and ST8 were ranked medium. In contrast, the designer gave a score of 1 for SS7 (“Use of permeable surfaces in landscaping against vulnerability to flooding”). Overall the project scored 58% resilience in this characteristic.

**Environmental responsiveness (ER):** The project scored highly in this aspect with an overall percentage of 60. More than half of the factors were implemented, including: SL8 (“Use secure cross-ventilation for passive cooling and occupants’ comfort”), SE6 (“Use energy-efficient windows and shading devices to reduce energy use”), SE1 (“Use appropriate insulation systems to reduce conduction through the thermal envelope”), SE8 (“Use advanced wall and framing techniques to reduce energy loss”), SS5 (“Prepare site landscape and landforms for high wind conditions as well as to reduce the noise, pollution, energy consumption, temperature degree and relative humidity") and SE14 ("Use appropriate exterior shading to reduce vulnerability to overheating"). In contrast, the designer give a score of 1 for SE5 ("Use an appropriate shape and angle of the roof to optimize ventilation and thermal comfort, as well as, to resist storms"), which is therefore not implemented.

### 12.11.2New Office for Unit Project in Portsmouth

This project was completed at 2013. The challenge of it was to provide a building of high quality, resilient to climate change, with a low budget. The building rectangular in form with sun-space glazing to the south.


Figure 12-7: New Office for Unit Project (Glenwright, 2014).

The designer, Stephen Glenwright (2014) said: "*The project was meant to be low budget, so no funds for energy saving equipment, solar shading features, etc. The windows are double glazed and the building is insulated to pass building regulations standards only. The structure is brick/block cavity wall with concrete floors so it has some mass which stops building heating up, rather than timber frame, which is I think better in south of England which is hotter than the north. The site is subject to tidal flooding and so the building is built about 900mm above external ground level to avoid flood damage, and there are voids in the walls at low level for water pressure to drain through. Previously the whole site was surfaced with tarmac - we dug up about half of this and added grass and planting beds so water would drain through. We ensured that an existing mature willow tree was kept, as this will use up a lot of ground water. There is a new holding tank for the surface water drainage, to regulate water run of from our site into the sewers. We added 3 new trees, mainly for visual appearance/ecology, but will also take up ground water. The local authority asked us to specify plants and trees which do not encourage the brown tailed moth, which is a problem locally. The site is quite near to the coast, so wind loading was considered. I didn't design the building plans myself, and I don't think enough consideration was given to the orientation of certain rooms - e.g. main rooms face south and can over heat in sunlight*."

Table 12-6: Present the designers' evaluations and the overall resilience scores of New Office for Unit in Portsmouth

| Project Name: New Office for Unit in Portsmouth | | | | |
|---|---|---|---|---|
| Office Name | Denovo Design Ltd | | | |
| Architect Name | Stephen Glenwright | | | |
| Project Location | Portsmouth | | | |
| resilient categories | To what extent the following factors are implemented and considered in this design ? | .S | T.P | D.P |
| **Robustness (RO)** | SE9: Specify windows, doors, and openings to withstand wind loads and windblown debris | 4 | 40 | 57% |
| | ST4: Oversize roof covering fixings to reduce windblown debris | 4 | | |
| | SY8: Build a permanent water-resistant barrier around HVAC equipment to protect from flooding. | 10 | | |
| | ST7: Provide anchorage between superstructure and substructure to increase resistance to high winds | 7 | | |
| | ST9: Construct masonry chimneys with continuous reinforced steel bracing to increase the resistance | 1 | | |
| | SE10: Oversize framing and bracing to increase redundancy | 4 | | |
| | SY2: Provide protection for the main electrical system from flooding | 10 | | |
| **Redundancy (R)** | SS2: Direct runoff of water to a catch basin or holding area to reduce erosion. | 1 | 28 | 70% |
| | ST5: Increase structure bracing to create strength redundancy to wind and snow loads. | 7 | | |
| | SY3: Specify cogeneration and solar power to run during blackouts. | 10 | | |
| | SY4: Size drainage system to vulnerability to high level of rain. | 10 | | |
| **Capacity for adaptation (CA)** | SS7: Use permeable surfaces in landscaping against vulnerability to flooding | 10 | 23 | 38% |
| | SE2: Provide expansion joints within the materials on vulnerability to expansion | 1 | | |
| | SL5: Use appropriate floor height to allow for future modification. | 2 | | |
| | SS6: Use optimum building orientation to improve resilience to high/low temperature. | 1 | | |
| | SL4: Use appropriate floor height to enhance and optimize thermal and ventilation processes. | 2 | | |
| | ST8: Use structure materials that are more resistant to pests to mitigate high temperature. | 7 | | |
| **Environmental responsiveness (ER)** | SL8: Use secure cross-ventilation for passive cooling and occupants' comfort. | 2 | 33 | 30% |
| | SL12: Specify the layout of rooms, corridors, stairwells etc. in a way that upholds a low-resistance airflow path through the building (both in plan and section) to thermal comfort | 2 | | |
| | SE14: Use appropriate exterior shading to reduce vulnerability to overheating | 2 | | |
| | SL13: Specify thermal zones, by facing rooms of high energy demand on the south and putting rooms such as cellars, stairs, garages and laundry rooms on the north to act as buffer space. | 2 | | |
| | SE6: Use energy-efficient windows and shading devices to reduce energy use | 4 | | |
| | SE1: Use appropriate insulation systems to reduce conduction through the thermal envelope. | 8 | | |
| | SE3: Use a high solar reflectance to reflect sunlight and heat away from a building | 3 | | |
| | SE8: Use advanced wall and framing techniques to reduce energy loss | 2 | | |
| | SS3: Plant mature trees to assist in dissipation of the wind force | 4 | | |
| | SS5: Prepare site landscape and landforms for high wind conditions as well as to reduce the noise, pollution, energy consumption, temperature degree and relative humidity | 1 | | |
| | SE5: Use an appropriate shape and angle of the roof to optimize ventilation and thermal comfort, as well as, to resist storms | 3 | | |
| Result | RBD tool $=\sum \frac{RO+R+CA+ER}{280} * 100$ | RDB tool = $\sum \frac{40+28+23+33}{280} = -$*100 | | |
| | The result= 44% | RDB Rate = Marginally resilient | | |

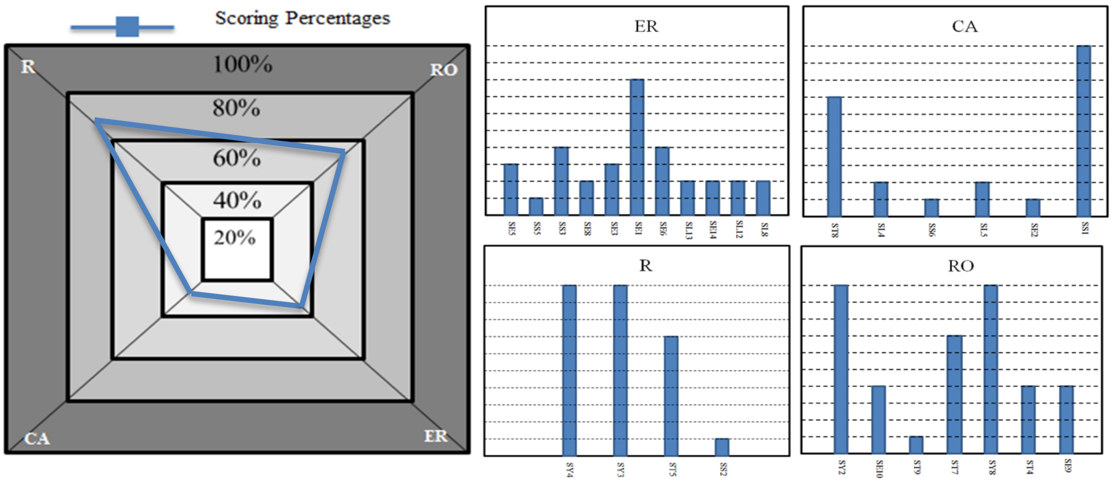


Table 12-7: Diagram for New Office for Unit Project.

**Robustness (RO):** The project used anchorage between superstructure and substructure to increase resistance to high winds. In addition, a permanent water-resistant barrier was built around the HVAC equipment and main electrical system to protect them from flooding. (These are strategies SY2 and SY8.) With regard to strategies SE9 (“Specify windows, doors, and openings to withstand wind loads and windblown debris”), ST4 (“Oversize roof covering fixings to reduce windblown debris”), and SE10 (“Oversize framing and bracing to increase redundancy”), the designer scored each of these has 4 out of 10 implement. In contrast, the designer scored ST9 (“Construct masonry chimneys with continuous reinforced steel bracing to increase the resistance”) only 1, which is therefore not implemented. However, the project received a good level in this category overall with a percentage of 57%.

**Redundancy (R):** In this category, the project achieved a 70% rating with more than half of the resilience being highly implemented. The highest implemeneted factors were SY4 (“Size drainage system to vulnerability to high level of rain”), SY3 (“Specify cogeneration and solar power to run during blackouts”) and ST5 (“Increase structure bracing to create strength redundancy to wind and snow loads”). In contrast, SS2 (“Direct runoff of water to a catch basin or holding area to reduce erosion”) was not implemented.

**Capacity for adaptation (CA):** The project used structural materials that are more resistant to pests to mitigate high temperature as well as permeable surfaces in landscaping against vulnerability to flooding (strategies SS7 and ST8). However the factors SE2 ("Provide expansion joints within the materials on vulnerability to expansion"), SL5 ("Use appropriate floor height to allow for future modification"), SS6 ("Use optimum building orientation to improve resilience to high/low temperature"), and SL4 ("Use appropriate floor height to enhance and optimize thermal and ventilation processes") had only a low implementation or were not implemented at all. Overall, the project achieved a resiliency rating of 58%.

**Environmental responsiveness (ER):** The project scored only 30% in this aspect. More than half of the factors were given a low implementation or were not implemented at all. These factors were: SL8 ("Use secure cross-ventilation for passive cooling and occupants' comfort"), SL12 ("Specify the layout of rooms, corridors, stairwells etc. in a way that upholds a low-resistance airflow path through the building (both in plan and section) to thermal comfort"), SE14 ("Use appropriate exterior shading to reduce vulnerability to overheating"), SL13 ("Specify thermal zones, by facing rooms of high energy demand on the south and putting rooms such as cellars, stairs, garages and laundry rooms on the north to act as buffer space"), SE3 ("Use a high solar reflectance to reflect sunlight and heat away from a building"), SE8 ("Use advanced wall and framing techniques to reduce energy loss"), SS5 ("Prepare site landscape and landforms for high wind conditions as well as to reduce the noise, pollution, energy consumption, temperature degree and relative humidity"), and SE5 ("Use an appropriate shape and angle of the roof to optimize ventilation and thermal comfort, as well as, to resist storms").

### 12.11.3New Office for Unit Project in Stoke on Trent

This project is in the process of being built. The designer, Stephen Glenwright (2014) said of it:

"*The project currently has no funds for energy saving equipment but the client is looking to add solar panels to the flat roof in the future. The windows are double glazed and the building is insulated to better than building regulations standards. The structure is steel frame with mainly brick cladding on secondary steel, concrete floors and roof. The metal cladding to the front elevation uses a high proportion of recycled copper. I was disappointed that mature trees in front of the building (south elevation), considered to be too large, have been cut down. They would have shaded the building in summer so reducing cooling costs, and allow the sun to heat up the building in winter when the leaves have fallen. Smaller trees will be planted on completion. I did not design the plans, and I don't think site orientation was given a high priority, other than positioning of the entrance facing the most public space. No flood issues or wind loading on site, but there are old coal mines under the building so the ground is poor and the foundations were piled*."

Figure 12-8: New Office for Unit Project (Glenwright, 2014).

Table 12-8: Present the designers' evaluations and the overall resilience scores of New Office for Unit in Stoke on Trent

| | | | | |
|---|---|---|---|---|
| Project Name: New Office for Unit in Stoke on Trent | | | | |
| Office Name | Denovo Design Ltd | | | |
| Architect Name | Stephen Glenright | | | |
| Project Location | Stoke on Trent | | | |
| Resilience categories | To what extent the following factors are implemented and considered in this design? | .S | T.P | D.P |
| **Robustness (RO)** | SE9: Specify windows, doors, and openings to withstand wind loads and windblown debris | 4 | 23 | 32% |
| | ST4: Oversize roof covering fixings to reduce windblown debris | 2 | | |
| | SY8: Build a permanent water-resistant barrier around HVAC equipment to protect from flooding. | 1 | | |
| | ST7: Provide anchorage between superstructure and substructure to increase resistance to high winds | 6 | | |
| | ST9: Construct masonry chimneys with continuous reinforced steel bracing to increase the resistance | 1 | | |
| | SE10: Oversize framing and bracing to increase redundancy | 4 | | |
| | SY2: Provide protection for the main electrical system from flooding | 5 | | |
| **Redundancy (R)** | SS2: Direct runoff of water to a catch basin or holding area to reduce erosion. | 1 | 17 | 42% |
| | ST5: Increase structure bracing to create strength redundancy to wind and snow loads. | 7 | | |
| | SY3: Specify cogeneration and solar power to run during blackouts. | 1 | | |
| | SY4: Size drainage system to vulnerability to high level of rain. | 8 | | |
| **Capacity for adaptation (CA)** | SS7: Use permeable surfaces in landscaping against vulnerability to flooding | 7 | 40 | 66% |
| | SE2: Provide expansion joints within the materials on vulnerability to expansion | 9 | | |
| | SL5: Use appropriate floor height to allow for future modification. | 8 | | |
| | SS6: Use optimum building orientation to improve resilience to high/low temperature. | 3 | | |
| | SL4: Use appropriate floor height to enhance and optimize thermal and ventilation processes. | 5 | | |
| | ST8: Use structure materials that are more resistant to pests to mitigate high temperature. | 7 | | |
| **Environmental responsiveness (ER)** | SL8: Use secure cross-ventilation for passive cooling and occupants' comfort. | 5 | 52 | 47% |
| | SL12: Specify the layout of rooms, corridors, stairwells etc. in a way that upholds a low-resistance airflow path through the building (both in plan and section) to thermal comfort | 5 | | |
| | SE14: Use appropriate exterior shading to reduce vulnerability to overheating | 2 | | |
| | SL13: Specify thermal zones, by facing rooms of high energy demand on the south and putting rooms such as cellars, stairs, garages and laundry rooms on the north to act as buffer space. | 4 | | |
| | SE6: Use energy-efficient windows and shading devices to reduce energy use | 4 | | |
| | SE1: Use appropriate insulation systems to reduce conduction through the thermal envelope. | 8 | | |
| | SE3: Use a high solar reflectance to reflect sunlight and heat away from a building | 8 | | |
| | SL13: Specify thermal zones, by facing rooms of high energy demand on the south and putting rooms such as cellars, stairs, garages and laundry rooms on the north to act as buffer space. | 4 | | |
| | SE8: Use advanced wall and framing techniques to reduce energy loss | 2 | | |
| | SS3: Plant mature trees to assist in dissipation of the wind force | 5 | | |
| | SS5: Prepare site landscape and landforms for high wind conditions as well as to reduce the noise, pollution, energy consumption, temperature degree and relative humidity | 2 | | |
| | SE5: Use an appropriate shape and angle of the roof to optimize ventilation and thermal comfort, as well as, to resist storms | 3 | | |
| Result | RBD tool $=\sum \frac{RO+R+CA+ER}{280} * 100$ | RDB tool $= \sum \frac{23+17+40+52}{280} = -*100$ | | |
| | The result = 47 % | RDB Rate = Marginally resilient | | |

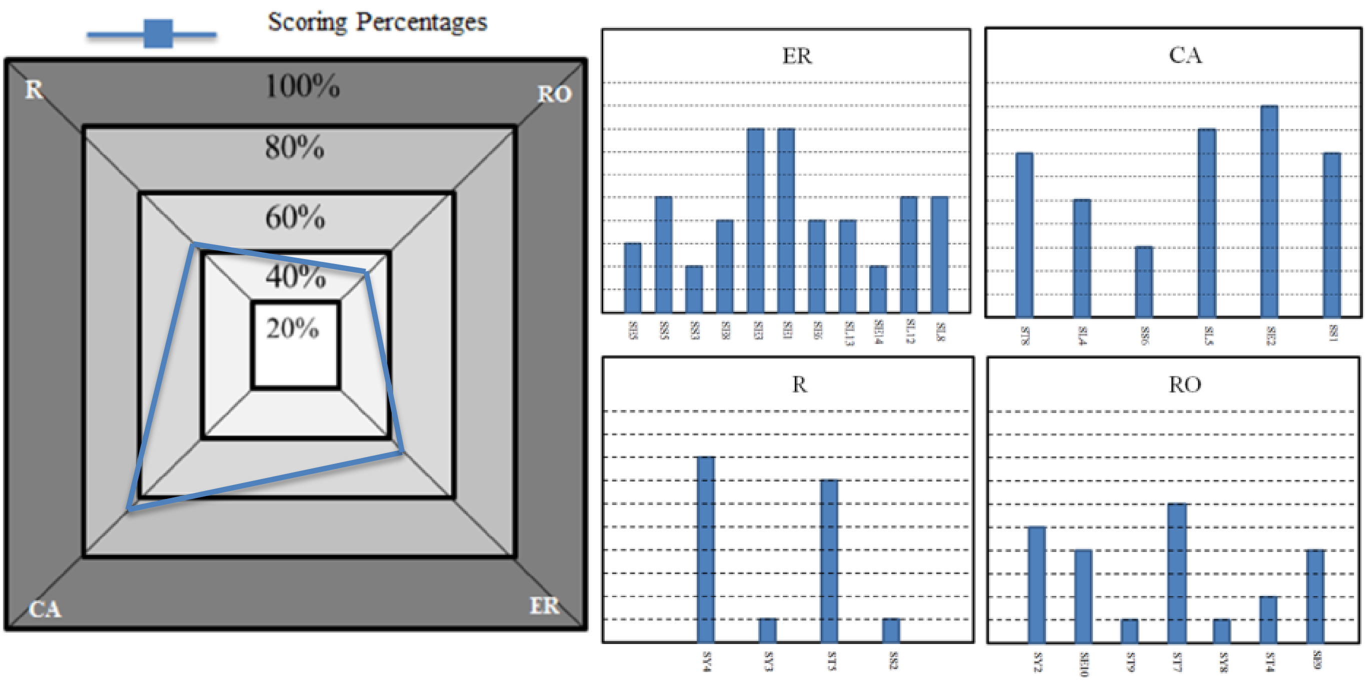


Figure 12-9: Diagram for New Office for Unit Project.

**Robustness (RO):** In this aspect, this project is implementing only 2 out of 7 strategies, which are: ST7 ("Provide anchorage between superstructure and substructure to increase resistance to high winds") and SY2 ("Provide protection for the main electrical system from flooding"). In contrast, 5 strategies have only a low level of implementation or none at all. These are: SE9 ("Specify windows, doors, and openings to withstand wind loads and windblown debris"), ST4 ("Oversize roof covering fixings to reduce windblown debris"), SY8 ("Build a permanent water-resistant barrier around HVAC equipment to protect from flooding"), ST9 ("Construct masonry chimneys with continuous reinforced steel bracing to increase the resistance") and SE10 ("Oversize framing and bracing to increase redundancy"). In this aspect the project received a resiliency percentage of 32%.

**Redundancy (R):** The project used structural bracing to create strength redundancy to wind and snow as well as a large size drainage system to decreases vulnerability to high levels of rain. In contrast, the rest of the factors are not considered significant in this project. These included SS2 (“Direct runoff of water to a catch basin or holding area to reduce erosion”), with a score of only 1 out of 10, and SY3 (“Specify cogeneration and solar power to run during blackouts”). The percentage score in this aspect was 42%.

**Capacity for adaptation (CA):** In this category, the percentage for the project was the highest of all, at 66%. The following factors, more that half of those in the category, were implemented: SS7 (“Use permeable surfaces in landscaping against vulnerability to flooding”), SE2 (“Provide expansion joints within the materials on vulnerability to expansion”), SL5 (“Use appropriate floor height to allow for future modification”) and ST8 (“Use structure materials that are more resistant to pests to mitigate high temperature”). In contrast, SS6 (“Use optimum building orientation to improve resilience to high/low temperature”) scored only 3 out of 10, and so was not implemented.

**Environmental responsiveness (ER):** The project implemented in 4 out of the 11 factors in the aspect. These factors are: SL8 (“Use secure cross-ventilation for passive cooling and occupants’ comfort”), SL12 (“Specify the layout of rooms, corridors, stairwells etc. in a way that upholds a low-resistance airflow path through the building (both in plan and section) to thermal comfort”), SE1 (“Use appropriate insulation systems to reduce conduction through the thermal envelope”), SE3 (“Use a high solar reflectance to reflect sunlight and heat away from a building”) and SS3 (“Plant mature trees to assist in dissipation of the wind force”). The rest of the factors in this aspect, however, received only low implementation or were not implement at all: SE14 (“Use appropriate exterior shading to reduce vulnerability to overheating”), SL13 (“Specify thermal zones, by facing rooms of high energy demand on the south and putting rooms such as cellars, stairs, garages and laundry rooms on the north to act as buffer space”), SE6 (“Use energy-efficient windows and shading devices to reduce energy use”), SE8 (“Use advanced wall and framing techniques to reduce energy loss”), SS5 (“Prepare site landscape and landforms for high wind conditions as well as to reduce the noise, pollution, energy consumption, temperature degree and relative humidity”), and SE5 (“Use an appropriate shape and angle of the roof to optimize ventilation and thermal comfort, as well as, to resist storms”). The overall percentage score of this aspect was 47%.

## 12.12 Implications and discussion

By applying the tools described above the researcher was able to assess the effectiveness of three different design resilience projects. This assessment employed two methods. The first made use of the scores given by the designers of the projects and then adapting the design quality indicators accordingly. The second took account of the separate weighting of each resilience factor. Applying these methods revealed the extent to which the designers had met resilience design needs in the various aspects of their building. In an ideal scenario, each SF would achieve a resilience score of 10 and the design would be maximally resilient.

The various projects achieved resiliency percentage scores by category as follows. Queens Court Project: RO 25%, R 35%, CA 36%, and ER 60%. New Office for Unit project in Portsmouth: RO 57%, R 70%, CA 38%, and ER 30%. New Office for Unit Project in Stoke: RO 32%, R 42%, CA 66%, and ER 47%.

## 12.13 Summary

The assessment tool was developed based on an adaptation of the design quality indicators and the rating systems of both LEED and BREEAM tools, and also through using a weighting on each SF. Then it was tested by applying it to three case studies. The final results were arrived at by using the scores for each resilience factor given by the designers of these projects as well as by the scoring of each SF based on data analysis. These examples illustrate the extent to which such a tool may be helpful to designers in assessing their designs and establishing whether or not they meet building resilience needs in the face of climate change. This tool can be extended and developed in future research.

# Chapter 13: Discussion

The main objective of this research was to determine the significance of various resilience factors (SFs) when confronted with events related to climate change and to establish a building designing resilience tool. The perceptions of architects and designers about the effectiveness of the SFs have been discussed in previous chapters. In this chapter, the significance of the findings of the whole research from the literature review section to the data analysis section will be examined. Summarised in what follows are the research findings in relation to the research questions, starting with the questions about the development model, then moving on to the findings and discussion, and ending with a recap of the development of an assessment tool based on the SFs identified earlier.

## 13.1 Climate change

Research question:

*What are suitable methods for capturing and integrating CCRs into SFs?*

The literature review (see Chapter 3) indicated that some architectural studies have been conducted on the resilience of buildings with regard to CCRs, for example that of Hertfordshire County Council (2013). Most of these, however, do not bridge the gap between CCR and design resilience strategy during the design process itself. Newman et al. (2013) consider ways to protect the purely physical aspects of buildings, but the purpose of the present research is wider, namely to develop strategies to meet CCRs from all different aspects of resilience design. Thus, what is new about the present study is that it provides architects with a way to incorporate into the design of a new building, specific methods of meeting the challenges posed by additional and more extreme events that are the result of climate change.

### 13.1.1 Climate change risk classification

Research question:

*What are the risks of climate change on buildings and how the buildings will be resilience?*

Although much interest has been shown over the past decade or so in CCRs to the built environment, the bulk of the research has tended to focus on social and economic aspects. The literature review of this topic indicated that there are a variety of ways of classifying CCRs, including both direct and indirect risks (McMichael, 2003). For the purposes of this research, CCRs are grouped into four classes: physical, social, economic and management. These risks are then introduced at the start of the resilience design process to help identify significant resilience strategies. Crucially, the present research presents one of the first practical schemes to help designers incorporate CCR, on a methodical basis, into their building plans from the outset. The model factors in the various categories of CCR, identified by earlier studies, in pointing out aspects of a building project that require attention with respect to adverse conditions arising from climate change.

## 13.2 Resilience characteristics classification

Research question:

- *How can these determinants be used to evaluate the resilience of designed buildings to emerging climate change risks?*

As described in Chapter 4, on the basis of reviewing the literature, the researcher selected four characteristics to describe and account for all the main aspects of resilience most relevant and significant to buildings in the context of climate change risks. These characteristics are: robustness, redundancy, capacity for adaptation, and environmental responsiveness.

## 13.3 Resilient design

Research question:

*What are resilient design strategies and how are they related to climate change risks?*

A central focus of this research is to map design resilient strategies to CCRs. As a result of the literature review it was decided to categorise the building aspects into site, layout, structure, envelope, system and operation, and resilience characteristics into robustness, redundancy, capacity for adaptation and environmental responsiveness, as described in Chapters 4 and 5. This classification helped the researcher organize the survey questionnaire in a simple, coherent and comprehensive way, as shown in Chapter 10.

As a result of the literature review, consultations with the supervisor of this research, and the researcher's own knowledge, it was possible to identify a comprehensive list of 85 resilient design strategies. These strategies were then organized into the six building aspects and resilience characteristics, an arrangement that formed the basis of the building design conceptual model. The model therefore represents a culmination of previous attempts to categorise CCRs and key building aspects, and then link these two in a way that makes identifying appropriate resilience strategies both clear and comprehensive.

## 13.4 Mapping SFs to CCR

Research question:

*What is the best way to map SFs to CCRs, and to show the most relevant connections between these?*

Once the resilience factors (SFs) and climate change risks (CCRs) had been identified, it was then possible to link each SF to one or more CCRs. The Gephi software package then used to graphically chart all of the SF–CCR interconnections in a series of network diagrams, one for each category of design resilience. The results are displayed in Chapter 6 and are believed to represent the most detailed and complex interconnectivity portrayed to date between climate change risks and resilience strategies.

## 13.5 Resilience building design conceptual model

Research question:

*What is a conceptual model that can help the designer to meet building needs during resilience design for CCRs?*

The 85 resilience strategies to be used against CCRs, identified as a result of the literature review, served as the starting point for a conceptual model – a process that the designer should follow to help design for building resilience in the face of climate change related events.

The proposed model is then formed from a merger of three components – the resilience strategies, the building design process and the resilience building design aspects. A questionnaire (see Appendix A) was used in the refinement of the model. The result was one of the most comprehensive models yet proposed for ensuring that building designs, at an early stage, incorporate all the necessary features to meet adverse future climate change-related events.

## 13.6 Data analysis discussion

Three stages were involved in the analysis: descriptive analysis, ranking the results and testing the hypotheses. For the statistical calculations SPSS and Excel software were used (see Chapter from 9 to 11). These methods were used to answer the questions in the following sections.

*What are the most effective SFs for building design resilience?*

The architect respondents’ views of the effectiveness of the SFs in building design resilience were analysed using SPSS to calculate the mean resilience value and other statistical measures to find out the most effective SFs (see Table 13-1). By this means, the researcher was able to ensure that the opinions and experiences of a wide sample of experts were incorporated into the selection of SFs.

Table 13-1: The highest ranked resilience factors (from Chapter 9).

| Code | Resilience building design factors (SF) | N | Mean | Std. deviation | Coefficient of variation | Severity index | General overall ranking | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | A | O |
| ES6 | Use energy-efficient windows and shading devices to reduce energy use | 77 | 4.43 | .834 | 18.83 | 88.57 | 1 | 1 |
| ES1 | Use appropriate insulation systems to reduce conduction through the thermal envelope | 77 | 4.40 | .765 | 17.39 | 88.05 | 2 | 2 |
| LS8 | Use secure cross-ventilation for passive cooling and occupants' comfort | 77 | 4.36 | .887 | 20.34 | 87.27 | 1 | 3 |
| LS5 | Use appropriate floor height to allow for future modification | 77 | 4.35 | .774 | 17.79 | 87.01 | 2 | 4 |
| SS5 | Prepare site landscape and landforms for high wind conditions as well as to reduce the noise, pollution, energy consumption, temperature degree and relative humidity | 77 | 4.34 | .837 | 19.29 | 86.75 | 1 | 5 |
| TS5 | Increase structure bracing to create strength redundancy to wind and snow loads | 77 | 4.32 | .834 | 19.31 | 86.49 | 1 | 6 |
| TS9 | Construct masonry chimneys with continuous reinforced steel bracing to increase the resistance | 77 | 4.29 | .792 | 18.46 | 85.71 | 2 | 7 |
| ES9 | Specify windows, doors, and openings to withstand wind loads and windblown debris | 77 | 4.26 | .750 | 17.61 | 85.19 | 3 | 8 |
| ES10 | Oversize framing and bracing to increase redundancy | 77 | 4.25 | .728 | 17.13 | 84.94 | 4 | 9 |
| TS8 | Use structure materials that are more resistant to pests to mitigate high temperature | 77 | 4.18 | .869 | 20.79 | 83.64 | 3 | 10 |
| ES14 | Use appropriate exterior shading to reduce vulnerability to overheating | 77 | 4.17 | .880 | 21.10 | 83.38 | 5 | 11 |
| YS8 | Build a permanent water-resistant barrier around HVAC equipment to protect from flooding | 77 | 4.14 | .838 | 20.24 | 82.86 | 1 | 12 |
| YS2 | Provide protection for the main electrical system from flooding | 77 | 4.10 | .836 | 20.39 | 82.08 | 2 | 13 |
| ES5 | Use an appropriate shape and angle of the roof to optimize ventilation and thermal comfort, as well as, to resist storms | 77 | 4.09 | .830 | 20.29 | 81.82 | 6 | 14 |
| SS3 | Plant mature trees to assist in dissipation of the wind force | 77 | 4.08 | .623 | 15.27 | 81.56 | 2 | 15 |
| TS7 | Provide anchorage between superstructure and substructure to increase resistance to high winds | 77 | 4.06 | .848 | 20.89 | 81.30 | 4 | 16 |
| ES8 | Use advanced wall and framing techniques to reduce energy loss | 77 | 4.06 | .848 | 20.89 | 81.30 | 7 | 17 |
| SS6 | Use optimum building orientation to improve resilience to high/low temperature | 77 | 4.05 | .826 | 20.40 | 81.04 | 3 | 18 |
| LS13 | Specify thermal zones, by facing rooms of high energy demand on the south and putting rooms such as cellars, stairs, garages and laundry rooms on the north to act as buffer space | 77 | 4.05 | .887 | 21.90 | 81.04 | 3 | 19 |
| ES3 | Use a high solar reflectance to reflect sunlight and heat away from a building | 77 | 4.04 | 1.032 | 25.54 | 80.78 | 8 | 20 |
| YS3 | Specify cogeneration and solar power to run during blackouts | 77 | 4.04 | .785 | 19.43 | 80.78 | 3 | 21 |
| ES2 | Provide expansion joints within the materials on vulnerability to expansion | 77 | 4.04 | .733 | 18.14 | 80.78 | 9 | 22 |
| LS4 | Use appropriate floor height to enhance and optimize thermal and ventilation processes | 77 | 4.03 | .794 | 19.70 | 80.52 | 4 | 23 |
| YS4 | Size drainage system to vulnerability to high level of rain | 77 | 4.01 | .851 | 21.22 | 80.26 | 4 | 24 |
| LS12 | Specify the layout of rooms, corridors, stairwells etc. in a way that upholds a low-resistance airflow path through the building (both in plan and section) to thermal comfort | 77 | 4.01 | .678 | 16.91 | 80.26 | 5 | 25 |
| SS7 | Use permeable surfaces in landscaping against vulnerability to flooding | 77 | 4.01 | .786 | 19.60 | 80.26 | 4 | 26 |
| TS4 | Oversize roof covering fixings to reduce windblown debris | 77 | 3.97 | .760 | 19.14 | 79.48 | 5 | 27 |
| SS2 | Direct runoff of water to a catch basin or holding area to reduce erosion | 77 | 3.96 | .880 | 22.22 | 79.22 | 5 | 28 |

## 13.7 Comparing the results

One of the questions on the questionnaire asked about the professional role of the architects and their experience: whether they were practising architects, academic and practicing architects, or academic architects, and whether their experience was 0-5 years, 5-10 years, or more than 10 years. This classification was used to see if there were any differences between the perceptions of respondents' with regard to SF ranking and to test the hypothesis that these rankings were affected by the respondents' roles or levels of experience. Differences were found and the results of the comparison were presented in Chapter 11. This is the first time, to the researcher's knowledge, that such a comparison has been made on a systematic basis – between the level of experience and role of an architect and their opinions about the relative value of building resilience strategies against CCRs. Further research is needed to determine if other factors are at work between such differences of perception, such as the specialties of the experts involved, their personal experiences in building design, and their location.

### 13.7.1 Ranking of site design resilience strategies

Table 13-2 shows the rankings of the resilience factors for the site design aspect for the various groups of respondents. Practicing and academic architects with more than 10 years of experience disagreed with the others (i.e., who have less than years of experience) about the rankings of five SFs – SS2, SS3, SS5, SS6 and SS7 – by giving these SFs a lower mean value. Their views are also in contradiction with the findings from the findings from the literature review. For example, Newman et al. (2013) stressed the importance of SS2, SS3, and SS5, the US Dept. of Energy (2001) indicated the importance of SS6, and Herefordshire County Council (2013) highlighted the importance of SS7.

Only SS1, was differently ranked by academic architects, and this was also in contradiction to Newman et al. (2013) who indicated its importance. Architects with 5-10 years' experience, viewed SS4 as not important. This is again contradict the findings from Newman et al. (2013). Possibly these differences can be attributed to type of level of design experiences by the respondents. One expects that academic architects are more aware about the design resilience strategies than practicing architects.

Table 13-2: The highlighted resilience strategy rankings for site design resilience.

| Code | academic & practicing | academic | practicing | 0-5 | 5-10 | More than 10 |
|---|---|---|---|---|---|---|
| | Overall ranking | | | | | |
| SS1 | | X | | | | |
| SS2 | X | | | | | X |
| SS3 | X | X | X | X | X | X |
| SS4 | X | | | X | | |
| SS5 | X | X | X | | X | X |
| SS6 | X | X | | | X | X |
| SS7 | X | X | | | | X |

### 13.7.2 Ranking of layout design resilience strategies

As illustrated in Table 13-3, for practicing, academic, academic and practicing architects, and those with 5-10 and more than 10 years' experience, three SFs were ranked differently, in terms of mean resilience values, than by the other two groups. These were: LS5, LS8 and LS12. This is in opposition to the findings of Saari and Heikkila (2008) on the importance of LS5 Newman et al. (2013) regarding LS8, and Liu and Nazaroff (2001) regarding LS12. Also, two SFs, LS9 and LS11, were ranked differently in terms of their mean value, by academic architects and architects with more than 10 years' experience than the other groups. However, all the groups were in agreement and confirmed the importance of LS2, LS10 and LS14, which indicate their alignment with the conclusions of, for example, Moharram (1980) on the LS2 factor, Slaughter (2001) on LS10, and Lomas and Ji (2009) on LS14.

Table 13-3: The highlighted resilience strategy rankings for layout design resilience.

| Code | academic & practicing | academic | practicing | 0-5 | 5-10 | More than 10 |
|---|---|---|---|---|---|---|
| | Overall ranking | | | | | |
| LS1 | | | | | X | |
| LS2 | | | | | | |
| LS4 | X | X | | | X | |
| LS5 | X | X | X | | X | X |
| LS8 | X | X | X | X | X | X |
| LS9 | | X | | | | X |
| LS10 | | | | | | |
| LS11 | | X | | | | X |
| LS12 | X | X | X | | X | X |
| LS13 | X | X | | | | X |
| LS14 | | | | | | |

### 13.7.3 Ranking of structure design resilience strategies

Based on the ranking of the SFs of this aspect, as shown in Table 13-4, for academic and practicing, academic architects and architects with more than 10 years' experience two SFs, TS4 and TS7, disagreed with the rankings given by the other four groups.

Four SFs, TS1, TS2, TS11 and TS12, showed no difference in ranking between the various groups. Academic architects ranked only one SF, TS6, differently. This was identified as a significant resilience factor by Newman et al. (2013). Again, the discrepancies in rankings between the categories of respondents could reflect on how the architects' experience and professional role influences judgement about this resilience factor.

Table 13-4: The highlighted resilience strategy rankings for structure design resilience.

| Code | academic & practicing | academic | practicing | 0-5 | 5-10 | More than 10 |
|---|---|---|---|---|---|---|
| | Overall ranking | | | | | |
| TS1 | | | | | | |
| TS2 | | X | | | | X |
| TS3 | | | | | | |
| TS4 | X | X | | | | X |
| TS5 | X | X | X | X | X | X |
| TS6 | | X | | | | |
| TS7 | X | X | | | | |
| TS8 | X | X | X | X | X | X |
| TS9 | X | X | X | X | X | X |
| TS11 | | | | | | |
| TS12 | | | | | | |

### 13.7.4 Ranking of envelope design resilience strategies

In Table 13-5 is presented the rankings of the resilience factors of this aspect of building design. In the case of academic architects and architects with more than 10 years’ experience, two SFs, ES16 and ES30, were ranked differently from the other four groups. This is in contradiction to the results of the literature review, which found that, for example, Ahsan (2009) and Lomas and Ji (2009) argue strongly in favour of these factors. ES4 was ranked differently by architects with between 5-10 years' experience, and ES3, ES5, ES8, ES10 and ES14 by academic and practicing and academic architects who have between 5-10 and more than 10 years' experience. For academic architects, one SF, ES13, was ranked differently from the other groups in terms of mean value, yet Akashi et al. (2006) indicated the strength of this factor. All the group rejected ES1 and ES6 as effective factors in terms of mean value rankings, which is in contradiction to the findings of, for example, Feist et al. (2005) and Bateson and Hoare Lea (2011). On the other hand, all the groups were in agreement over the effectiveness of 14 SFs (ES7, ES12, ES15, ES17, ES20, ES21, ES22, ES23, ES24, ES25, ES26, ES27, ES28 and ES31).

Table 13-5: The highlighted resilience strategic ranking in envelope design resilience.

| Code | academic & practicing | academic | practicing | 0-5 | 5-10 | More than 10 |
|---|---|---|---|---|---|---|
| | Overall ranking | | | | | |
| ES1 | X | X | X | X | X | X |
| ES2 | X | X | X | | | X |
| ES3 | X | X | | | X | X |
| ES4 | X | X | | | | X |
| ES5 | X | X | | | X | X |
| ES6 | X | X | X | X | X | X |
| ES7 | | | | | | |
| ES8 | X | X | | | X | X |
| ES9 | X | X | X | | X | X |
| ES10 | X | X | | | X | X |
| ES12 | | | | | | |
| ES13 | | X | | | | |
| ES14 | X | X | | | X | X |
| ES15 | | | | | | |
| ES16 | | X | | | | X |
| ES17 | | | | | | |
| ES18 | | X | | | X | |
| ES19 | X | X | | | | |
| ES20 | | | | | | |
| ES21 | | | | | | |
| ES22 | | | | | | |
| ES23 | | | | | | |
| ES24 | | | | | | |
| ES25 | | | | | | |
| ES27 | | | | | | |
| ES28 | | | | | | |
| ES29 | | | | | X | |
| ES30 | | X | | | | X |
| ES31 | | | | | | |
| ES32 | | X | | | X | X |

### 13.7.5 Ranking of system design resilience strategies

Table 13-6 illustrates the ranking of the SFs of this aspect. For academic and practicing, academic architects and architects with between 5-10 and more than 10 years, experience, three SFs, YS2, YS3 and YS8 were ranked differently. YS9 and YS10 received different rankings from the academic and practicing architects in disagreement with the findings of the literature review, specifically the conclusions of Newman et al. (2013) with regard to YS9 and Kane (2009) in respect of YS10. Three SFs,YS5, YS11 and YS 12 were ranked as effective by all the groups of respondents, in agreement with the findings of the literature review, notably the conclusions of Ross, Saunders and Novakovic (2007) and Newman et al. (2013).

Table 13-6: The highlighted resilience strategy ranking for system design resilience.

| Code | academic & practicing | academic | practicing | 0-5 | 5-10 | More than 10 |
|---|---|---|---|---|---|---|
| | Overall ranking | | | | | |
| YS2 | X | X | | | X | X |
| YS3 | X | X | | | X | X |
| YS4 | X | X | | X | | X |
| YS5 | | | | | | |
| YS6 | X | | | | X | |
| YS7 | X | X | | | | X |
| YS8 | X | X | | | X | X |
| YS9 | X | | | | | |
| YS10 | X | | | | | |
| YS11 | | | | | | |
| YS12 | | | | | | |
| YS14 | X | | | | X | X |

## 13.8 Testing the hypotheses

In Chapter 11, a one-way analysis of variance was used to test the hypotheses for each aspect based on the professional role and experience of the architects involved. The present study provides the first evidence, so far as is known, of discrepancies between the perceptions and opinions of architects on the basis of these factors. The results are shown in the following table:

Table 13-7: The rejected resilience strategies.

| aspects | Analysis based on professional role | Analysis based on years' experience |
|---|---|---|
| SDS | -- | -- |
| SDL | SL9 | SL4 |
| SDT | ST6 | -- |
| SDE | SE7, SE10, SE12, SE13, SE24, SE25, | -- |
| SDY | SY3, SY6, SY10 | SY1 |
| SDO | SO2 | -- |

Table 13-7 indicates that 14 SFs have been rejected. In terms of professional role, only 12 SFs out of the 85 SFs were rejected. In addition to that, only two SFs out of 85 SFs were rejected based on the architects' experience. This result is unexpected because all of these SFs were selected based on a literature review, as shown in Chapter 5. It is possible that the discrepancies involving the rejected SFs are connected with the length of experience of this group of architects or one their specific past experiences in building design. The experience and awareness could play a clear role in decreasing the rejected SFs. The justifications for the rejected factor are listed in Tables 13-8 and 13-9:

Table 13-8: Research Question, the rejected hypothesis based on professional role: A2, A3, A4, A5 and A6 Result.

| | |
|---|---|
| Research Question | Does a significant difference exist between the opinions of the architects involved in the survey, based on their professional capacity, regarding the level of effectiveness of the SFs? |
| Hypotheses | $A_2$(P> 0.05): There is no statistically significant difference between the respondents' perceptions on the effectiveness of resilience factors, of "resilience building design layout" based on their professional capacity.<br>$A_3$ (P > 0.05): There is no statistically significant difference between the respondents' perceptions on the effectiveness of resilience factors, of "resilience building design structure" based on their professional capacity.<br>$A_4$(P > 0.05): There is no statistically significant difference between the respondents' perceptions on the effectiveness of resilience factors, of "resilience building design envelope" based on their professional capacity.<br>$A_5$ (P > 0.05): There is no statistically significant difference between the respondents' perceptions on the effectiveness of resilience factors, of "resilience building design system" based on their professional capacity.<br>$A_6$(p > 0.05): There is no statistically significant difference between the respondents' perceptions on the effectiveness of resilience factors, of "resilience building design operation" based on their professional capacity. |
| Result | As a consequence of the ANOVA analysis, significant differences were found between the perceptions of architects, based on their professional capacity, as to the importance of the following SFs: SL9, ST6, SE7, SE10, SE12, SE13, SE24, SE25, SY3, SY6, SY10 and SO2. |
| Research perceptions | The 12 SFs were selected based on a literature review, as follows:<br>SL9: Oversize space to reduce occupants' stress.<br>ST6: Oversize walls and roofs to create strength redundancy for wind and snow loads.<br>SE7: Specify window film to prevent injuries from shattered glass.<br>SE10: Oversize framing and bracing to increase redundancy.<br>SE12: Use green roofs to reduce the heat island effect in urban settings.<br>SE13: Use green roofs to minimize runoff rainwater.<br>SE24: Avoid the use of long roof eaves due to vulnerability to storms.<br>SE25: Use double façades for natural ventilation as an outlet or inlet path.<br>SY3: Specify cogeneration and solar power to run during blackouts.<br>SY6: Specify water-efficient fittings and devices to ensure the continuity of operation of the building.<br>SY10: Use multiple lighting resources to avoid electricity shutdown.<br>SO2: Secure interior furnishings and equipment to ensure continuity of operation.<br>In conclusion:<br>• On the basis of discrepancies between architects' perceptions based on their professional roles, two of the original 85 SFs, SY10 and SO2, are rejected.<br>• The rejected factors are related to four types of aspects, which are not covered in the other type of aspect. |
| Conclusion | The following null hypotheses, A2, A3, A4, A5 and A6 |

Table 13-9: Research question, the rejected hypothesis based on experience: $A_2$, and $A_5$ result.

| | |
|---|---|
| Research Question | Does a significant difference exist between the opinions of the architects involved in the survey, based on their level of experience, regarding the level of effectiveness of the SFs? |
| Hypotheses | A2 (P > 0.05): There is a statistically significant difference between the respondents' perceptions on the effectiveness of resilience factors, of "resilience building design layout" based on their level of experience.<br>A5 (p > 0.05): There is a statistically significant difference between the respondents' perceptions on the effectiveness of resilience factors, of "resilience building design system" based on their level of experience. |
| Result | As a consequence of the ANOVA analysis, significant differences were found between the perceptions of architects, based on their level of experience, as to the importance of the following SFs: SL4 and SY1. |
| Research Perceptions | The two SFs were selected based on a literature review, as follows:<br>SL4: Use appropriate floor height to enhance and optimise thermal and ventilation processes.<br>SY1: Ensure the provision of HVAC systems redundancy or overcapacity to cope with unexpected load.<br>In conclusion:<br>• On the basis of discrepancies between architects' perceptions based on experience, two of the original 85 SFs, SL4 and SY1, are rejected.<br>• These factors are from two different building aspects; no factors from the other four types of aspect are rejected on this basis.<br>• The different years of experience of the architects could affect rejection of these SFs because the perception of the architects who have between 0-5 years' experience might be different than architects who have more than 10 years' experience or between 5-10 years' experience. |
| Conclusion | The following null hypotheses, A2, A5. |

## 13.9 Resilience Building Design Assessment Tool

The tool is mathematically underpinned by a formula for the design resilience rating, as described in Chapter 11. The resilience strategies against climate change risks were first identified by a literature review and then refined as a result of the responses to the proposed strategies by a large sample of professional architects. Finally, it was simplified in order to make it easy to use and handle. The assessment tool, represents a new contribution to the applications available to the architect is weighing the resilience of a building project to future possible climate change-related events. It is intended to compliment the model in that it extends the capability to assess to resilience to CCRs to existing buildings, revealing any potential weaknesses in the design where SFs are concerned.

Research question:

*What is the most appropriate tool for evaluate building resilience?*

The majority of existing design tools that incorporate the climate change risks or resilience are too general to be used in the design of buildings. The model presented here is constructed to address specifically the key aspects of buildings (site, layout, structure, envelope, system and operation) and the most pertinent resilience characteristics (robustness, redundancy, capacity for adaptation and environmental responsiveness). Application of the Building Design Resilience tool is intended to enhance building resilience to meet design resilient buildings to CCR and identify any weaknesses or omissions in the design before submission. In addition, Design Resilience tool will affect the building resilience as follows:

- Through use of the Resilience Building Design model and tool, architects are guided through the process of matching design resilience strategies of buildings to climate change risks.
- The model and tool enable building resilience to be accomplished alongside meeting CCR requirements.

- The potential to maximize the design resilience of buildings can be achieved while at the same time limiting the number of complaints arising before the design is finished.
- Matching the design resilience of buildings to CCRs is effected through consideration of building resilience with the following aspects and characteristics: site, layout, structure, envelope, system, and operation; and robustness, redundancy, capacity for adaptation, and environmental responsiveness.
- Following the process of building design resilience can help the designer to ensure achieves the level of design resilient buildings to CCR for various aspects.

To test the tool, the designers of three projects – Queens Court, New Office for Unit Project in Portsmouth and New Office for Unit in Portsmouth – were asked to fill in the Building Design Resilience form, which included the 28 SFs identified during the review, analysis and survey phases of the research (Appendix A). The designers were asked to score each SF in the light of whether they had considered it or implemented it in the design of their project. The results, including the SF scores, were then examined discover the resilience of the project and where any gaps might exist in the designs.

## 13.10 The Issues That the Researcher Learned

In this research, a variety of different design methods have been examined in order solve the problem of integrating resilience strategies with climate change risks. From the systematic review it emerged that although the integration of building needs with CCR was cited in many references, it was only sporadically discussed and never systematically addressed. From the outset this posed a challenge in terms of reconciling between the variety of terminologies in use and the development of innovative building resilience concepts that are more appropriate to current building design practices. The author tackled the problem through an iterative process of cross-referencing between current building designs practices and integrating building resilience strategies into the design process. The author cannot foresee any other ways of carrying out this task.

The second challenge posed by this research was how to progress from the initial results of the literature review to the development of a conceptual model. The author tackled this by learning from the methods that had already been devised for the construction of analogous models.

The third challenge was to find and gain access to a credible sample of designers who have had experience in design resilience. Initially, the author used block emails to invite designers to complete the questionnaire but this method proved ineffective. An alternative strategy was the adopted in which individual invitations were sent out to solicit participation in the survey together a small incentive in the form of a £10 Amazon voucher. The methodology applied in the analysis of data from the survey is generic for this type of work. The most significant problem to be addressed was how to reduce the number of SFs without losing the captured information.

## 13.11 Implications

The resilience building design conceptual model was developed to manage both design resilient buildings to CCR and design resilience. It bridges the gap between design resilient buildings to CCR and design resilience, and could be used not only in architectural design practice but also in research and education.

Use of the assessment tool should enable architects to better equip their designs for resilience against climate change risks across a wide range of building types. The tool is also readily adaptable and expandable, enabling, for example, new resilience factors to be integrated into its model. A particular strength of the tool as that brings resilience to CCR into the heart of new designs and may thus serve encourage the evolution of designs that give prominence to minimising the vulnerability of buildings to events related to climate change. The incorporation of all relevant aspects of design resilience at an early stage of the design also has cost advantages, cutting back the need for expensive maintenance and modifications during the life-cycle of the building.

The assessment tool also has educational merits in that it could be used in the training of designers to highlight the importance of adopting a proactive approach to design resilience. It might encourage the student to examine a design from a variety of perspectives in order to accommodate a variety of situations, most notably changing environmental conditions over time.

In terms of research, it is hoped that the present study will serve as a starting point for further wider investigations of design resilience in relation to CCRs. There is still a paucity of academic studies on the effects of climate change on buildings, and a need to investigate the design resilience of different building types. Development of the resilience strategies proposed here as well as the evolution of new ones is a goal for the future.

## 13.12 Summary

The significance of the findings of the study, from literature review to data analysis and hypothesis testing have been reviewed, the rankings of the resilience factors reviews, and the main research findings examined. A recap is provided of the design resilience tool and some suggestions for how it might be used and developed in the future.

# Chapter 14: Conclusions and Further Research

In recent years, there has been a growing amount of interest shown in building assessment and resilience evaluation; however, most of the studies in this field consider only general aspects of resilience without attention to factors specific to climate change risks. Some of the assessment tools, such as that developed by AECOM, focus on resilience of transport and other non-building systems; others, such as the HCA tool, are applicable only to certain types of buildings.

This study presents a new building design resilience tool that is focussed on CCRs. At its core are a number of carefully selected resilience factors, arranged into different groups. A summary, discussion of contributions and limitations, and recommendations for future study follow.

## 14.1 Summary

A key challenge of this research was to match CCR factors to appropriate resilience strategies (SFs) so that these SFs can be incorporated into the overall design process from the outset. It is often the case that designing for resilience against climate change is not a central part of the design of new buildings, and, when it is taken into consideration by an architect it is based on personal experience. The Building Resilience Design model developed here brings the SFs against CCRs into prominence and provides a powerful tool for the designer to instantiate resilience into the building design at an early stage.

An important and early objective of this study was to find a way to match key resilient building features to CCRs before moving on to develop an assessment tool that can help the designer to assess design resilience. This model can be thought of as an attempt to develop a tool that bridges the gap between resilience design and CCRs through the various aspects of a building – site, layout, structure, envelope, system and operation. Design resilience strategies and existing assessment tools were used by the researcher to construct the model and make it more practical. The scores of the SFs could be put into the formula for design resilience to obtain an overall design resilience percentage that reflects how well the building is conceived to meet the demands of CCRs.

## 14.2 Contribution

This research has made several contributions Such as; (CCR, SFs, Mapping, model and assessment tool). The CCR is to identify the key of climate change on buildings. Following that, The SFs is to identify the key resilient strategies of the buildings in the light of climate change. Mapping is the connections between resilience strategies (SFs) and climate change risks (CCRs).then, is to develop a conceptual model that can help designers or architects to assess the resilience of their designs to meet CCRs. Finally, assessment tool is to help the designer to evaluate building resilience design. The details for these contributions will be explained in the following sections.

### 14.2.1 Climate change risks

Five categories of climate change risks (CCRs) were identified for inclusion in the building resilience design model because of their potential direct impact on buildings. These are: temperature extremes, precipitation, windstorms, sea-level rise, and floods. In turn these CCRs were grouped into four classes, representing the different aspects of a building that would by impacted by CCRs: physical (PR1–PR22), economic (ER1–ER13), social (SR1–SR17), and management (MR1–MR13).

### 14.2.2 Design resilience strategies

This research stems from a literature review of six design aspects for which a total of 85 SFs were identified. These SFs were then scrutinised and refined through several stages of data analysis in order to select the final set SFs, 28 of them, to be included in the building design resilience assessment tool. The contribution of this assessment tool is discussed below.

### 14.2.3 Mapping

The selected resilience factors were mapped to the relevant climate change risks and a serious of network diagrams generated by the Gephi software page. These diagrams showed not only all the nodes within any given building resilience category but also all the interconnections between the SF and CCR nodes and the relative importance of the nodes in terms of their interconnectivity.

### 14.2.4 Building Design Resilience model

The conceptual model of the research is made up of four main components: CCRs, the dimensions of the design resilience strategies, the design process and the design resilience aspects. The SFs were dispersed into groups, making the framework more coherent and the questionnaire easier to design. Additionally, the design issues were considered in terms of process and building needs to CCR in relation to various aspects.

### 14.2.5 Building Design Resilience assessment tool contribution

The building design resilience tool is based on EVOLVE and other existing assessment tools. However, it is also unique in its content and field of application:

- It incorporates a set of SFs that were selected through critical literature review, then reviewed and refined in the light of expert feedback (see Chapter 10).
- It can help the architect more accurately design buildings for resilience to CCR.
- It is easy to use.
- It can be updated through adding or removing SFs.

### 14.2.6 Other contributions

Other contributions of this research, besides developing a resilience assessment tool, include identifying and categorizing different building resilience design aspects and climate change risks, as well as follows:

- Different definition based on the researcher perceptions, as follows: building design resilience. Design resilience aspects, SS, SL, ST, SE, SY, SO, CCR, PR, SR, EOR and MR.
- Extraction of SFs based on the critical literature review (see Chapters 5).
- Ranked SFs in design resilience (85 SFs see Chapter 10 rankings).

## 14.3 Limitations

1. Even though this conceptual model (as shown in Figure 7-15) included initially 85 SFs, it may be that other factors will arise or become more significant as climate change risks become more extreme.
2. This model was developed to be suitable for all building types. However, a model could be created specifically for each building type such as schools, office buildings, etc.
3. The sample used for the questionnaire involved respondents with a wide range of experience and professional roles. However, had the group been more specific group in experience level, area of expertise or nationality, different evaluations of the resilience factors may have been obtained.
4. A larger sample size could have been used.
5. Had the resilience strategies been clustered differently, the outcome of the survey and the eventual selection of SFs for the model may have been different.

The clustering of the resilience strategies affords clarity to the designer and helps avoid repetition of effort in the design process. Some of the strategies cannot be used together because they are mutually exclusive (for example, green roofs and solar panels). The researcher extracted the strategies to afford scope to the designer in assessing different solutions then selecting the one most suitable. However, there are many different ways to do the clustering and to choose the four dimensions of design resilience. Others might construct models based on different strategies that could be worked together without any conflict, leading to a reduction in the number of SFs.

## 14.4 Recommendation and suggestions for further research

This research is focused specifically on the SFs that could help the designer to improve the resilience of different aspects of building to the effects of climate change. Further research could investigate more SFs that might help to improve the resilience of the buildings in other ways.

## 14.5 Further research on the model:

- Evaluate strengths and weaknesses of the model in more detail by using a wide range of actual designs or case studies.
- Construct assessment models that are tailored to specific types of buildings, such as domestic residential, hospitals, schools, and commercial (Jones, 2011).
- Tailor the model so that it applies more specifically to certain types of location or climate.
- Acquire more data and conduct more studies to develop more thoroughly each aspect of the model develop.
- A database will be constructed based on the results of this study that will contain all the resilience factor profiles, which, in turn, will be integrated with BIM processes. The resilience design information, together with the BIM data, will then be available to designers in order to develop conceptual design solutions. In addition, in the proposed building design resilience model, there is the possibility of design aspects being used as a benchmark for gauging the design solutions' compliance with building requirements to climate change risks.

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# Appendix A; Questionnaire

3/11/2014 Alfraidi, Yahya - Outlook Web App

Hi Yahya,

Thank you for getting in touch and I'm glad to hear the paper you reference might be useful to your research.

From your questionnaire, it is clear that you are focussing on the building itself, and perhaps what can be done within the building envelope and structure to make that structure more resilient. While looking at this scale is important, the work I have been engaged in on building resilient cities suggests that you need to think beyond the building or specific piece of infrastructure, and take a urban systems view on how that piece of infrastructure contributes to a more effective delivery of a particular outcome or system performance. For example, its not much use if the building remains standing in a flood but no one is able to access it (i.e. a hospital) and it cant receive the food, energy, supplies etc it needs to function – in this case the health system fails to deliver the outcome of meeting the health needs of residents during and potentially after a shock.

I have attached two further peer reviewed papers and a shorter thought piece which go into this approach in more detail, and I recommend that you broaden your own research to consider what role the buildings you are focused on in the built environment, and the broader issues that need to be considered beyond the building envelope or structure (even if these are, as usual, beyond the control or influence of the land owner or developer).

Thank you and good luck

Sam

Adrian Neville <Adrian@1st-architects.com>
Sent: Tue 20/05/2014 14:18
To: 'Alfraidi, Yahya'

I have just had a very quick look, but the survey appears to assume acceptance of a certain proposition in relation to resilience and climate change. I suspect may architects would have questions about that proposition so I think the survey may be misplaced or only attract responses from those who take the same view. If you are having difficulty getting responses this may be one of the reasons. Hope this feedback helps.
Adrian

1st architects
10 Post Office Lane, North Queensferry, Fife, KY11 1JP
t: 01383 417509 www.1st-architects.com

## validate questionnaire

**Martin Roders - OTB [M.J.Roders@tudelft.nl]**

Actions

*In response to the message from Martin Roders - OTB, Mon 22:46*

To:
Alfraidi, Yahya [Y.Alfraidi@liverpool.ac.uk]
Cc:
Ad Straub - OTB [A.Straub@tudelft.nl]

12 March 2014 12:24

Dear Yahya,

I think you are aiming for a very interesting and specific topic, concrete technical measures to make buildings climate resilient.

I have looked at your questions and have some remarks, which I hope can help you improving your questionnaire and targeted outcomes.

In general, I think it is quite a large survey. Are you planning to ask all the questions at once, or in different surveys? Will it be in an online survey or interviews? Maybe you could consider focusing on one theme (heat/water) because of the number of measures that can be developed for each theme.

Have you considered creating answer categories, or otherwise, how do you define "effective"?

I also found some questions that do not specifically refer to climate change adaptation, but more to future adaptability in general:

Site design:

@5. Try to be more specific regarding the impact you are really aiming for

@6. Try to be more specific, it is obvious that an 'optimum orientation' is effective, but optimal to what?

Building layout:

@5. Is beneficial in general

@6. More resilience to what? What are the implications if you aim for resilience to more heat, likewise, what are the implications if you aim for resilience to increasing precipitation or flooding? Are the design solutions the same, or are they different for each impact?

@9. Stress because of what?

Etc..

There are also some good examples in your list, to name a few:

Site design nr. 2 and 3 specifically state what the measure should prevent.

Presuming that you will be writing your results in a journal paper, try to think what you really want to focus on, which topic, which type of measures.

For the discussion of the article I recommend you to pay attention to the topic of Mainstreaming (Klein et al. 2005) because climate change adaptation as a stand-alone topic is still underdeveloped and the implementation of measures is confronted with a lot of barriers.

Recommended reading: Jones et al 2013; Hertin et al 2003.

I hope I have helped you with these comments, good luck with the writing and if you need more information or validation activities I will be happy to help you.

Kind regards,

Martin Roders

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**M.J. (Martin) Roders MSc**
PhD researcher

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Jonas Joerin [jonas.joerin@gmail.com]

Actions

*In response to the message from Alfraidi, Yahya, Mon 13:24*

**To:**
Alfraidi, Yahya [Y.Alfraidi@liverpool.ac.uk]
**Attachments:**

Yahya alfraidi_Jonas.pdf (1 MB)[Open as Web Page]

11 March 2014 14:29

Dear Yahya,

thank you for your interest on my work and opinion. Your work seems interesting and relevant to today's problems related to climate change. I have checked your file and provided some comments inside.

In general two points:
1. I am not very clear in which context you are using those strategies. Is it a survey which you plan to develop? Also, clarify the context in terms of location. Measures/strategies are not all adequate/relevant for all buildings/houses. Are these strategies reflecting the context of Liverpool?
2. Reflect again the terminology of vulnerability, resilience, etc. It seems to me that you like to use both of them in your work. I would, however, recommend you to focus on either one of them. Resilience and vulnerability studies do have many elements in common, but are not the same. For example, reducing the vulnerability does not always mean that you increase resilience and vice versa. Thus, focus only on one aspect. This will give you greater confidence when explaining your work to others.

Kind regards,
Jonas

**Ethics Reviewers Checklist Application 2.afraldi.doc.docx**

Tyrrell, Belinda

Sent: Wed 14/05/2014 11:04

To: Alfraidi, Yahya; Boussabaine, Halim

Message | Ethics Reviewers Checklist Application 2.afraldi.doc.docx (49 KB)

Dear both,

The Research Ethics review panel for SOTA has reviewed your application for ethical approval. The panel found no ethical issues but have made some suggestions (see attached checklist) of areas which you may want to review.

Best wishes with your research

Belinda

**Belinda Tyrrell**
**Team Leader**
**Finance and Research Team**
**School of the Arts**
**University of Liverpool**
**19 - 23 Abercromby Square**
**Liverpool**
**L69 7WW**

**Telephone Number 0151 795 3133**
**Email belinda.tyrrell@liverpool.ac.uk**

University of Liverpool

# Questionnaire

School of Architecture

by

Yahya Alfraidi

Under supervisor

Dr H Boussabaine

Participants consent

Do you wish to participate in this study?*

By clicking YES you acknowledge that you have given consent to participate in this study. I understand that my participation is voluntary and that I can discontinue the completion of the questionnaire at any time by clicking CANCEL . This is an anonymous survey, it is not possible to withdraw your answers once you have clicked on DONE button

( ) yes ( ) no

Introduction

Several governmental reports and research publications have demonstrated that it is very likely that changes in climate will increase the risk to housing stock of shocks/disturbances, which will have an impact on the health and safety of occupants, especially of vulnerable groups. Designing resilient housing stock will reduce the vulnerability of buildings and their occupants to disturbances and will maximise their chance of recovery from extreme climate change events and disturbances. Resilience of housing stock to withstand climate change shocks is therefore vital.

Understanding how and when resilience-related information is formed is key to optimal timing, and to incorporating solutions into housing design processes that improve all aspects of the building's resilience. The aim of this research is to develop a set of design resilience measures to allow buildings to respond to changing climate conditions and threats over time.

Your input can help us to extract acceptable solutions on how best to design resilient housing.

We estimate that it will take you approximately 10-15 minutes to complete the survey. All respondents who complete the full questionnaire will receive a £10 Amazon gift voucher.

All individual responses will remain confidential, and study data will be amalgamated and analysed as a whole. Results will be reported in summary form to protect confidentiality. If you have any questions or concerns about the questionnaire or about participating in this research, you may contact me on 07588 550060 (alfraidi@liv.ac.uk). Alternatively, you may communicate with my supervisor, Dr Boussabaine on 01517942619 (halim@liv.ac.uk).

Please also feel free to forward the URL of the web survey to relevant built-environment stakeholders.

Simply click on the link below, or cut and paste the entire URL into your browser to access the survey:
http://survey.liv.ac.uk/building-resilience

We would appreciate your response within no more than one week.

Thank you for your time and support, and I look forward to sharing the outcomes of this survey with all of the participants.
Best Regards

Yahya Nasser Alfraidi

BSc. MSc. PhD researcher

Phone No: 00447588550060

E-mail: alfraidi@liv.ac.uk

How effective the following **Site design** strategies for the design of resilient housing to climate change risks?

Please check one box from the effects:

| | Very ineffective | ineffective | Neutral | Effective | Very effective |
|---|---|---|---|---|---|
| Use site stabilization techniques to prevent erosion | | | | | |
| Direct runoff of water to a catch basin or holding area to reduce erosion | | | | | |
| Plant mature trees to assist in dissipation of the wind force | | | | | |
| Use water catchment systems/cistern to reduce flooding | | | | | |
| Prepare site landscape and landforms for high wind conditions as well as to reduce the noise, pollution, energy consumption, temperature degree and relative humidity | | | | | |
| Use optimum building orientation to improve resilience to high/low temperature | | | | | |
| Use permeable surfaces in landscaping against vulnerability to flooding | | | | | |

How effective the following **Building layout design** strategies for the design of resilient housing to climate change risks?

Please check one box from the effects:

| | Very ineffective | ineffective | Neutral | Effective | Very effective |
|---|---|---|---|---|---|
| Plan spaces and layout based on future use scenarios to create usage resilience | | | | | |
| Specify multiple access within and between spaces to avoid access shutdown | | | | | |
| Minimize partitions between spaces to allow for thermal buoyancy effect | | | | | |
| Use appropriate floor height to enhance and optimize thermal and ventilation processes | | | | | |
| Use appropriate floor height to allow for future modification | | | | | |
| Specify spaces to perform multiple functions to enhance use resilience | | | | | |
| Use stack ventilation for passive cooling | | | | | |
| Use secure cross-ventilation for passive cooling and occupants' comfort | | | | | |
| Oversize space to reduce occupants' stress | | | | | |
| Specify "generic layout and program spaces" for future flexibility of use (use of modularity and standardization) | | | | | |
| Specify layout for maximum daylighting to take advantage of light and thermal energy | | | | | |
| Specify the layout of rooms, corridors, stairwells etc. in a way that upholds a low-resistance airflow path through the building (both in plan and section) to thermal comfort | | | | | |
| Specify thermal zones, by facing rooms of high energy demand on the south and putting rooms such as cellars, stairs, garages and laundry rooms on the north to act as buffer space | | | | | |
| Provide 'safe spaces' in the building to protect the occupants from extreme events | | | | | |

How effective the following **Building structure design** strategies for the design of resilient housing to climate change risks?

Please check one box from the effects:

| | Very ineffective | ineffective | Neutral | Effective | Very effective |
|---|---|---|---|---|---|
| Elevate structure above flood level | | | | | |
| Use flexible pipes and joints to resist high wind and other pressures | | | | | |
| Use an appropriate shape and angle of the roof for optimum ventilation and thermal comfort | | | | | |
| Oversize roof covering fixings to reduce windblown debris | | | | | |
| Increase structure bracing to create strength redundancy to wind and snow loads | | | | | |
| Oversize walls and roofs to create strength redundancy for wind and snow loads | | | | | |
| Provide anchorage between superstructure and substructure to increase resistance to high winds | | | | | |
| Use structure materials that are more resistant to pests to mitigate high temperature | | | | | |
| Construct masonry chimneys with continuous reinforced steel bracing to increase the resistance | | | | | |
| Oversize connections or attachments among building parts to facilitate the operation | | | | | |
| Use thermal mass on floor/ceiling/walls to moderate internal temperatures and reduce electricity demand | | | | | |
| Specify durable and robust materials and construction methods to resist the increasing number of significant extreme weather events | | | | | |

How effective the following **Building envelope design** strategies for the design of resilient housing to climate change risks?

Please check one box from the effects:

| | Very ineffective | ineffective | Neutral | Effective | Very effective |
|---|---|---|---|---|---|
| Use appropriate insulation systems to reduce conduction through the thermal envelope | | | | | |
| Provide expansion joints within the materials on vulnerability to expansion | | | | | |
| Use a high solar reflectance to reflect sunlight and heat away from a building | | | | | |
| Use appropriate materials to prevent the effects of flooding | | | | | |
| Use an appropriate shape and angle of the roof to optimize ventilation and thermal comfort, as well as, to resist storms | | | | | |
| Use energy-efficient windows and shading devices to reduce energy use | | | | | |
| Specify window film to prevent injuries from shattered glass | | | | | |
| Use advanced wall and framing techniques to reduce energy loss | | | | | |
| Specify windows, doors, and openings to withstand wind loads and windblown debris | | | | | |
| Oversize framing and bracing to increase redundancy | | | | | |
| Oversize anchors for roof-/wall-mounted heating, ventilation, and air conditioning units | | | | | |
| Use green roofs to reduce the heat island effect in urban settings | | | | | |
| Use light shelves or specially-designed reflective-louvered blinds to reflect light deep into rooms | | | | | |
| Use green roofs to minimize runoff rainwater | | | | | |
| Use appropriate exterior shading to reduce vulnerability to overheating | | | | | |
| Use openings in the envelope to ensure that floodwaters enter and exit | | | | | |
| Specify materials that can get wet and dry out without permanent damage | | | | | |
| Specify airtight junctions and details | | | | | |

| | | | | | |
|---|---|---|---|---|---|
| Specify light paint colours for interior ceilings and walls to improve internal distribution of daylight | | | | | |
| Use fenestration high on walls or roofs to bring daylight deep into rooms | | | | | |
| Specify dry flood-proofing e.g., watertight structure using sealants, flood shields, etc. to protect against floods | | | | | |
| Avoid the use of forms shapes that create a wind-suction bag effect during storms | | | | | |
| Avoid the use of long rectangular plans with the ratio between the length and width over 2.5 (a ratio over 2.5 creates vulnerability to storms) | | | | | |
| Avoid the use of long roof eaves due to vulnerability to storms | | | | | |
| Use double façades for natural ventilation as an outlet or inlet path | | | | | |
| Specify roofs' shape and orientation to strengthen the natural driving forces | | | | | |
| Specify roofs sloping upward towards the outlet to lead the ventilation air to the outlet | | | | | |
| Specify smaller windows for spaces to the north of the building to minimize heat loss | | | | | |
| Specify glazing ratio of 30-50% for vertical surfaces and 20% for rooflights to provide adequate daylight and avoid overheating | | | | | |
| Specify buffer spaces such as earth sheltering and conservatories to reduce heat losses or increase heat gains | | | | | |
| Specify forms that follow many future functions | | | | | |
| Use mass construction with suitable insulation to moderate the effects of high external temperatures | | | | | |

How effective the following **Building systems** strategies for the design of resilient housing to climate change risks?

Please check one box from the effects:

| | Very ineffective | ineffective | Neutral | Effective | Very effective |
|---|---|---|---|---|---|
| Ensure the provision of HVAC systems redundancy or overcapacity to cope with unexpected load | | | | | |
| Provide protection for the main electrical system from flooding | | | | | |
| Specify cogeneration and solar power to run during blackouts | | | | | |
| Size drainage system to vulnerability to high level of rain | | | | | |
| Separate the power system from the roof and walls to facilitate the process of replacement and maintenance | | | | | |
| Specify water-efficient fittings and devices to ensure the continuity of operation of the building | | | | | |
| Specify ductile-utility connectors to reduce breakage during disturbance events | | | | | |
| Build a permanent water-resistant barrier around HVAC equipment to protect from flooding | | | | | |
| Separate electrical circuits between levels under and above expected flooded levels | | | | | |
| Use multiple lighting resources to avoid electricity shutdown | | | | | |
| Raise electrical service above expected flood levels (system) | | | | | |
| Specify backup power to avoid electricity shutdown | | | | | |
| Provide onsite renewables to protect against power shutdown and create redundant sources of energy | | | | | |
| Specify heat and cold storage in the ground to protect against power shutdown | | | | | |
| Specify spray systems on roofs and terraces for evaporative cooling | | | | | |
| Specify water features in an atrium to provide evaporative cooling | | | | | |

How effective the following **Building operation** strategies for the design of resilient housing to climate change risks?

Please check one box from the effects:

| | Very ineffective | ineffective | Neutral | Effective | Very effective |
|---|---|---|---|---|---|
| Specify early warning systems, to alert vulnerable building occupants | | | | | |
| Secure interior furnishings and equipment to ensure continuity of operation | | | | | |
| Design for emergency repairs to ensure readiness for any risks and ensure continuity of operation | | | | | |
| Specify temperature controls to cater for different needs of occupants | | | | | |

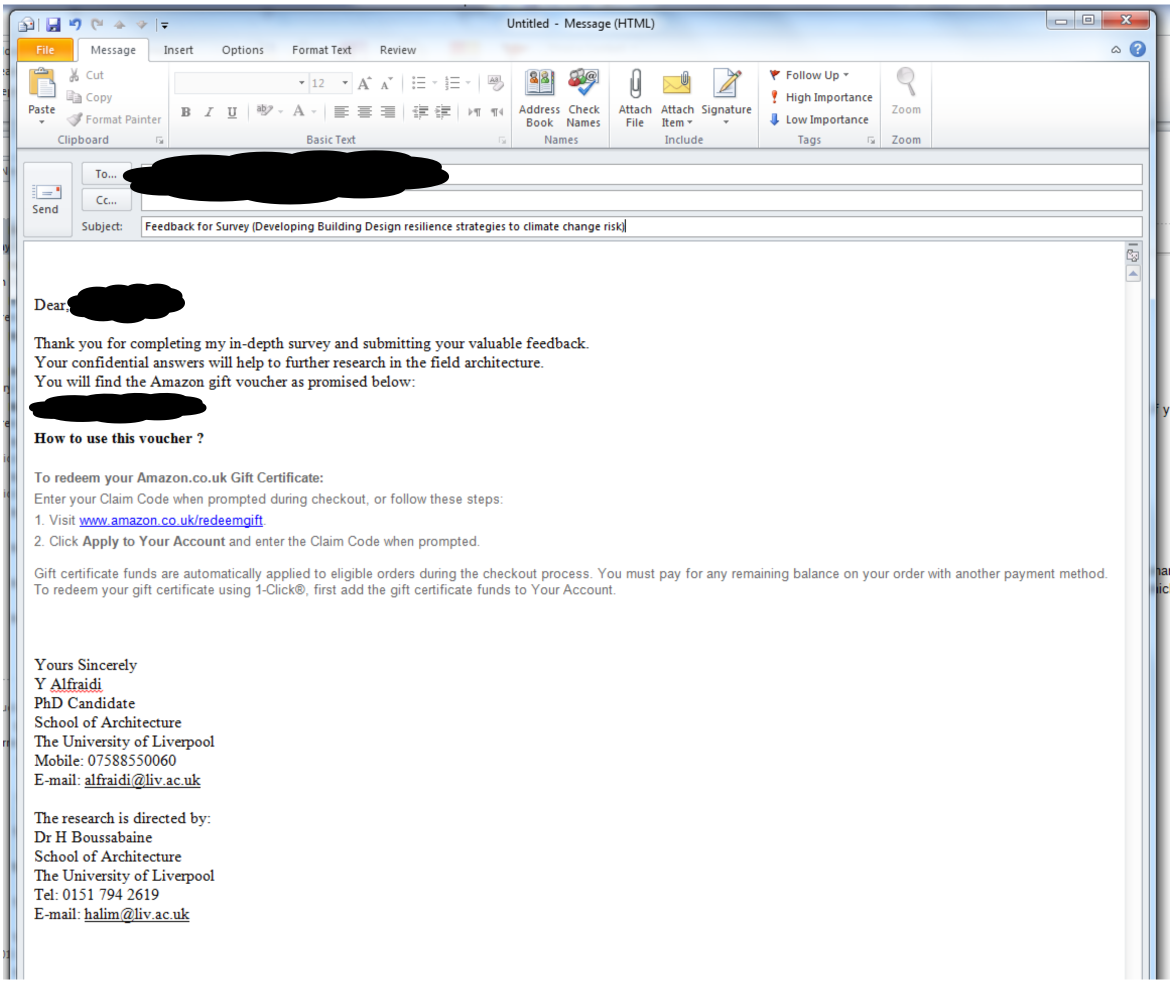
General Information:

| | |
|---|---|
| What is your name? (Optional) | |
| Company name: (Optional) | |

| What is your professional role? | | |
|---|---|---|
| ○ Architect practicing | ○ Academic and Architect practicing | ○ Academic |

| How many years of experience do you have? | | |
|---|---|---|
| ○ 0 – 5 years | ○ 5 – 10 years | ○ More than 10 years |

You have completed the survey. Please Click on DONE to submit the survey Thank you for your participation



Untitled - Message (HTML)

To... [redacted]

Cc...

Subject: Feedback for Survey (Developing Building Design resilience strategies to climate change risk)

Dear [redacted]

Thank you for completing my in-depth survey and submitting your valuable feedback.
Your confidential answers will help to further research in the field architecture.
You will find the Amazon gift voucher as promised below:

[redacted]

**How to use this voucher ?**

**To redeem your Amazon.co.uk Gift Certificate:**

Enter your Claim Code when prompted during checkout, or follow these steps:

1. Visit www.amazon.co.uk/redeemgift.
2. Click **Apply to Your Account** and enter the Claim Code when prompted.

Gift certificate funds are automatically applied to eligible orders during the checkout process. You must pay for any remaining balance on your order with another payment method. To redeem your gift certificate using 1-Click®, first add the gift certificate funds to Your Account.

Yours Sincerely
Y Alfraidi
PhD Candidate
School of Architecture
The University of Liverpool
Mobile: 07588550060
E-mail: alfraidi@liv.ac.uk

The research is directed by:
Dr H Boussabaine
School of Architecture
The University of Liverpool
Tel: 0151 794 2619
E-mail: halim@liv.ac.uk

Figure 16-1: Sample of mail that sends to the respondents.

## Appendix B: Assessment Tool

| Project Name: | | | | |
|---|---|---|---|---|
| Office Name | | | | |
| Architect Name | | | | |
| Project Location | | | | |
| resilient categories | To what extent the following factors are implemented and considered in this design ? | .S | T.P | D.P |
| **Robustness (RO)** | SE9: Specify windows, doors, and openings to withstand wind loads and windblown debris | | | |
| | ST4: Oversize roof covering fixings to reduce windblown debris | | | |
| | SY8: Build a permanent water-resistant barrier around HVAC equipment to protect from flooding. | | | |
| | ST7: Provide anchorage between superstructure and substructure to increase resistance to high winds | | | |
| | ST9: Construct masonry chimneys with continuous reinforced steel bracing to increase the resistance | | | |
| | SE10: Oversize framing and bracing to increase redundancy | | | |
| | SY2: Provide protection for the main electrical system from flooding | | | |
| **Redundancy (R)** | SS2: Direct runoff of water to a catch basin or holding area to reduce erosion. | | | |
| | ST5: Increase structure bracing to create strength redundancy to wind and snow loads. | | | |
| | SY3: Specify cogeneration and solar power to run during blackouts. | | | |
| | SY4: Size drainage system to vulnerability to high level of rain. | | | |
| **Capacity for adaptation (CA)** | SS7: Use permeable surfaces in landscaping against vulnerability to flooding | | | |
| | SE2: Provide expansion joints within the materials on vulnerability to expansion | | | |
| | SL5: Use appropriate floor height to allow for future modification. | | | |
| | SS6: Use optimum building orientation to improve resilience to high/low temperature. | | | |
| | SL4: Use appropriate floor height to enhance and optimize thermal and ventilation processes. | | | |
| | ST8: Use structure materials that are more resistant to pests to mitigate high temperature. | | | |
| **Environmental responsiveness (ER)** | SL8: Use secure cross-ventilation for passive cooling and occupants' comfort. | | | |
| | SL12: Specify the layout of rooms, corridors, stairwells etc. in a way that upholds a low-resistance airflow path through the building (both in plan and section) to thermal comfort | | | |
| | SE14: Use appropriate exterior shading to reduce vulnerability to overheating | | | |
| | SL13: Specify thermal zones, by facing rooms of high energy demand on the south and putting rooms such as cellars, stairs, garages and laundry rooms on the north to act as buffer space. | | | |
| | SE6: Use energy-efficient windows and shading devices to reduce energy use | | | |
| | SE1: Use appropriate insulation systems to reduce conduction through the thermal envelope. | | | |
| | SE3: Use a high solar reflectance to reflect sunlight and heat away from a building | | | |
| | SE8: Use advanced wall and framing techniques to reduce energy loss | | | |
| | SS3: Plant mature trees to assist in dissipation of the wind force | | | |
| | SS5: Prepare site landscape and landforms for high wind conditions as well as to reduce the noise, pollution, energy consumption, temperature degree and relative humidity | | | |
| | SE5: Use an appropriate shape and angle of the roof to optimize ventilation and thermal comfort, as well as, to resist storms | | | |
| Result | RBD tool $=\sum \frac{RO+R+CA+ER}{} * 100$ | RDB tool $= \sum \frac{18+14+35+67}{280} = -$*100 | | |
| | The result= | RDB Rate = | | |

| Project Name: | | Architect Name: | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Office Name: | | Project Location: | | | | | | | | | |
| Scoring<br>Implantation or consideration of factors in Design | | Not Implantation ← Considered → Highly Implantation | | | | | | | | | |
| To what extent the following factors are implemented and considered in this design ? | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| Site Desgin Resilience strategic (SDS) | Direct runoff of water to a catch basin or holding area to reduce erosion | | | | | | | | | | |
| | Plant mature trees to assist in dissipation of the wind force | | | | | | | | | | |
| | Prepare site landscape and landforms for high wind conditions as well as to reduce the noise, pollution, energy consumption, temperature degree and relative humidity | | | | | | | | | | |
| | Use optimum building orientation to improve resilience to high/low temperature | | | | | | | | | | |
| | Use permeable surfaces in landscaping against vulnerability to flooding | | | | | | | | | | |
| Layout Desgin Resilience strategic (SDL) | Use appropriate floor height to enhance and optimize thermal and ventilation processes. | | | | | | | | | | |
| | Use appropriate floor height to allow for future modification. | | | | | | | | | | |
| | Use secure cross-ventilation for passive cooling and occupants' comfort. | | | | | | | | | | |
| | Specify the layout of rooms, corridors, stairwells etc. in a way that upholds a low-resistance airflow path through the building (both in plan and section) to thermal comfort | | | | | | | | | | |
| | Specify thermal zones, by facing rooms of high energy demand on the south and putting rooms such as cellars, stairs, garages and laundry rooms on the north to act as buffer space. | | | | | | | | | | |
| Structure Desgin Resilience strategic (SDT) | Oversize roof covering fixings to reduce windblown debris | | | | | | | | | | |
| | Increase structure bracing to create strength redundancy to wind and snow loads | | | | | | | | | | |
| | Provide anchorage between superstructure and substructure to increase resistance to high winds | | | | | | | | | | |
| | Use structure materials that are more resistant to pests to mitigate high temperature | | | | | | | | | | |
| | Construct masonry chimneys with continuous reinforced steel bracing to increase the resistance | | | | | | | | | | |
| | Use appropriate insulation systems to reduce conduction through the thermal envelope. | | | | | | | | | | |
| | Provide expansion joints within the materials on vulnerability to expansion | | | | | | | | | | |

| | |
|---|---|
| Envelope Desgin Resilience strategic (SDE) | Use a high solar reflectance to reflect sunlight and heat away from a building |
| | Use an appropriate shape and angle of the roof to optimize ventilation and thermal comfort, as well as, to resist storms |
| | Use energy-efficient windows and shading devices to reduce energy use |
| | Use advanced wall and framing techniques to reduce energy loss |
| | Specify windows, doors, and openings to withstand wind loads and windblown debris |
| | Oversize framing and bracing to increase redundancy |
| | Use appropriate exterior shading to reduce vulnerability to overheating |
| System Desgin Resilience strategic (SDY) | Provide protection for the main electrical system from flooding |
| | Specify cogeneration and solar power to run during blackouts. |
| | Size drainage system to vulnerability to high level of rain. |
| | Build a permanent water-resistant barrier around HVAC equipment to protect from flooding. |

## Appendix C: Publications

Publications:

- Alfraidi Y, Boussabaine, A. H. (2014). Risks Impact of Climate Change on Buildings. (ICCSEE): International Conference on Civil, Structural and Environment Engineering. London, United Kingdom. Paper code 15UK01000737. (ISBN: 2010 - 376X). Page: 1083.
- Alfraidi Y, Boussabaine, A. H. (2014). Design resilient building strategies in face of climate change. Architectural and Environmental Engineering. (ICTLT): International Conference on Transportation and Logistics Technology. Istanbul, Turkey. Paper code 15TR01000729. (ISBN: 2010 - 376X). Page: 2389.
- Alfraidi Y, Boussabaine, A. H. (2012). Building resilience to Climate Change risks on Buildings. Presented poster in Saudi Scientific international Conference on 11th-14th October 2012 at the Brunel University.
- Alfraidi Y, Boussabaine, A. H. (2013). Building resilience to Climate Change risks on Buildings. Presented poster in Saudi Scientific international Conference on 1th-2th Feb 2014 at the Edinburgh University.
- Alfraidi Y, Boussabaine, A. H. (2014). Building resilience to Climate Change risks on Buildings. Presented poster in 5th PhD Experience Conference on 14th-15th Mar 2014 at the Hull University.

# Appendix D: Test Hypothesis

## Tables of Hypothesis and Reliability Testing

## ANOVAs Rating Based on Architects' Professional role

## Table of Site Design Resilience Strategies

**ANOVA**

| | | Sum of Squares | df | Mean Square | F | P |
|---|---|---|---|---|---|---|
| SS1 | Between Groups | 4.612 | 2 | 2.306 | 3.002 | .056 |
| | Within Groups | 56.843 | 74 | .768 | | |
| | Total | 61.455 | 76 | | | |
| SS2 | Between Groups | .183 | 2 | .091 | .117 | .889 |
| | Within Groups | 57.610 | 74 | .779 | | |
| | Total | 57.792 | 76 | | | |
| SS3 | Between Groups | .634 | 2 | .317 | .837 | .437 |
| | Within Groups | 28.041 | 74 | .379 | | |
| | Total | 28.675 | 76 | | | |
| SS4 | Between Groups | 1.187 | 2 | .594 | .999 | .373 |
| | Within Groups | 43.982 | 74 | .594 | | |
| | Total | 45.169 | 76 | | | |
| SS5 | Between Groups | .956 | 2 | .478 | .681 | .509 |
| | Within Groups | 51.927 | 74 | .702 | | |
| | Total | 52.883 | 76 | | | |
| SS6 | Between Groups | 2.218 | 2 | 1.109 | 1.686 | .192 |
| | Within Groups | 48.665 | 74 | .658 | | |
| | Total | 50.883 | 76 | | | |
| SS7 | Between Groups | 2.151 | 2 | 1.076 | 1.775 | .177 |
| | Within Groups | 44.836 | 74 | .606 | | |
| | Total | 46.987 | 76 | | | |

**Table 19-1: The F-value and significant value of the ANOVA analysis.**

**Layout design Resilience Strategies:**

| | | Sum of Squares | df | Mean Square | F | P |
|---|---|---|---|---|---|---|
| LS1 | Between Groups | .903 | 2 | .452 | .593 | .555 |
| | Within Groups | 56.344 | 74 | .761 | | |
| | Total | 57.247 | 76 | | | |
| LS2 | Between Groups | .235 | 2 | .117 | .153 | .858 |
| | Within Groups | 56.752 | 74 | .767 | | |
| | Total | 56.987 | 76 | | | |
| LS3 | Between Groups | .120 | 2 | .060 | .081 | .922 |
| | Within Groups | 54.582 | 74 | .738 | | |
| | Total | 54.701 | 76 | | | |
| LS4 | Between Groups | 3.465 | 2 | 1.732 | 2.946 | .059 |
| | Within Groups | 43.522 | 74 | .588 | | |
| | Total | 46.987 | 76 | | | |
| LS5 | Between Groups | 2.763 | 2 | 1.381 | 2.408 | .097 |
| | Within Groups | 42.458 | 74 | .574 | | |
| | Total | 45.221 | 76 | | | |
| LS6 | Between Groups | .378 | 2 | .189 | .329 | .721 |
| | Within Groups | 42.506 | 74 | .574 | | |
| | Total | 42.883 | 76 | | | |
| LS7 | Between Groups | 1.060 | 2 | .530 | .580 | .563 |
| | Within Groups | 67.641 | 74 | .914 | | |
| | Total | 68.701 | 76 | | | |
| LS8 | Between Groups | 3.694 | 2 | 1.847 | 2.447 | .093 |
| | Within Groups | 55.839 | 74 | .755 | | |
| | Total | 59.532 | 76 | | | |
| LS9 | Between Groups | 4.692 | 2 | 2.346 | 3.820 | .026 |
| | Within Groups | 45.438 | 74 | .614 | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| | Total | 50.130 | 76 | | | |
| LS10 | Between Groups | .683 | 2 | .341 | .520 | .596 |
| | Within Groups | 48.538 | 74 | .656 | | |
| | Total | 49.221 | 76 | | | |
| LS11 | Between Groups | 1.196 | 2 | .598 | .744 | .479 |
| | Within Groups | 59.506 | 74 | .804 | | |
| | Total | 60.701 | 76 | | | |
| LS12 | Between Groups | .098 | 2 | .049 | .107 | .899 |
| | Within Groups | 33.902 | 74 | .458 | | |
| | Total | 34.000 | 76 | | | |
| LS13 | Between Groups | 2.807 | 2 | 1.403 | 1.817 | .170 |
| | Within Groups | 57.141 | 74 | .772 | | |
| | Total | 59.948 | 76 | | | |
| LS14 | Between Groups | 4.702 | 2 | 2.351 | 2.573 | .083 |
| | Within Groups | 67.610 | 74 | .914 | | |
| | Total | 72.312 | 76 | | | |

**Table 19-2: The F-value and significant value of the ANOVA analysis.**

**LS9**

Tukey HSD[a,b]

| job | N | Subset for alpha = 0.05 1 | 2 |
|---|---|---|---|
| 2 | 21 | 3.52 | |
| 3 | 36 | 3.83 | 3.83 |
| 1 | 20 | | 4.20 |
| Sig. | | .364 | .244 |

## Structure design Resilience Strategies:

**ANOVA**

| | | Sum of Squares | df | Mean Square | F | P |
|---|---|---|---|---|---|---|
| TS1 | Between Groups | 1.427 | 2 | .713 | .893 | .414 |
| | Within Groups | 59.093 | 74 | .799 | | |
| | Total | 60.519 | 76 | | | |
| TS2 | Between Groups | 2.915 | 2 | 1.458 | 2.120 | .127 |
| | Within Groups | 50.877 | 74 | .688 | | |
| | Total | 53.792 | 76 | | | |
| TS3 | Between Groups | .086 | 2 | .043 | .054 | .947 |
| | Within Groups | 59.160 | 74 | .799 | | |
| | Total | 59.247 | 76 | | | |
| TS4 | Between Groups | 3.016 | 2 | 1.508 | 2.800 | .067 |
| | Within Groups | 39.867 | 74 | .539 | | |
| | Total | 42.883 | 76 | | | |
| TS5 | Between Groups | 3.319 | 2 | 1.660 | 2.496 | .089 |
| | Within Groups | 49.200 | 74 | .665 | | |
| | Total | 52.519 | 76 | | | |
| TS6 | Between Groups | 6.120 | 2 | 3.060 | 5.583 | .006 |
| | Within Groups | 40.556 | 74 | .548 | | |
| | Total | 46.675 | 76 | | | |
| TS7 | Between Groups | 2.544 | 2 | 1.272 | 1.837 | .167 |
| | Within Groups | 51.248 | 74 | .693 | | |
| | Total | 53.792 | 76 | | | |
| TS8 | Between Groups | .855 | 2 | .428 | .566 | .570 |
| | Within Groups | 55.950 | 74 | .756 | | |
| | Total | 56.805 | 76 | | | |
| TS9 | Between Groups | .275 | 2 | .138 | .215 | .807 |
| | Within Groups | 47.439 | 74 | .641 | | |
| | Total | 47.714 | 76 | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| TS10 | Between Groups | .842 | 2 | .421 | .682 | .509 |
| | Within Groups | 45.677 | 74 | .617 | | |
| | Total | 46.519 | 76 | | | |
| TS11 | Between Groups | 1.816 | 2 | .908 | 1.066 | .350 |
| | Within Groups | 63.041 | 74 | .852 | | |
| | Total | 64.857 | 76 | | | |
| TS12 | Between Groups | 2.158 | 2 | 1.079 | 1.554 | .218 |
| | Within Groups | 51.375 | 74 | .694 | | |
| | Total | 53.532 | 76 | | | |

**Table 19-3: The F-value and significant value of the ANOVA analysis.**

**TS6**

Tukey HSD[a,b]

| job | N | Subset for alpha = 0.05 | |
|---|---|---|---|
| | | 1 | 2 |
| 2 | 21 | 3.33 | |
| 3 | 36 | | 3.94 |
| 1 | 20 | | 4.00 |
| Sig. | | 1.000 | .964 |

## Envelope design Resilience Strategies:

**ANOVA**

| | | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| ES1 | Between Groups | 1.151 | 2 | .576 | .987 | .378 |
| | Within Groups | 43.160 | 74 | .583 | | |
| | Total | 44.312 | 76 | | | |
| ES2 | Between Groups | .246 | 2 | .123 | .229 | .796 |
| | Within Groups | 39.702 | 74 | .537 | | |
| | Total | 39.948 | 76 | | | |
| ES3 | Between Groups | 1.071 | 2 | .536 | .502 | .607 |
| | Within Groups | 78.877 | 74 | 1.066 | | |
| | Total | 79.948 | 76 | | | |
| ES4 | Between Groups | 2.027 | 2 | 1.013 | 1.351 | .265 |
| | Within Groups | 55.506 | 74 | .750 | | |
| | Total | 57.532 | 76 | | | |
| ES5 | Between Groups | 3.825 | 2 | 1.912 | 2.966 | .058 |
| | Within Groups | 47.708 | 74 | .645 | | |
| | Total | 51.532 | 76 | | | |
| ES6 | Between Groups | 1.541 | 2 | .770 | 1.114 | .334 |
| | Within Groups | 51.160 | 74 | .691 | | |
| | Total | 52.701 | 76 | | | |
| ES7 | Between Groups | 4.842 | 2 | 2.421 | 3.560 | .033 |
| | Within Groups | 50.327 | 74 | .680 | | |
| | Total | 55.169 | 76 | | | |
| ES8 | Between Groups | .894 | 2 | .447 | .625 | .538 |
| | Within Groups | 52.898 | 74 | .715 | | |
| | Total | 53.792 | 76 | | | |
| ES9 | Between Groups | 2.770 | 2 | 1.385 | 2.592 | .082 |
| | Within Groups | 39.541 | 74 | .534 | | |
| | Total | 42.312 | 76 | | | |
| ES10 | Between Groups | 4.115 | 2 | 2.058 | 4.268 | .018 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | Within Groups | 35.677 | 74 | .482 | | |
| | Total | 39.792 | 76 | | | |
| ES11 | Between Groups | 2.938 | 2 | 1.469 | 2.029 | .139 |
| | Within Groups | 53.582 | 74 | .724 | | |
| | Total | 56.519 | 76 | | | |
| ES12 | Between Groups | 6.715 | 2 | 3.358 | 4.920 | .010 |
| | Within Groups | 50.506 | 74 | .683 | | |
| | Total | 57.221 | 76 | | | |
| ES13 | Between Groups | 8.284 | 2 | 4.142 | 6.905 | .002 |
| | Within Groups | 44.391 | 74 | .600 | | |
| | Total | 52.675 | 76 | | | |
| ES14 | Between Groups | 2.720 | 2 | 1.360 | 1.816 | .170 |
| | Within Groups | 55.410 | 74 | .749 | | |
| | Total | 58.130 | 76 | | | |
| ES15 | Between Groups | .306 | 2 | .153 | .199 | .820 |
| | Within Groups | 56.915 | 74 | .769 | | |
| | Total | 57.221 | 76 | | | |
| ES16 | Between Groups | 1.347 | 2 | .674 | 1.263 | .289 |
| | Within Groups | 39.458 | 74 | .533 | | |
| | Total | 40.805 | 76 | | | |
| ES17 | Between Groups | 1.513 | 2 | .757 | 1.004 | .371 |
| | Within Groups | 55.760 | 74 | .754 | | |
| | Total | 57.273 | 76 | | | |
| ES18 | Between Groups | 1.544 | 2 | .772 | .990 | .376 |
| | Within Groups | 57.702 | 74 | .780 | | |
| | Total | 59.247 | 76 | | | |
| ES19 | Between Groups | .372 | 2 | .186 | .292 | .748 |
| | Within Groups | 47.160 | 74 | .637 | | |
| | Total | 47.532 | 76 | | | |
| ES20 | Between Groups | .565 | 2 | .282 | .480 | .621 |
| | Within Groups | 43.565 | 74 | .589 | | |
| | Total | 44.130 | 76 | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| ES21 | Between Groups | 3.183 | 2 | 1.591 | 1.961 | .148 |
| | Within Groups | 60.038 | 74 | .811 | | |
| | Total | 63.221 | 76 | | | |
| ES22 | Between Groups | .709 | 2 | .354 | .352 | .705 |
| | Within Groups | 74.538 | 74 | 1.007 | | |
| | Total | 75.247 | 76 | | | |
| ES23 | Between Groups | 2.894 | 2 | 1.447 | 2.634 | .078 |
| | Within Groups | 40.639 | 74 | .549 | | |
| | Total | 43.532 | 76 | | | |
| ES24 | Between Groups | 4.839 | 2 | 2.419 | 3.895 | .025 |
| | Within Groups | 45.967 | 74 | .621 | | |
| | Total | 50.805 | 76 | | | |
| ES25 | Between Groups | 4.553 | 2 | 2.276 | 4.014 | .022 |
| | Within Groups | 41.967 | 74 | .567 | | |
| | Total | 46.519 | 76 | | | |
| ES26 | Between Groups | 1.734 | 2 | .867 | 1.335 | .269 |
| | Within Groups | 48.058 | 74 | .649 | | |
| | Total | 49.792 | 76 | | | |
| ES27 | Between Groups | .877 | 2 | .439 | .692 | .504 |
| | Within Groups | 46.915 | 74 | .634 | | |
| | Total | 47.792 | 76 | | | |
| ES28 | Between Groups | .374 | 2 | .187 | .312 | .733 |
| | Within Groups | 44.327 | 74 | .599 | | |
| | Total | 44.701 | 76 | | | |
| ES29 | Between Groups | .553 | 2 | .276 | .442 | .644 |
| | Within Groups | 46.252 | 74 | .625 | | |
| | Total | 46.805 | 76 | | | |
| ES30 | Between Groups | .092 | 2 | .046 | .060 | .942 |
| | Within Groups | 57.077 | 74 | .771 | | |
| | Total | 57.169 | 76 | | | |
| ES31 | Between Groups | .455 | 2 | .228 | .287 | .752 |
| | Within Groups | 58.791 | 74 | .794 | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| | Total | 59.247 | 76 | | | |
| ES32 | Between Groups | .620 | 2 | .310 | .412 | .664 |
| | Within Groups | 55.744 | 74 | .753 | | |
| | Total | 56.364 | 76 | | | |

**Table 19-4: The F-value and significant value of the ANOVA analysis.**

**ES7**

Tukey HSD[a,b]

| job | N | Subset for alpha = 0.05 | |
|---|---|---|---|
| | | 1 | 2 |
| 2 | 21 | 3.14 | |
| 3 | 36 | 3.61 | 3.61 |
| 1 | 20 | | 3.80 |
| Sig. | | .128 | .709 |

**ES10**

Tukey HSD[a,b]

| job | N | Subset for alpha = 0.05 | |
|---|---|---|---|
| | | 1 | 2 |
| 2 | 21 | 3.86 | |
| 1 | 20 | | 4.35 |
| 3 | 36 | | 4.39 |
| Sig. | | 1.000 | .980 |

**ES12**

Tukey HSD[a,b]

| job | N | Subset for alpha = 0.05 | |
|---|---|---|---|
| | | 1 | 2 |
| 2 | 21 | 3.00 | |
| 3 | 36 | | 3.64 |
| 1 | 20 | | 3.70 |
| Sig. | | 1.000 | .965 |

**ES13**

Tukey HSD[a,b]

| job | N | Subset for alpha = 0.05 | |
|---|---|---|---|
| | | 1 | 2 |
| 2 | 21 | 3.29 | |
| 3 | 36 | | 3.89 |
| 1 | 20 | | 4.15 |
| Sig. | | 1.000 | .477 |

**ES24**

Tukey HSD[a,b]

| job | N | Subset for alpha = 0.05 | |
|---|---|---|---|
| | | 1 | 2 |
| 2 | 21 | 3.33 | |
| 1 | 20 | 3.85 | 3.85 |
| 3 | 36 | | 3.92 |
| Sig. | | .067 | .954 |

**ES25**

Tukey HSD[a,b]

| job | N | Subset for alpha = 0.05 | |
|---|---|---|---|
| | | 1 | 2 |
| 2 | 21 | 3.33 | |
| 1 | 20 | 3.65 | 3.65 |
| 3 | 36 | | 3.92 |
| Sig. | | .319 | .442 |

## System design Resilience Strategies:

**ANOVA**

| | | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| YS1 | Between Groups | .108 | 2 | .054 | .055 | .947 |
| | Within Groups | 72.594 | 74 | .981 | | |
| | Total | 72.701 | 76 | | | |
| YS2 | Between Groups | 1.592 | 2 | .796 | 1.160 | .319 |
| | Within Groups | 50.771 | 74 | .686 | | |
| | Total | 52.364 | 76 | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| YS3 | Between Groups | 5.109 | 2 | 2.555 | 4.629 | .013 |
| | Within Groups | 40.839 | 74 | .552 | | |
| | Total | 45.948 | 76 | | | |
| YS4 | Between Groups | .590 | 2 | .295 | .409 | .666 |
| | Within Groups | 53.410 | 74 | .722 | | |
| | Total | 54.000 | 76 | | | |
| YS5 | Between Groups | .391 | 2 | .196 | .333 | .718 |
| | Within Groups | 43.427 | 74 | .587 | | |
| | Total | 43.818 | 76 | | | |
| YS6 | Between Groups | 2.397 | 2 | 1.198 | 1.585 | .212 |
| | Within Groups | 55.967 | 74 | .756 | | |
| | Total | 58.364 | 76 | | | |
| YS7 | Between Groups | 1.530 | 2 | .765 | 1.096 | .339 |
| | Within Groups | 51.639 | 74 | .698 | | |
| | Total | 53.169 | 76 | | | |
| YS8 | Between Groups | 6.060 | 2 | 3.030 | 4.807 | .011 |
| | Within Groups | 46.641 | 74 | .630 | | |
| | Total | 52.701 | 76 | | | |
| YS9 | Between Groups | 3.304 | 2 | 1.652 | 2.185 | .120 |
| | Within Groups | 55.943 | 74 | .756 | | |
| | Total | 59.247 | 76 | | | |
| YS10 | Between Groups | 6.703 | 2 | 3.351 | 5.392 | .007 |
| | Within Groups | 45.998 | 74 | .622 | | |
| | Total | 52.701 | 76 | | | |
| YS11 | Between Groups | 4.781 | 2 | 2.391 | 2.466 | .092 |
| | Within Groups | 71.738 | 74 | .969 | | |
| | Total | 76.519 | 76 | | | |
| YS12 | Between Groups | 3.062 | 2 | 1.531 | 2.492 | .090 |
| | Within Groups | 45.458 | 74 | .614 | | |
| | Total | 48.519 | 76 | | | |
| YS13 | Between Groups | 1.430 | 2 | .715 | .948 | .392 |
| | Within Groups | 55.791 | 74 | .754 | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| | Total | 57.221 | 76 | | | |
| YS14 | Between Groups | 1.773 | 2 | .886 | 1.267 | .288 |
| | Within Groups | 51.760 | 74 | .699 | | |
| | Total | 53.532 | 76 | | | |
| YS15 | Between Groups | 1.042 | 2 | .521 | .653 | .523 |
| | Within Groups | 59.036 | 74 | .798 | | |
| | Total | 60.078 | 76 | | | |
| YS16 | Between Groups | .514 | 2 | .257 | .350 | .706 |
| | Within Groups | 54.343 | 74 | .734 | | |
| | Total | 54.857 | 76 | | | |

**Table 19-5: The F-value and significant value of the ANOVA analysis.**

**YS3**

Tukey HSD[a,b]

| job | N | Subset for alpha = 0.05 | |
|---|---|---|---|
| | | 1 | 2 |
| 2 | 21 | 3.67 | |
| 1 | 20 | 3.95 | 3.95 |
| 3 | 36 | | 4.28 |
| Sig. | | .389 | .285 |

**YS8**

Tukey HSD[a,b]

| job | N | Subset for alpha = 0.05 | |
|---|---|---|---|
| | | 1 | 2 |
| 2 | 21 | 3.71 | |
| 1 | 20 | 4.10 | 4.10 |
| 3 | 36 | | 4.39 |
| Sig. | | .220 | .423 |

**YS10**

Tukey HSD[a,b]

| job | N | Subset for alpha = 0.05 | |
|---|---|---|---|
| | | 1 | 2 |
| 2 | 21 | 3.43 | |
| 1 | 20 | 3.85 | 3.85 |
| 3 | 36 | | 4.14 |
| Sig. | | .161 | .418 |

## Operation design Resilience Strategies:

**ANOVA**

| | | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| OS1 | Between Groups | 5.167 | 2 | 2.584 | 2.164 | .122 |
| | Within Groups | 88.365 | 74 | 1.194 | | |
| | Total | 93.532 | 76 | | | |
| OS2 | Between Groups | 5.653 | 2 | 2.827 | 4.218 | .018 |
| | Within Groups | 49.594 | 74 | .670 | | |
| | Total | 55.247 | 76 | | | |
| OS3 | Between Groups | 1.443 | 2 | .722 | .585 | .560 |
| | Within Groups | 91.258 | 74 | 1.233 | | |
| | Total | 92.701 | 76 | | | |
| OS4 | Between Groups | 1.147 | 2 | .573 | .550 | .579 |
| | Within Groups | 77.165 | 74 | 1.043 | | |
| | Total | 78.312 | 76 | | | |

**Table 19-6: The F-value and significant value of the ANOVA analysis.**

**OS2**

Tukey HSD[a,b]

| job | N | Subset for alpha = 0.05 | |
|---|---|---|---|
| | | 1 | 2 |
| 2 | 21 | 2.86 | |
| 3 | 36 | 3.22 | 3.22 |
| 1 | 20 | | 3.60 |
| Sig. | | .277 | .254 |

## ANOVA Testing Based on Architects' Experience

### Site design Resilience Strategies:

**ANOVA**

| | | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| SS1 | Between Groups | .392 | 2 | .196 | .235 | .791 |
| | Within Groups | 61.738 | 74 | .834 | | |
| | Total | 62.130 | 76 | | | |
| SS2 | Between Groups | .812 | 2 | .406 | .517 | .598 |
| | Within Groups | 58.071 | 74 | .785 | | |
| | Total | 58.883 | 76 | | | |
| SS3 | Between Groups | .104 | 2 | .052 | .131 | .878 |
| | Within Groups | 29.429 | 74 | .398 | | |
| | Total | 29.532 | 76 | | | |
| SS4 | Between Groups | .173 | 2 | .087 | .139 | .871 |
| | Within Groups | 46.190 | 74 | .624 | | |
| | Total | 46.364 | 76 | | | |
| SS5 | Between Groups | 3.959 | 2 | 1.979 | 2.973 | .057 |
| | Within Groups | 49.262 | 74 | .666 | | |
| | Total | 53.221 | 76 | | | |
| SS6 | Between Groups | 1.959 | 2 | .979 | 1.454 | .240 |
| | Within Groups | 49.833 | 74 | .673 | | |
| | Total | 51.792 | 76 | | | |
| SS7 | Between Groups | 1.677 | 2 | .839 | 1.370 | .261 |
| | Within Groups | 45.310 | 74 | .612 | | |
| | Total | 46.987 | 76 | | | |

**Table 19-7: The F-value and significant value of the ANOVA analysis.**

### Layout design Resilience Strategies:

**ANOVA**

| | | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| LS1 | Between Groups | .390 | 2 | .195 | .247 | .782 |
| | Within Groups | 58.286 | 74 | .788 | | |
| | Total | 58.675 | 76 | | | |
| LS2 | Between Groups | 1.201 | 2 | .601 | .773 | .465 |
| | Within Groups | 57.500 | 74 | .777 | | |
| | Total | 58.701 | 76 | | | |
| LS3 | Between Groups | .701 | 2 | .351 | .461 | .632 |
| | Within Groups | 56.286 | 74 | .761 | | |
| | Total | 56.987 | 76 | | | |
| LS4 | Between Groups | 4.734 | 2 | 2.367 | 4.053 | .021 |
| | Within Groups | 43.214 | 74 | .584 | | |
| | Total | 47.948 | 76 | | | |
| LS5 | Between Groups | 3.080 | 2 | 1.540 | 2.684 | .075 |
| | Within Groups | 42.452 | 74 | .574 | | |
| | Total | 45.532 | 76 | | | |
| LS6 | Between Groups | .043 | 2 | .022 | .035 | .966 |
| | Within Groups | 45.905 | 74 | .620 | | |
| | Total | 45.948 | 76 | | | |
| LS7 | Between Groups | .058 | 2 | .029 | .030 | .970 |
| | Within Groups | 70.929 | 74 | .958 | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| | Total | 70.987 | 76 | | | |
| LS8 | Between Groups | 1.628 | 2 | .814 | 1.035 | .360 |
| | Within Groups | 58.190 | 74 | .786 | | |
| | Total | 59.818 | 76 | | | |
| LS9 | Between Groups | 1.905 | 2 | .952 | 1.423 | .247 |
| | Within Groups | 49.524 | 74 | .669 | | |
| | Total | 51.429 | 76 | | | |
| LS10 | Between Groups | 1.240 | 2 | .620 | .924 | .401 |
| | Within Groups | 49.643 | 74 | .671 | | |
| | Total | 50.883 | 76 | | | |
| LS11 | Between Groups | .097 | 2 | .049 | .059 | .943 |
| | Within Groups | 61.071 | 74 | .825 | | |
| | Total | 61.169 | 76 | | | |
| LS12 | Between Groups | .701 | 2 | .351 | .757 | .473 |
| | Within Groups | 34.286 | 74 | .463 | | |
| | Total | 34.987 | 76 | | | |
| LS13 | Between Groups | 2.935 | 2 | 1.468 | 1.910 | .155 |
| | Within Groups | 56.857 | 74 | .768 | | |
| | Total | 59.792 | 76 | | | |
| LS14 | Between Groups | 3.628 | 2 | 1.814 | 1.912 | .155 |
| | Within Groups | 70.190 | 74 | .949 | | |
| | Total | 73.818 | 76 | | | |

**Table 19-8: The F-value and significant value of the ANOVA analysis.**

**LS4**

Tukey HSD[a,b]

| exp | N | Subset for alpha = 0.05 |
|---|---|---|
| | | 1 |
| 3 | 14 | 3.79 |
| 1 | 42 | 3.93 |
| 2 | 21 | 4.33 |
| Sig. | | .061 |

## Structure design Resilience Strategies:

**ANOVA**

| | | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| TS1 | Between Groups | .292 | 2 | .146 | .175 | .840 |
| | Within Groups | 61.786 | 74 | .835 | | |
| | Total | 62.078 | 76 | | | |
| TS2 | Between Groups | 3.247 | 2 | 1.623 | 2.336 | .104 |
| | Within Groups | 51.429 | 74 | .695 | | |
| | Total | 54.675 | 76 | | | |
| TS3 | Between Groups | 2.173 | 2 | 1.087 | 1.362 | .263 |
| | Within Groups | 59.048 | 74 | .798 | | |
| | Total | 61.221 | 76 | | | |
| TS4 | Between Groups | .734 | 2 | .367 | .628 | .536 |
| | Within Groups | 43.214 | 74 | .584 | | |
| | Total | 43.948 | 76 | | | |
| TS5 | Between Groups | .026 | 2 | .013 | .018 | .982 |
| | Within Groups | 52.857 | 74 | .714 | | |
| | Total | 52.883 | 76 | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| TS6 | Between Groups | .483 | 2 | .241 | .375 | .688 |
| | Within Groups | 47.595 | 74 | .643 | | |
| | Total | 48.078 | 76 | | | |
| TS7 | Between Groups | 2.032 | 2 | 1.016 | 1.429 | .246 |
| | Within Groups | 52.643 | 74 | .711 | | |
| | Total | 54.675 | 76 | | | |
| TS8 | Between Groups | .955 | 2 | .477 | .625 | .538 |
| | Within Groups | 56.500 | 74 | .764 | | |
| | Total | 57.455 | 76 | | | |
| TS9 | Between Groups | .476 | 2 | .238 | .373 | .690 |
| | Within Groups | 47.238 | 74 | .638 | | |
| | Total | 47.714 | 76 | | | |
| TS10 | Between Groups | .335 | 2 | .168 | .256 | .775 |
| | Within Groups | 48.548 | 74 | .656 | | |
| | Total | 48.883 | 76 | | | |
| TS11 | Between Groups | 1.344 | 2 | .672 | .761 | .471 |
| | Within Groups | 65.357 | 74 | .883 | | |
| | Total | 66.701 | 76 | | | |
| TS12 | Between Groups | .483 | 2 | .241 | .326 | .723 |
| | Within Groups | 54.738 | 74 | .740 | | |
| | Total | 55.221 | 76 | | | |

**Table 19-9: The F-value and significant value of the ANOVA analysis.**

## Envelope design Resilience Strategies:

**ANOVA**

| | | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| ES1 | Between Groups | .519 | 2 | .260 | .437 | .648 |
| | Within Groups | 44.000 | 74 | .595 | | |
| | Total | 44.519 | 76 | | | |
| ES2 | Between Groups | .312 | 2 | .156 | .284 | .753 |
| | Within Groups | 40.571 | 74 | .548 | | |
| | Total | 40.883 | 76 | | | |
| ES3 | Between Groups | 4.669 | 2 | 2.334 | 2.267 | .111 |
| | Within Groups | 76.214 | 74 | 1.030 | | |
| | Total | 80.883 | 76 | | | |
| ES4 | Between Groups | 1.247 | 2 | .623 | .803 | .452 |
| | Within Groups | 57.429 | 74 | .776 | | |
| | Total | 58.675 | 76 | | | |
| ES5 | Between Groups | 3.721 | 2 | 1.860 | 2.830 | .065 |
| | Within Groups | 48.643 | 74 | .657 | | |
| | Total | 52.364 | 76 | | | |
| ES6 | Between Groups | .286 | 2 | .143 | .201 | .818 |
| | Within Groups | 52.571 | 74 | .710 | | |
| | Total | 52.857 | 76 | | | |
| ES7 | Between Groups | .519 | 2 | .260 | .340 | .713 |
| | Within Groups | 56.571 | 74 | .764 | | |
| | Total | 57.091 | 76 | | | |
| ES8 | Between Groups | 2.104 | 2 | 1.052 | 1.481 | .234 |
| | Within Groups | 52.571 | 74 | .710 | | |
| | Total | 54.675 | 76 | | | |
| ES9 | Between Groups | .615 | 2 | .307 | .539 | .586 |
| | Within Groups | 42.190 | 74 | .570 | | |
| | Total | 42.805 | 76 | | | |
| ES10 | Between Groups | 1.931 | 2 | .965 | 1.861 | .163 |
| | Within Groups | 38.381 | 74 | .519 | | |
| | Total | 40.312 | 76 | | | |
| ES11 | Between Groups | .677 | 2 | .339 | .432 | .651 |
| | Within Groups | 58.024 | 74 | .784 | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| | Total | 58.701 | 76 | | | |
| ES12 | Between Groups | 1.175 | 2 | .588 | .749 | .476 |
| | Within Groups | 58.071 | 74 | .785 | | |
| | Total | 59.247 | 76 | | | |
| ES13 | Between Groups | .649 | 2 | .325 | .450 | .640 |
| | Within Groups | 53.429 | 74 | .722 | | |
| | Total | 54.078 | 76 | | | |
| ES14 | Between Groups | .615 | 2 | .307 | .391 | .678 |
| | Within Groups | 58.190 | 74 | .786 | | |
| | Total | 58.805 | 76 | | | |
| ES15 | Between Groups | .597 | 2 | .299 | .377 | .687 |
| | Within Groups | 58.571 | 74 | .792 | | |
| | Total | 59.169 | 76 | | | |
| ES16 | Between Groups | .344 | 2 | .172 | .305 | .738 |
| | Within Groups | 41.786 | 74 | .565 | | |
| | Total | 42.130 | 76 | | | |
| ES17 | Between Groups | 1.844 | 2 | .922 | 1.231 | .298 |
| | Within Groups | 55.429 | 74 | .749 | | |
| | Total | 57.273 | 76 | | | |
| ES18 | Between Groups | 1.747 | 2 | .873 | 1.097 | .339 |
| | Within Groups | 58.929 | 74 | .796 | | |
| | Total | 60.675 | 76 | | | |
| ES19 | Between Groups | .009 | 2 | .004 | .007 | .993 |
| | Within Groups | 48.667 | 74 | .658 | | |
| | Total | 48.675 | 76 | | | |
| ES20 | Between Groups | .214 | 2 | .107 | .174 | .840 |
| | Within Groups | 45.500 | 74 | .615 | | |
| | Total | 45.714 | 76 | | | |
| ES21 | Between Groups | 1.050 | 2 | .525 | .606 | .548 |
| | Within Groups | 64.119 | 74 | .866 | | |
| | Total | 65.169 | 76 | | | |
| ES22 | Between Groups | .312 | 2 | .156 | .150 | .861 |
| | Within Groups | 76.857 | 74 | 1.039 | | |
| | Total | 77.169 | 76 | | | |
| ES23 | Between Groups | 1.626 | 2 | .813 | 1.380 | .258 |
| | Within Groups | 43.595 | 74 | .589 | | |
| | Total | 45.221 | 76 | | | |
| ES24 | Between Groups | 2.935 | 2 | 1.468 | 2.223 | .115 |
| | Within Groups | 48.857 | 74 | .660 | | |
| | Total | 51.792 | 76 | | | |
| ES25 | Between Groups | 2.738 | 2 | 1.369 | 2.253 | .112 |
| | Within Groups | 44.976 | 74 | .608 | | |
| | Total | 47.714 | 76 | | | |
| ES26 | Between Groups | .519 | 2 | .260 | .368 | .694 |
| | Within Groups | 52.286 | 74 | .707 | | |
| | Total | 52.805 | 76 | | | |
| ES27 | Between Groups | .162 | 2 | .081 | .119 | .888 |
| | Within Groups | 50.643 | 74 | .684 | | |
| | Total | 50.805 | 76 | | | |
| ES28 | Between Groups | .312 | 2 | .156 | .251 | .779 |
| | Within Groups | 46.000 | 74 | .622 | | |
| | Total | 46.312 | 76 | | | |
| ES29 | Between Groups | 1.812 | 2 | .906 | 1.442 | .243 |
| | Within Groups | 46.500 | 74 | .628 | | |
| | Total | 48.312 | 76 | | | |
| ES30 | Between Groups | .961 | 2 | .481 | .629 | .536 |
| | Within Groups | 56.571 | 74 | .764 | | |
| | Total | 57.532 | 76 | | | |
| ES31 | Between Groups | .312 | 2 | .156 | .190 | .828 |
| | Within Groups | 60.857 | 74 | .822 | | |
| | Total | 61.169 | 76 | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| ES32 | Between Groups | .390 | 2 | .195 | .252 | .778 |
| | Within Groups | 57.143 | 74 | .772 | | |
| | Total | 57.532 | 76 | | | |

**Table 19-10: The F-value and significant value of the ANOVA analysis.**

## System design Resilience Strategies:

**ANOVA**

| | | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| YS1 | Between Groups | 10.286 | 2 | 5.143 | 5.894 | .004 |
| | Within Groups | 64.571 | 74 | .873 | | |
| | Total | 74.857 | 76 | | | |
| YS2 | Between Groups | .407 | 2 | .203 | .285 | .753 |
| | Within Groups | 52.762 | 74 | .713 | | |
| | Total | 53.169 | 76 | | | |
| YS3 | Between Groups | .216 | 2 | .108 | .172 | .843 |
| | Within Groups | 46.667 | 74 | .631 | | |
| | Total | 46.883 | 76 | | | |
| YS4 | Between Groups | .130 | 2 | .065 | .088 | .916 |
| | Within Groups | 54.857 | 74 | .741 | | |
| | Total | 54.987 | 76 | | | |
| YS5 | Between Groups | .128 | 2 | .064 | .104 | .901 |
| | Within Groups | 45.405 | 74 | .614 | | |
| | Total | 45.532 | 76 | | | |
| YS6 | Between Groups | .009 | 2 | .004 | .005 | .995 |
| | Within Groups | 59.524 | 74 | .804 | | |
| | Total | 59.532 | 76 | | | |
| YS7 | Between Groups | 1.816 | 2 | .908 | 1.279 | .284 |
| | Within Groups | 52.548 | 74 | .710 | | |
| | Total | 54.364 | 76 | | | |
| YS8 | Between Groups | 1.071 | 2 | .536 | .757 | .473 |
| | Within Groups | 52.357 | 74 | .708 | | |
| | Total | 53.429 | 76 | | | |
| YS9 | Between Groups | .128 | 2 | .064 | .078 | .925 |
| | Within Groups | 60.548 | 74 | .818 | | |
| | Total | 60.675 | 76 | | | |
| YS10 | Between Groups | .996 | 2 | .498 | .696 | .502 |
| | Within Groups | 52.952 | 74 | .716 | | |
| | Total | 53.948 | 76 | | | |
| YS11 | Between Groups | 2.478 | 2 | 1.239 | 1.209 | .304 |
| | Within Groups | 75.833 | 74 | 1.025 | | |
| | Total | 78.312 | 76 | | | |
| YS12 | Between Groups | 3.082 | 2 | 1.541 | 2.424 | .096 |
| | Within Groups | 47.048 | 74 | .636 | | |
| | Total | 50.130 | 76 | | | |
| YS13 | Between Groups | .509 | 2 | .254 | .320 | .727 |
| | Within Groups | 58.738 | 74 | .794 | | |
| | Total | 59.247 | 76 | | | |
| YS14 | Between Groups | 2.294 | 2 | 1.147 | 1.621 | .205 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | Within Groups | 52.381 | 74 | .708 | | |
| | Total | 54.675 | 76 | | | |
| YS15 | Between Groups | 2.900 | 2 | 1.450 | 1.800 | .172 |
| | Within Groups | 59.619 | 74 | .806 | | |
| | Total | 62.519 | 76 | | | |
| YS16 | Between Groups | .511 | 2 | .255 | .335 | .717 |
| | Within Groups | 56.476 | 74 | .763 | | |
| | Total | 56.987 | 76 | | | |

**Table 19-11: The F-value and significant value of the ANOVA analysis.**

**YS1**

Tukey HSD[a,b]

| exp | N | Subset for alpha = 0.05 |
|---|---|---|
| | | 1 |
| 1 | 42 | 3.12 |
| 2 | 21 | 3.76 |
| 3 | 14 | 3.79 |
| Sig. | | .060 |

## Operation design Resilience Strategies:

**ANOVA**

| | | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| OS1 | Between Groups | 2.639 | 2 | 1.319 | 1.018 | .366 |
| | Within Groups | 95.881 | 74 | 1.296 | | |
| | Total | 98.519 | 76 | | | |
| OS2 | Between Groups | .240 | 2 | .120 | .153 | .858 |
| | Within Groups | 58.071 | 74 | .785 | | |
| | Total | 58.312 | 76 | | | |
| OS3 | Between Groups | 3.983 | 2 | 1.991 | 1.566 | .216 |
| | Within Groups | 94.095 | 74 | 1.272 | | |
| | Total | 98.078 | 76 | | | |
| OS4 | Between Groups | 2.366 | 2 | 1.183 | 1.090 | .342 |
| | Within Groups | 80.310 | 74 | 1.085 | | |
| | Total | 82.675 | 76 | | | |

**Table 19-12: The F-value and significant value of the ANOVA analysis.**

# Appendix F: Gephi Codes

Gephi Code:

| No | Code | No | Code | No | Code | No | Code |
|---|---|---|---|---|---|---|---|
| 1 | PR1 | 41 | SR6 | 81 | LS6 | 121 | ES20 |
| 2 | PR2 | 42 | SR7 | 82 | LS7 | 122 | ES21 |
| 3 | PR3 | 43 | SR8 | 83 | LS8 | 123 | ES22 |
| 4 | PR4 | 44 | SR9 | 84 | LS9 | 124 | ES23 |
| 5 | PR5 | 45 | SR10 | 85 | LS10 | 125 | ES24 |
| 6 | PR6 | 46 | SR11 | 86 | LS11 | 126 | ES25 |
| 7 | PR7 | 47 | SR12 | 87 | LS12 | 127 | ES26 |
| 8 | PR8 | 48 | SR13 | 88 | LS13 | 128 | ES27 |
| 9 | PR9 | 49 | SR14 | 89 | LS14 | 129 | ES28 |
| 10 | PR10 | 50 | SR15 | 90 | TS1 | 130 | ES29 |
| 11 | PR11 | 51 | SR16 | 91 | TS2 | 131 | ES30 |
| 12 | PR12 | 52 | SR17 | 92 | TS3 | 132 | ES31 |
| 13 | PR13 | 53 | MR1 | 93 | TS4 | 133 | ES32 |
| 14 | PR14 | 54 | MR2 | 94 | TS5 | 134 | YS1 |
| 15 | PR15 | 55 | MR3 | 95 | TS6 | 135 | YS2 |
| 16 | PR16 | 56 | MR4 | 96 | TS7 | 136 | YS3 |
| 17 | PR17 | 57 | MR5 | 97 | TS8 | 137 | YS4 |
| 18 | PR18 | 58 | MR6 | 98 | TS9 | 138 | YS5 |
| 19 | PR19 | 59 | MR7 | 99 | TS10 | 139 | YS6 |
| 20 | PR20 | 60 | MR8 | 100 | TS11 | 140 | YS7 |
| 21 | PR21 | 61 | MR9 | 101 | TS12 | 141 | YS8 |
| 22 | PR22 | 62 | MR10 | 102 | ES1 | 142 | YS9 |
| 23 | ER1 | 63 | MR11 | 103 | ES2 | 143 | YS10 |
| 24 | ER2 | 64 | MR12 | 104 | ES3 | 144 | YS11 |
| 25 | ER3 | 65 | MR13 | 105 | ES4 | 145 | YS12 |
| 26 | ER4 | 66 | MR14 | 106 | ES5 | 146 | YS13 |
| 27 | ER5 | 67 | MR15 | 107 | ES6 | 147 | YS14 |
| 28 | ER6 | 68 | MR16 | 108 | ES7 | 148 | YS15 |
| 29 | ER7 | 69 | SS1 | 109 | ES8 | 149 | YS16 |
| 30 | ER8 | 70 | SS2 | 110 | ES9 | 150 | OS1 |
| 31 | ER9 | 71 | SS3 | 111 | ES10 | 151 | OS2 |
| 32 | ER10 | 72 | SS4 | 112 | ES11 | 152 | OS3 |
| 33 | ER11 | 73 | SS5 | 113 | ES12 | 153 | OS3 |
| 34 | ER12 | 74 | SS6 | 114 | ES13 | | |
| 35 | ER13 | 75 | SS7 | 115 | ES14 | | |
| 36 | SR1 | 76 | LS1 | 116 | ES15 | | |
| 37 | SR2 | 77 | LS2 | 117 | ES16 | | |
| 38 | SR3 | 78 | LS3 | 118 | ES17 | | |
| 39 | SR4 | 79 | LS4 | 119 | ES18 | | |
| 40 | SR5 | 80 | LS5 | 120 | ES19 | | |