EVIDENCE AND DESIGN: AN INVESTIGATION OF THE USE OF EVIDENCE IN THE DESIGN OF HEALTHCARE ENVIRONMENTS

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Ph.D Thesis **2013**

EVIDENCE AND DESIGN: AN INVESTIGATION OF THE USE OF EVIDENCE IN THE DESIGN OF HEALTHCARE ENVIRONMENTS

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Submitted in Partial Fulfilment of the Requirements of the Degree of Doctor of Philosophy, February 2013

CONTENTS

ACKNOWLEDGEMENTS **12**

DECLARATION **13**

ACRONYMS **14**

ABSTRACT **15**

1 INTRODUCTION **16**

1.1 Background *16*

1.2 Research Problem *17*

1.3 Focus and Scope of the Research *20*

1.4 Contributions to Knowledge *20*

1.5 Outline Research Methodology *21*

1.6 Structure of Thesis *22*

2 RESEARCH METHOD **24**

2.1 Research Process *25*

2.2 Research Strategy *29*

2.2.1 Summary 33

2.3 Research Design *34*

2.3.1 Research Method Part 1 35

2.3.2 Research Method Part 2 35

2.3.3 Research Method Part 3 37

3 PHILOSOPHICAL ANALYSIS OF EVIDENCE **44**

3.1 Introduction *44*

3.2 Ontology *46*

3.3 Epistemology *47*

3.3.1 Knowledge 48

3.3.2 Sources of Knowledge 52

3.3.3 Skepticism 57

3.3.4 Summary and Discussion 60

3.4 Evidence *61*

3.4.1 Etymology 62

3.4.2 Definitions 62

3.4.3 Characterisation of Evidence 63

3.4.4 Classification of Evidence in relation to the Source of Reasoning 68
3.4.5 Roles of Evidence 69
3.4.6 Summary and Discussion 70
3.5 Theory Building 71
3.5.1 Definitions and Terms 72
3.5.2 Functions 75
3.5.3 Trade-offs 76
3.5.4 Summary and Discussion 78
3.6 Conceptual Framework of Evidence 80
4 PRESCRIPTIVE DESIGN METHODS 83
4.1 The Method of Analysis and Synthesis 85
4.1.1 Analysis and synthesis: Ancient Description 85
4.1.2 Prior to Analysis and Synthesis 86
4.1.3 Analysis 90
4.1.4 Synthesis 100
4.2 Modern Design Methods and Analysis and Synthesis 110
4.2.1 Morris Asimow 110
4.2.2 Herbert Simon 115
4.2.3 Thomas Markus and Thomas Maver 120
4.2.4 Leonard Bruce Archer 122
4.2.5 Vladimir Hubka and W. Ernst Eder 126
4.2.6 Kevin Forsberg and Hal Mooz 130
4.2.7 Nam Suh 135
4.2.8 Armand Hatchuel and Benoit Weil 140
4.2.9 Bryan Lawson 145
4.2.10 Empirical Observation in Healthcare Facilities Design 148
4.2.11 Discussion 151
4.3 Evidence and the Method of Analysis and Synthesis 156
5 EXTERNAL EVIDENCE IN DESIGN 166
5.1 Evidence-Based Design: Process Overview 167
5.2 The Built Environment and Health Outcomes: Evidence Characterisation 172
5.2.1 The Theoretical Principles linking the Built Environment and Well-being 174
5.2.2 Measures of Health and Well-being 178
5.2.3 Characteristics of Individuals 182

5.2.4 Characterisation of the Built Environment in Healthcare 185
5.2.5 Evidence: The Impact of the Built Environment on Health Outcomes 190
5.2.6 Summary and Final Considerations 196
5.3 External Evidence from Project Investigation 199
5.4 Discussion – External Evidence in Design 200
5.4.1 EBD as External Evidence 201
5.4.2 Experience as External Evidence 203
5.4.3 External Evidence and JTB 203
6 SUMMARY AND CONCLUSIONS 206
6.1 Significance and Relevance to Research and Practice 213
6.2 Limitations of the Research 214
6.3 Recommendations for Further Research 215
7 REFERENCES 217
8 APPENDICES 251
8.1 Appendix 1 - Systematic Literature Review Process: A Discussion 252
8.2 Appendix 2 - List of academic journals publishing articles about BE&HO 268
8.3 Appendix 3 - Glossary of Terms 275
8.4 Appendix 4 – Evidence data base: data preparation 277
8.5 Appendix 5 – Observation of Design Meetings 287
8.6 Appendix 6 – Design process models 304
8.6.1 Markus and Maver process model 304
8.6.2 Archer process model 304
8.6.3 Hubka and Eder process models 304
8.6.4 Forsberg and Mooz process model 307
8.6.5 Nam Suh process model 308
8.6.6 Bryan Lawson process model 309
8.7 Appendix 7 – Better informed decisions through evidence-based design 310
8.8 Appendix 8 - The method of analysis in production management 321

LIST OF FIGURES

Figure 1 – Outline research methodology 21

Figure 2 - Overview of analytical and synthetic routes.. 33

Figure 3 - Research Design 34

Figure 4 – Ontological and epistemological arrangement matrix (adapted from Johnson and Duberley 2004; and Lantelme 2005) 57

Figure 5 – Conceptual framework for assessing evidence in a knowledge formation system. 82

Figure 6 – Descartes and Pappus decomposition (Adapted from: Gedenryd, 1998) 94

Figure 7 – Solution for proposition I 95

Figure 8 - Iteration in the method of analysis and synthesis and in the design process........... 154

Figure 9 – Descartes' hierarchical decomposition (adapted from Gedenryd, 1998).............. 157

Figure 10 – Hierarchical decomposition interpretation of design... 158

Figure 11 - Hierarchical decomposition interpretation of design prior production 159

Figure 12 - Hierarchical decomposition interpretation of design post construction 160

Figure 13 – The 'Vee' model and analysis and synthesis 161

Figure 14 – The 'Vee' model with an additional validation process 162

Figure 15 – Transformative feature of analysis and synthesis and the 'Vee' model................. 163

Figure 16 – Evidence in Design: Conceptual framework.. 164

Figure 17 - An evidence model for the pharmacologic treatment of obesity (Source: Mulrow *et al*., 1997) 171

Figure 18 - Relationships among measures of patient outcomes in a health-related quality of life conceptual model (Source: Wilson and Cleary, 1995) 180

Figure 19 – Framework for the built environment in healthcare facilities.................................. 187

Figure 20 - Evidence in Design: Conceptual framework 200

Figure 21 – Evidence, justification, truth and belief 205

Figure 22 – Internal and external evidence in design 210

Figure 23 - Framework of cause and effects relationships 265

Figure 24. Knowledge areas and health outcomes framework 267

Figure 25 - The Markus/Maver map of the design process (Source: Lawson, 2006)................. 304

Figure 26 - A breakdown of basic design procedure 304

Figure 27 - The main phases of design 304

Figure 28 - "Black Box" Block Diagram of the Design Process (Hubka and Eder, 1996) 305

Figure 29 – General model of the transformation systems – parts 1 and 2 (Hubka and Eder, 1996).. 305

Figure 30 – Models of technical systems (TS Model) (Hubka and Eder, 1996)........................... 306

Figure 31 – Overview of the technical aspect of the project cycle (The "Vee") (Adapted from: Forsberg and Mooz, 1991) 307

Figure 32 - System Analysis and Design Process (Adapted from: Forsberg and Mooz, 1991) 307

Figure 33 - System Verification and Integration Process (Adapted from: Forsberg and Mooz, 1991)... 308

Figure 34 – Four domains of the design world (Suh, 2001) 308

Figure 35 - The design process seen as a negotiation between problem and solution through the three activities of analysis, synthesis and evaluation (Lawson 2006). 309

LIST OF TABLES

Table 1 - Searched databases.. 39

Table 2 - Selected keywords 40

Table 3 - Manual inclusion criteria 41

Table 4 - Quality assessment criteria 41

Table 5 - Elements of a theory according to different authors 74

Table 6 - Functions of a theory according to its relation with its scientific and practical use 76

Table 7 – Ontological and epistemological approaches as related to the argument of illusion 81

Table 8 – Analysis and Synthesis as complementary methods 109

Table 9 - Comparative investigation of analysis and synthesis and Asimow (1962) 115

Table 10 – Comparative investigation of analysis and synthesis and Simon (1969; 1988) 119

Table 11 - Comparative investigation of analysis and synthesis and Markus and Maver (1969; 1970) 122

Table 12 - Comparative investigation of analysis and synthesis and L.B. Archer (1979; 1984) 126

Table 13 - Comparative investigation of analysis and synthesis and Hubka and Eder (1996) 130

Table 14 - Comparative investigation of analysis and synthesis and Forsberg and Mooz (1994; 1998) 134

Table 15 – Domains characteristics for different designs (Suh, 2001) 137

Table 16 - Comparative investigation of analysis and synthesis and Nan Suh (2001) 140

Table 17 - Comparative investigation of analysis and synthesis and Hatchuel and Weil (2002; 2003) 144

Table 18 - Comparative investigation of analysis and synthesis and Lawson (2006) 147

Table 19 - Comparative investigation of analysis and synthesis and observation of design meetings 150

Table 20 – Analysis, synthesis and modern design methods – cross analysis 152

Table 21 - Existing theories about the effects of the environment on humans' reaction 177

Table 22 – Categories and related health outcomes 181

Table 23 – Categories and characteristics of individuals 184

Table 24 – Characteristics and their variants in healthcare facilities 189

Table 25 - Protocol for data extraction (adapted from Boaz *et al.* 2002) 257

Table 26 - Sources of further information on Systematic Literature Reviews 260

Table 27 – Academic Journals Publishing Articles about BE&HO 268

EPIGRAPH

"And there was never agreement amongst them. If they could speak the same language, they would realise they were saying exactly the same things." Ricardo Codinhoto, 24th of March 2012.

To my mum…

ACKNOWLEDGEMENTS

The undertaking of a PhD thesis is an extremely challenging task. During the time of carrying out the research and writing I received support and help from many people. In particular, I am profoundly indebted to my supervisor, Professor Mike Kagioglou, and co-supervisor, Professor Lauri Koskela, who were very generous with their time, knowledge and patience and assisted me in each step along the way to completing the thesis.

I am extremely grateful to the School of the Built Environment at The University of Salford, to the Salford Centre for Research and Innovation (SCRI), the Health and Care Infrastructure Research and Innovation Centre (HaCIRIC) who granted me a scholarship to the PhD programme at Salford University.

Many thanks also go to my colleagues for their time spent listening and discussing the research topics addressed in this thesis, for their friendship in times of despair (when you really believe that you will not achieve the end of the writing process), for their encouragement and kind words throughout the years. I am grateful to all and in particular my friends Dr. Bronwyn Platten, Dr. Christopher Boyko, Dr. Clementinah Rooke (big sister); Dr. John Rooke, Mrs. Kathryn Yates ('lil' syster), Lisiane Lima, Dr. Patricia Tzortzopoulos, Mrs Rita Newton, Miss Sheila Walker, Mr. Stelios Sapountzis, Dr. Therese Lawlor Wright and Dr. Tuba Kocaturk.

Last, but not least, thanks goes to my whole family who have been an important and indispensable source of spiritual support. Special thanks to my dad, Mr Rui Codinhoto (you inspire me) and to my partner Jamie Rowlands his love, support and attention.

However, I am the only person responsible for errors in the thesis.

DECLARATION

The systematic review presented in this thesis was conducted as part of another research project, hence, the acknowledgement of co-authors. The role of the PhD candidate in conducting the review was to define the systematic method for compilation of 'evidence'; to perform the search for articles complying with the systematic criteria; and to write the reports that were presented as outputs of the related research projects. Co-authors contributed through the discussion of the findings with the researcher. The interpretation of the data generated in the systematic review, as promoted in this thesis, was not published in those reports, and did not have the participation of the above-mentioned co-authors.

ACRONYMS

ANSI: American National Standards Institute

ASHRAE: American Society of Heating, Refrigerating and Air-Conditioning

ASSIA: Applied Social Sciences Index and Abstracts

BE: Built Environment

CA: Costumer Attributes

CABE: Commission for Architecture and the Built Environment

CHD: Centre for Health Design

CINAHL: Cumulative Index to Nursing and Allied Health Literature

CR: Client Representative

DAAI: Design and Applied Arts Index

DFX: Design for X

DP: Design Parameters

DT: Design Team

EBM: Evidence-Based Medicine

EDAC: Evidence-based Design Accreditation and Certification

EE: External Evidence

FR: Functional Requirements

HMIC: Health management information Consortium

HO: Health Outcome

IDEF0: Integration DEFinition for Function Modeling

IE: Internal Evidence

ISO: International Standards Organisation

JTB: Justification, Truth and Belief

NASA: National Aeronautics and Space Administration

NHS: National Health System (UK)

OCCL: Online Computer Library Center

PDR: Preliminary Design Review

POE: Post Occupancy Evaluation

PV: Process Variables

QFD: Quality Function Deployment

RIBA: Royal Institute of British Architects

ROI: Return on Investment

SLR: Systematic Literature Review

SRR: System Requirement Review

WHO: World Health Organisation

ABSTRACT

In construction many problems exist that lead to poor quality of the built environment, for example, lack of integration between service and facility design and poor requirements management. Aiming to mitigate these problems, academics and practitioners have engaged in debating ways of improving the process of designing new facilities. One of the approaches that has been investigated is the use of scientific evidence to support decision makers within the design process. This process is called evidence-based design (EBD). In this respect, a range of studies developed in healthcare sectors encourages the application of EBD in order to add value to the design of these environments and to produce better building outcomes for patients and staff. In this respect, this study was designed to address this issue and is aimed at better understanding how evidence supports design. The achievement of the aim was based on (a) revisiting the philosophical debate about the definitions of evidence and knowledge formation to propose a conceptual framework that can be used to classify evidence within the design domain; (b) investigating the proposed use of evidence within prescriptive design methods of design; (c) understanding how evidence has been used in design practice (specifically in the design of healthcare facilities) and to propose a taxonomy for different categories of evidence that support building design and their advantages and disadvantages; and (d) exploring the existence of opportunities to improve design practice with a basis on a better understanding of evidence. The focus of the research was the design process of healthcare facilities and the unit of analysis was the role of evidence within design. The findings of this research enhance our understanding of design as a knowledge formation system. In this respect, the use of this approach opens opportunities for future studies related to the interpretation and the development of tools that assist design. This research also provides insights related to analysis and synthesis as the proto-theory of design as well as distributed intelligence in design.

1 INTRODUCTION

1.1 Background

Problems related to value loss in building design are well known (Huovila *et al*., 1997; Koskela, 2000). Common problems include clients' requirements not being captured or lost throughout the design process; little improvement and optimisation of design solutions and mistakes whilst developing design (Huovila *et al*., 1997). Solutions developed to date are considered to be still insufficient to resolve these issues.

Many authors discuss problems associated with the design process in construction including Cross *et al.*, 1981; Cooper *et al.*, 2003; Dorst, 2006; Koskela and Kagioglou, 2006b; Lawson, 2006. In general, the range of problems associated with design vary from the integration of the design team as discussed by Huovila *et al.* (1994), practical issues related to the exchange of information as suggested by Cooper *et al.* (2003) to the lack of a unified design theory as argued by Bayazit (2004). Contributions to the improvement of the design process come from many areas. For instance, there are several works that discuss design theory. Amongst these are the suggestion of design principles and the axiomatic design approach (Suh 1998; 2001), the method of analysis and synthesis as argued by Gedenryd (1998), Koskela & Kagioglou (2006) and Koskela *et al*. (n.d.); also the C-K Theory (Hatchuel & Benoît Weil 2002; 2003; 2008).

Research also exists to support the development of systematic tools to assist design such as Design for X (DFX - Pahl and Beitz, 1996), Quality Function Deployment (QFD - Kamara *et al*., 2000; Bruseberg & Mcdonagh-philp 2000; Tzortzopoulos *et al*., 2002), the Integration DEFinition for Function Modeling (IDEF0 - Austin *et al*., 1994; Austin *et al*., 1999; Austin et al., 2000; Austin *et al*., 2001; and Thomson *et al*., 2006); the Last Planner System (Miles, 1998; Tzortzopoulos *et al*., 2001; Codinhoto, 2003; Trescastro, 2005); and design approaches such as Concurrent Engineering (Prasad, 1996; Kamara *et al*., 2000; Codinhoto, 2003) and Evidence-based Design (Ulrich *et al*., 2004; Codinhoto *et al*., 2008).

However, the lack of a common understanding about design hinders relevant improvements of the design practice (Love, 2000; 2002) and impedes proper communication across different fields of design such as the arts, science and technology (Love, 2002 and Cross, 2006). It also makes challenging the investigation of the '*raison d'être*' of current pragmatic approaches that supports value generation and reduces value loss within design.

Thus, the development of the design science field is entangled due to the lack of nexus between theory and practice. On the one hand, design theory lacks common principles to support better design practice. Consequently, design practice suffers with the constant increase of product complexity and the numbers of intervenients necessary to design a product leading to complicated issues related to the explicit control of multidisciplinary work and the traceability of shared responsibility (Kocaturk & Codinhoto, 2009). Hence, these two sides of design must be better understood. In this respect, the perspective adopted and the specific research problem targeted in this thesis are presented in the following section.

1.2 Research Problem

Towards the end of the first decade of the 21st century, there are many issues impacting design. Firstly, the continuous pressure related to the development of products and processes in a context of increasing complexity. Also, innovative solutions that promote better performance are constantly demanded from designers. Moreover, risk-averse organisations impose more and more parameters for which products and processes have to comply with. Finally, the increased competition enforces financial pressures and contracts the time for the development of products that involves an expanded group of experts. These, amongst other problems are general issues across all fields of design.

In this thesis, focus is placed on the design of healthcare facilities. This area is chosen as the design of healthcare facilities has additional internal and external complexities. Externally, for instance, it involves providing care in an environment that is constantly changing to accommodate the needs of a continuous evolving demographic configuration. Internally, on the other hand, is the search for continuous improvements that escalates the need for constant change. In this case, improvement is sought through many ways. For instance, by setting higher efficiency and efficacy targets, through the incorporation of constantly emerging medical and service innovations, and also by systematically considering the requirements of a vast number of stakeholders with conflicting demands (Tzortzopoulos *et al.,* 2006).

This need for constant change in the demand and in the environment where healthcare is delivered has led to the development of lessons about which solutions works and which ones does not. In this respect, many authors (as compiled by Evans, 1998; Ulrich *et al*., 2004; 2008) have argued that there design features and characteristics of the built environment can have positive and negative physical and psychological impacts on patients and staff. Thus, an alternative to the improvement of healthcare delivery has also been sought through the development of state-of-the-art infrastructure that incorporates these healing characteristics.

In searching for evidence to support the idea that design impacts on peoples health, the concept of a managerial approach that was originally developed in the medical field (and so called evidence-based medicine) has been applied to the improvement of healthcare building design. The dispute underpinning such argument is based on the premise that the use of scientific evidence can support decision-making in the development of better healthcare facilities. This approach became known as evidence-based design (EBD). The use of scientific evidence to support decision-making is in principle a simple and powerful concept. The underpinning concept is that evidence can be used to support the solving of trade-offs in design as it does in medicine. Thus, conflicting requirements that are commonplace, and decision-making structures that tend to be complex (Campobasso and Hosking, 2004) and dynamic can be dealt with.

Despite the emerging relevance of this conceptual approach, the process of embedding evidence within design as well as the concept of evidence itself and the categories of evidence that have been used in the design are not clear within the design literature. For instance, the Centre for Health Design developed the Evidence-based Design Accreditation (EDAC) initiative (CHD, 2008a, 2008b, and 2008c). This group provide guidelines for the implementation of the EBD approach, however, the discussion about what is evidence and the role it plays within design is only briefly addressed. More importantly, the role of evidence is not discussed with clarity amongst those (mentioned above) developing theories and methods for design, thus revealing an important knowledge gap in design theory and practice.

However, it is unacceptable to think that knowledge about the concept of evidence and the role it plays does not exist. Indeed, knowledge is the subject discussed in the field of epistemology, and so is evidence. In current times relevant academics discussing its concept include the works of (Carnap 1936; 1937; 1945; 1946; 1948) and the debate promoted by (Achinstein 1978; 1994; 1995; 1998) and the seminal work developed by (Gettier 1966). Understanding about the concept of evidence is also promoted within theories of knowledge and knowledge formation as those proposed in the works of Goldman (1967; 1976); Unger (1968); Lehrer & Paxson Jr (1969); Williamson (1997); Harman (2003); O'Brien (2006) and Morton (2008).

Despite the availability of literature in the philosophical domain, the bridge linking this area of knowledge with the design domain seems rather fragile or inexistent. Therefore, in view of the current practical problems faced by designers and the lack of a common theoretical understanding about evidence within the design field, the research question formulated in this study is:

How evidence supports better design in the context of healthcare facilities?

The objectives of this study are:

1. Revisiting the philosophical debate about the definitions of evidence and knowledge formation. In this respect, the a priori definitions of evidence and knowledge were investigated and the conceptual elements encompassed within these constructs were identified and used as a field independent conceptual framework for the identification and classification of evidence.
2. Investigating the proposed use of evidence within systematic design methods of design. This investigation involved comparing relevant design models and identifying the features that compose current design process models. In this respect, the 'holistic model' was interpreted as a knowledge formation system so to generate understanding about evidence in design.
3. Understanding how evidence is used in design practice (specifically in the design of healthcare facilities). The classification of 'use' of evidence in practice is based

on the conceptual framework developed and envisaged explaining the use of evidence in the context of healthcare facilities design.

4. Discuss the existence of opportunities to improve design practice with a basis on a better understanding of evidence

1.3 Focus and Scope of the Research

The focus of this thesis is the design process in the construction industry. Overall, researchers in the field of product development (in many industries) highlight that it is within the design process that major improvements to the product and its production process are achieved. The design process can be defined in a variety of ways. For example, as referring to the managerial phases and stages throughout the product development process as defined by Clark and Fujimoto (1991), Clark and Wheelwright (1993), Pahl and Beitz (1996), Ulrich and Eppinger (2000), Crawford and Benedetto (2000). This process can also refer to the cognitive process used to generate design solutions, as discussed in the works of Hatchuel and Weil (2002; 2003; 2008); (Suh 1990; 2001) and Koskela and Kagioglou (2006) and Koskela *et al.*, (n.d.) amongst others.

In this thesis, both concepts are investigated to form an overview related to the current understanding about the emergence of evidence within the cognitive and managerial process of design. To this end, prescriptive (cognitive) models of design are interpreted as a knowledge generation system. These models were chosen from different fields of design. In regards to managerial process, it is part of the scope of this thesis to closely examine the use of evidence within the conceptual design phase of healthcare buildings. All other design phases are excluded from the scope of this thesis. Finally, it is assumed that the investigation of both viewpoints is necessary to link theory with practice.

1.4 Contributions to Knowledge

This research aims at contributing to knowledge by investigating the role of evidence within current developments in the theory and practice of design. It also focuses on identifying how initial stages of design can benefit most from using a deeper concept of evidence. As it will be demonstrated throughout the development of this thesis, the different roles, hierarchies, qualities, uses and release of evidence within the design process has been neglected and there is confusion in relation to its meaning.

1.5 Outline Research Methodology

Assumptions: the ontological approach of this work is realist in nature, i.e. reality exists and can be accessed through our senses. The epistemological approach is rationalist in regards to the definition of concepts and empiricist to the extent that concepts, once applied can be observed and classified.

The research method proposed for this study was framed within the method of analysis and synthesis. In this respect, the analytical route is adopted and the research work was devised in three phases. Figure 1 depicts the 3 phases that are described in the following paragraphs. The reverse direction of the arrows represents the learning process of the researcher in relation to the migration from the domain-independent discussion of the concept of evidence to the domain-specific (i.e. design domain) application.

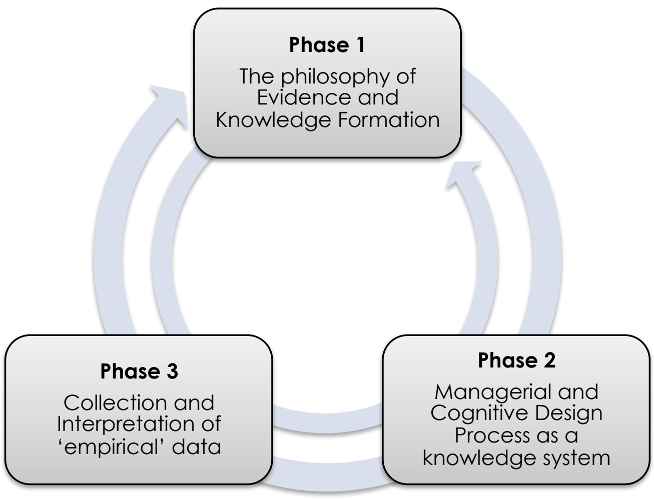

Figure 1 – Outline research methodology

'Phase 1' referred to the philosophical investigation about evidence and knowledge. In this respect, a literature review gave access to the debate about the intelligibility of both concepts (evidence and knowledge) by means of rational argumentation concerning their presuppositions, implications, and interrelationships independently of the field of application. The output of this phase is a conceptual framework to analyse evidence.

Subsequently, 'Phase 2' referred to the investigation of prescriptive cognitive design models followed by its interpretation with the conceptual framework generated in Phase 1. To this end, only prescriptive design models were selected for interpretation. At the end of this section, a discussion is conducted that explains design as a knowledge generation system.

Finally, in 'Phase 3' evidence (as understood in building design practice) was collected and re-interpreted in relation to its role within design and classified as part of a knowledge system. A mixed approach was used for data collection. In this respect, an extensive systematic literature review was carried out as part of the mixed approach. The review focused on compiling data (evidence) about the links between the built environment and its impact on health outcomes. Additionally, data was gathered from the conceptual design phase of a healthcare building design project. Data was collected through non-participant observation in design meetings between the design team and clients representatives. The interpretation of data was done using the conceptual framework generated in Phase 1 and further discussions were elaborated based on Phase 2. Further details about the research method are presented in Chapter 2.

1.6 Structure of Thesis

This thesis is organised in seven chapters, which are summarised as follows.

The first chapter presents a general introduction, outlining the research background, the research problem, the knowledge gap, its aims and objectives, relevance and contributions. It also provides an outline of the research strategy and methodology utilised.

Chapter Two describes the research process. The chapter describes the research approach, design and method adopted in this study. The justification for the selection of sources of evidence is also presented in the chapter. The decision for presenting the methodological chapter up-front relies on the fact that the review of the literature is part of the strategy adopted. Differently from conventional structures, this thesis is not dependent only on the collection of empirical evidence. In this respect, the discussion that precede the collection of empirical data is part of the research and follows a rationalist approach and the conceptual development presented in chapters three and four contribute, to a great extent, to the achievement of the research aims and objectives.

Chapter Three presents an analysis of the concepts ‘evidence’ and ‘knowledge’. The intelligibility of both concepts is discussed by means of rational and field-independent argumentation concerning their presuppositions, implications, and interrelationships. As a result, a conceptual framework that supports the investigation of evidence within a knowledge system is presented within this chapter.

Chapter Four presents an analysis of prescriptive design methods. In total, ten methods were investigated. In this respect, the conceptual framework developed in phase 1 is used to interpret the studied design methods as a knowledge system. For the further understanding of the results in this section, empirical data was collected by means of non-participant observation.

Chapter Five is divided into three main subsections. Subsection one presents an investigation about the evidence-based design approach and the use of evidence in design according to the existing literature about the topic. In subsection two, data was gathered by means of a systematic literature review about the effects of the built environment on health outcomes. Finally, subsection three presents a discussion based on chapters three and four.

Chapter Six concentrates on highlighting the main conclusions of the research. In this chapter, the achievement of the aims and objectives of the research is also examined and the limitations of the research and recommendations for future research and practice presented.

References are presented in Chapter 7 and Chapter 8 contains the Appendices which provide additional detailed information related to the research.

2 RESEARCH METHOD

Inherent to any research is the selection of an appropriate research method. In this respect, the criteria for selection must account for a research process that is neutral, objective, sound, robust, rigorous, controlled and systematic (Dubin, 1969; Flanigan, 1984; Whetten 1989). This refers not only to the procedures used for theoretical conceptualisation of the phenomenon, data collection and analysis, but also to the chain of decisions that are made and the logic behind the arguments presented.

The phenomenon investigated imposed challenges in the selection of a research process that satisfied all criteria. This was related to a problem already identified by Koskela and Kagioglou (2006) that relates to the lack of clarity related to the conceptualisation of design. According to those authors, the philosophical proposition that explains design is cumbersome, confusing and contradictory, thus requiring a challenging re-investigation of the phenomenon from its philosophical interpretation.

2.1 Research Process

The definition of the research strategy is dependent on the proposed research question that in this thesis was formulated as: What is the role of evidence in design? In this respect, decisions were made at different levels. The range varied from the definition of the epistemological position at its highest level, to the definition of the research strategy and its operationalization at the lowest level. The decisions required awareness of the different approaches and what they offered to the research. Certain decisions were made with a focus on that criterion, whereas others based on the limitations of carrying out the study.

In respect to the research philosophy, the proposed research question was open to two contrasting epistemological streams from which the research could have been developed. The first refers to the adoption of an empiricist approach that relies on data collected from sensorial observation. In this research, adopting an empiricist perspective would have implied the observation of the phenomenon 'design' and the occurrence of patterns related to the use of 'evidence' within it. The definitions of concepts 'design' and 'evidence' would have been established and the relationships inferred from sensorial experience and observation. Such an approach (inductive empiricism) finds its foundations on the use of analogy and as such it carries out disadvantages, which are discussed in Section 4.1.4.

The second refers to a rationalist approach and in particular the 'intuition/deduction thesis' (Markie, 2013). According to Markie (2013) the intuition/deduction thesis refer to knowledge being obtained either through intuition or from deduction that is derived from our intuition. In this respect, deduction refers to studies where a conceptual and theoretical structure is developed based on a rationalist approach and tested by empirical observation; thus, particular instances are deduced from general inferences moving from the general to the particular (Vickers, 2006).

As discussed by Markie (2013) these streams are not necessarily conflicting. Thus, this research had a rationalist perspective where the concepts and its relationships were investigated not with a basis on sense experience, but with a basis on reason. The deductive approach has advantages in relation to the inductive process, as it does not rely on analogy for the definition of relationships a priori. Another reason for using a deductive approach relates to the fact that previous research in the field of design that were based on inductive methods presented many limitations (these are discussed in Section 2.2.2). Furthermore, the subject of study is atemporal as neither concepts of 'design' and 'evidence' change over time, nor the relationships between them. Thus, making a rationalist approach appropriate.

The method of analysis and synthesis was selected as the research strategy. The selection was made with a basis on the adequacy of the method to the context of the research. In addition, the researcher's own involvement in parallel research investigating the method of analysis and synthesis influenced this decision.

As discussed by Riemann (1866, *as cited in* Ritchey, 1991), the first step within the method of analysis refers to the gathering of knowledge related to the phenomenon investigated so inferences can be drawn (the first step, as well as the whole method of analysis and synthesis is discussed in detail in Section 2.2 and Chapter 4).

The gathering of information started with a literature review about the evidence-based design approach and a systematic review about how the built environment impact on health outcomes. The review provided the first insights in terms of principles justifying the use of evidence within design as well as what has been considered evidence in this particular field. At this stage, no attempt was made in terms of interpreting the data and generating a relationship model between evidence and design.

Concomitantly, the method of analysis and synthesis was investigated as a research strategy for this thesis and as a candidate proto-theory of design (this is also discussed in Chapter 4)[1]. The investigation involved an extensive literature review on the method of analysis and synthesis, and numerous discussions with scholars so to reach consensus in the interpretation of the scarce literature material acquired. Within this stage, a comparison between the method of analysis (as a proto-theory of design) and contemporary candidate theories were made, so to restrict the

[1] Despite the adoption of the method of analysis and synthesis as the research strategy, the testing of the method was not part of the scope of this research.

understanding of evidence within design by looking at the more robust theory (which in fact was confirmed to be the method of analysis). The comparison, involved identifying the principles underpinning the investigated design models. In this respect, empirical evidence was sought to support the findings present in the literature review.

For the empirical research two methods were considered for data collection: unstructured observation or protocol analysis. Both alternatives have limitations related to the reliability of data (as respectively discussed by Kothari, 2004 and Feng and Zeng, 2009). These limitations are inherent to research in design, i.e. design presented in a finished form appears as purely demonstrative; the process as it happens in the mind of the designer is difficult to be captured. Thus, non-participant observations of design meetings were the adopted method, since the interference of the researcher in the process is considerably smaller than in protocol analysis exercises. The observation was focused on identifying actions, comments and decisions that could be associated with the features of the method of analysis (as presented in Table 8). Actions, comments and decisions were registered and the interpretation of data carried out at a later stage.

Last, but not least, the final aspect of gathering information was related to investigating knowledge formation and evidence from a philosophical point of view. This step was not planned in advance and its consideration was an act of insight. The researcher experienced difficulties in understanding the role of evidence by acquaintance with design theories and approaches. These difficulties were overcome by looking at the role of evidence in its original field, i.e. epistemology. A literature review was carried out so to understand the state-of-the-art and the most relevant concepts in the field: knowledge and evidence.

As suggested in the method of analysis, after gathering relevant existing knowledge, the analysis starts by the definition of what the "system" investigated accomplishes. It became clear to the researcher that the goal of design at its most abstract level is to generate knowledge. At this stage, it became clear that design could be interpreted as a knowledge formation system and therefore the role of evidence in knowledge formation was also valid for design.

At this point, contextualisation was required so to understand the role of evidence within a range of design disciplines. Many strategies could have been used such as experiment, case study research or literature review. Both experiment and case study strategies entail a positivistic characteristic predominant in research in engineering design. In this respect, experimental approaches are fundamentally quantitative exercises (Kothari, 2004). In the context of this research, to test all possible variations in terms of roles that evidence plays in design was considered inadequate due to time constraints. Similarly, case study research was not considered adequate. Despite case studies can be essentially qualitative exercises (Yin, 1999; Kothari, 2004) that provides depth of information, this strategy would not have fulfilled, the field independent requirement inherent to the research[2]. Thus, a literature review was the approach chosen and the review carried out to compare the method of analysis with contemporary methods across different design disciplines.

The interpretation of the findings led to the identification of evidence occurring internally and externally to the design process. The literature review was adequate to characterise the use of internal evidence and insufficient to explain external evidence. In this respect, the literature review about the impacts of the built environment on health outcomes provided contextual (empirical) meaning for what is denominated as veridical and potential evidence, but very little in terms of its role within design. The literature reviews about evidence-based design as well as other methods such as post-occupancy evaluation also indicated a gap related to the role of external evidence in the design process. For this purpose, the observations of design meetings were used to support the investigation about the use of external evidence in design. The use of observations for investigating external evidence in design had limitations, as they do not provide multi-disciplinary perspective of the use of evidence in design. It was not possible in this research to use multiple sources of evidence (such as from experiments) to avoid bias inherent to the subjective character of data collection and analysis. These limitations are acknowledged in this thesis. The analysis carried out was of qualitative nature. As argued by Kothari (2004) a qualitative approach is appropriate for discovering the underlying motives behind the phenomenon investigated. In this respect, the observations were revisited so to identify the types of external evidence being used to justify decisions.

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[2] The researcher did not have access to any case study that had a design team formed by designer within different design domains (e.g. industrial design, architectural design, software design).

2.2 Research Strategy

The research method proposed for this study was framed within the method of analysis and synthesis (referred to in this research as 'the method of analysis') as a research strategy[3]. The analytical route (as opposed to the synthetic one) was adopted for the investigation of the roles of evidence in design. The method of analysis does not provide a prescriptive sequence for the development of research. Instead, it provides a powerful structure for discovery (Ritchey, 1996; Koskela and Kagioglou, 2006). The application of the method of analysis in research is novel in current times (even though the method has existed for more than two thousands years).

According to Riemann (1866, as cited in Ritchey, 1991), three important foundations guide the process of gaining knowledge of any system. These foundations include (a) previous knowledge (i.e. knowing the existing/available natural laws and principles related to the investigated system[4]; (b) system objective/function (i.e. to know what the investigated system performs, does or accomplishes. This can be done through empirical observation or experiment of the system in different situations; and (c) systems construction (i.e. to understand which are the parts, components and elements of the system. This type of knowledge can be obtained by understanding the internal structure and processes of the system, especially the relationships between the parts and components.

In this respect, according to Riemann (1866, as cited in Ritchey, 1991), there are two ways of gaining knowledge from a system: by either adopting an analytical route or a synthetic route. The following paragraph briefly explains both routes in the context of Riemann's investigation about the mechanism of the ear.

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[3] It is important to highlight that the method of analysis is used in this thesis as a method for discovery and a candidate theory that explains design. This fact creates difficulties in terms of writing the thesis because it would be expected that the reader has some pre knowledge regarding the method of analysis and synthesis as a method of discovery. Thus, for those less familiar with the method of analysis, it is recommended the reading of section four prior to continuing reading this text.

[4] Here, the word "system" is used to generalise Riemann's approach. In the original text, Riemann used the "organ" as his investigation was focused on identifying the mechanisms of the ear. Thus, by "system" it is meant: a group of interacting, interrelated, or interdependent elements forming a complex whole that performs a function. In Riemann's context that includes the physical structure of the ear, its parts, the relationship between parts as well as the universal natural rules that explain those relationships.

> *"…there are two possible ways of gaining knowledge about the organ's functions. Either we can proceed from its construction, and from there seek to determine the laws of the mutual interaction of its parts as well as its response to external stimuli; or we can begin with what the organ accomplishes and then attempt to account for this. …By the first route we infer effects from given causes, whereas by the second route we seek causes of given effects. Following Newton and Herbart, we can call the first route synthetic, and the second analytic (Riemann, 1866 as cited in Ritchey, 1991)."*

Ritchey (1996) argues that the adoption of the synthetic route, despite being possible, has inherent risks. For instance, such an approach may lead to the formulation of explanations based upon something other than the parts and components of the system due to the lack of sufficiently precise knowledge about how the components of the system actually function and interact. Ritchey (1996) argues that this problem usually happens because our interpretation is formed through the use of analogy with other systems that are familiar to us or through attributing to these parts a purpose or utility (as well as in analogy to familiar systems).

For Ritchey (1996) the risk of using analogy relates to the fact that systems with similar functions may have quite different mechanisms to realise such function and therefore the suggested interaction between parts is either forcefully created or non-existent. In the context of Riemann's research, another limitation was related to the fact that to start from the organs parts would have required precise instruments that were not available at that time. Therefore, the only reliable alternative was to study sound and hearing independently of the ear system (i.e. an analytical approach).

Conversely, the analytical route accounts for what the system's function is. This process, according to Riemann (1866) *as cited in* Ritchey (1996) has three parts.

> *1. "The search for an hypothesis which is sufficient to explain what the organ accomplishes. …We must, as it were, [conceptually] reinvent the organ; and, insofar <u>as we consider what the organ accomplishes to be its purpose</u>, we must also consider <u>its formation as the means to that purpose</u>. However, this <u>purpose cannot be based upon presumption, but rather is given by experience</u>; and if we disregard how the organ was actually [physiologically] produced, we need not at all bring into play the concept of final cause. …[Ultimately,] in order to explain what the organ actually accomplishes, we look to its construction. In our search for this explanation, however, we must first analyze the organ's task [i.e. the problem it must solve]. This will result in a series of secondary tasks [or problems], and only after we have become convinced that [all of] these must be solved, do we then look to the organ's construction in order to*

> *infer the manner in which they are solved (Riemann, 1866 as cited in Ritchey, 1996).*"

The term hypothesis in Riemann's work refers to the function that the system accomplishes (i.e. the effect that is the object of analysis). Ritchey (1996) explains that, if the internal properties of a system cannot be determined with certainty, the only way of investigating it is to start with something about the system that is not dependent upon knowledge about its construction. For Ritchey, this is done through the elaboration of a conceptual model of the system (a theorem in mathematical terms) that explains its functioning rules. Here, the conceptual model contains the explanation for its possible causes.

> *"…In order to gain a complete understanding of a system's workings, we must eventually examine its construction. But we cannot begin here, and attempt to draw conclusions about how the system functions, if sufficient knowledge concerning its internal properties is not available to us. We must, instead, invert the process: we need some kind of theoretical framework within which we can first draw conclusions about the system's internal properties. And in order to do this, we must analyze the problem that the system must solve in order for it to accomplish what it does (Ritchey, 1996, p15)."*

This process, as discussed by Ritchey (1996), is known as the analysis of function (in opposition to the analysis of composition – synthetic route). The objective of this type of analysis is to describe the system through the principles that explains it's functioning. Ritchey (1996) emphasizes that the conceptual model (effect) should be explained independently from its causes. For instance, sound can be explained as a system of waves independently from its causes (i.e. whether the sound waves are originated from voice, engine or any other system that can generate them). Additionally, Ritchey explains that another step might be the breakdown of functions into sub-functions that makes the explanation of what the system accomplishes easier. This process is carried out until all the sufficient[5] and necessary explanations are found as described in the following.

[5] According to Ritchey (1996, p16): "A sufficient explanation for a phenomenon implies that if all the conditions contained in the explanation are in fact satisfied, then the phenomenon must exist and function according to the explanation. This means that a sufficient explanation for a given phenomenon is a possible explanation but not necessarily the correct explanation: there may be other explanations, involving other conditions, which also suffice to explain the phenomenon. …A necessary explanation consists of conditions that must always be satisfied if the phenomenon is to exist at all. A necessary explanation need not be sufficient, but it is essential and 'unconditional'. Our next step, therefore, must be to work our way from an explanation that is merely sufficient, to an explanation that

2. "The investigation of the extent to which this explanation is a necessary one. …II. Once we have arrived at a conception that is sufficient to explain the organ, we cannot fail to inquire about the extent to which this explanation is a necessary one. We must carefully distinguish between those assumptions that are unconditional - - or necessary by virtue of incontestable laws of nature -- and those classes of conception that could just as well be replaced by others. We thereby sort out all completely arbitrary, tacked- on [ad hoc] notions. Only in this way can we eliminate the detrimental consequences of the use of analogy in our search. This also makes it considerably easier to test our explanation by reference to experience (i.e. by framing questions to be answered)."

As discussed by Ritchey (1996), once the system's functioning conceptual framework is devised, the next step is to test the explanation empirically.

3. "Comparison with experience in order to verify or correct (the explanation). To test our explanation by reference to experience, we can in part draw upon what we have concluded about what the organ accomplishes, and in part upon what that explanation presupposes as to the physical characteristics of the organ's constituent parts. As for what the organ accomplishes, this is extremely difficult to precisely compare with experience -- and for the most part we must confine our theory-testing to the question of whether the theory is contradicted by experimental results or observations[6]. In contrast, conclusions about the physical characteristics of the constituent parts can have universal scope, and can give rise to advances in our knowledge of the laws of nature -- as was the case, for example, with Euler's efforts to account for achromatism of the eye (Riemann, 1866 as cited by Ritchey, 1996)."

For Ritchey (1996) two paths are possible: to test the system's performance or its construction. In respect to the former, if on the one hand empirical tests of the system's performance can be imprecise, on the other it may bring to light inconsistencies and contradictions between explanation and empirical observations. In regards to the latter, Ritchey emphasizes that remarkable findings can be reached as our conceptual framework may lead to certain necessary conclusions about unknown internal properties of the system. In other words, by analyzing the system's principles and the problems it may solve, the resulting conceptual framework may lead to insights about the characteristics of the constituent parts of the system. Consequently, new insights and perspectives about the principles may emerge. In

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is necessary -- even if this means ending up with an explanation that is no longer complete. …Following the previous example, whilst 'sound is constituted of waves' is a sufficient explanation, the explanation of sound waves and its behaviour is a necessary one."

[6] Without further discussion this is related to Karl Popper's theory of falsiability.

the following section, the research design is presented following the three principles of the analytical route.

2.2.1 Summary

In this section a short overview related to the method of analysis was presented (Figure 2). In this respect, the analytical route starts with the identification of the relevant *a priori* knowledge related to the investigated phenomenon followed by the definition/conceptualisation of a hypothesis. Subsequently, a functional analysis is carried out so to 'decompose' effects to its minimum elements and their relationships. In this process a compositional analysis can be carried out so to explore the mechanisms that allows for effects to happen. Finally, empirical observations are conducted so to test the performance of the system 'designed' and its construction. It is throughout testing that inconsistencies can be identified and corrected. Conversely, the synthetic route starts with testing so to measure the outcomes and finishes with the deduction of rules that may explain cause-effect.

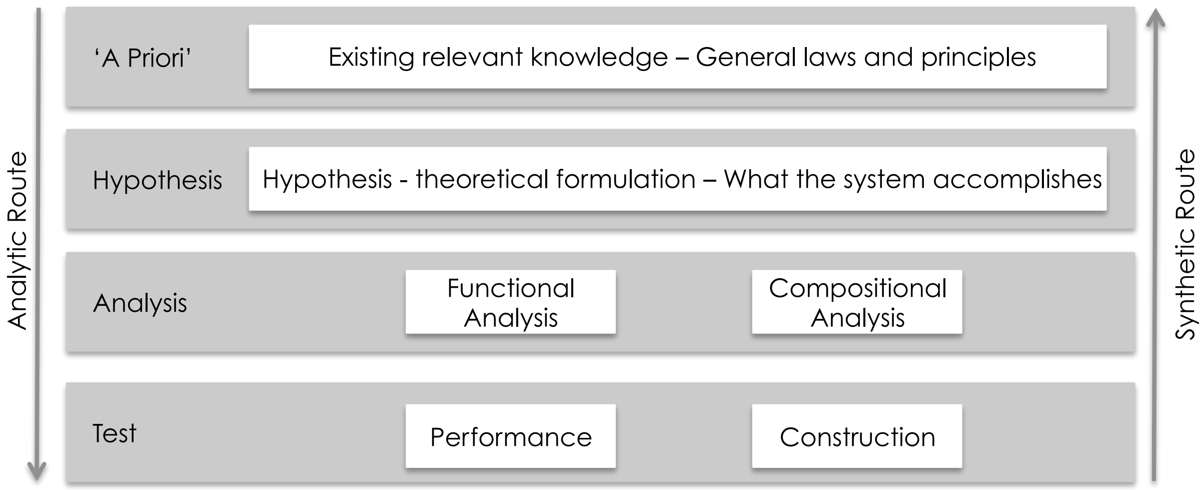

Figure 2 - Overview of analytical and synthetic routes

The following section presents the research design that consists of the contextualisation of the research approach to the problem investigated in this thesis.

2.3 Research Design

The hypothesis of this study has its origins in the practice of design and in its shortest format can be stated as '*evidence is part of design*'. In this respect, '*evidence'* is considered as something (a concept) that exists and has characteristics that makes it identifiable, that design is something that exists (a process) and evidence is one of its components that if properly utilised can improve design.

The initial literature review revealed that there is uncertainty regarding the concept, use and generation of evidence in the design field. This problem triggered this current investigation that is focused on the explanation of the concept of evidence and how it relates to the design process. The research process had embedded in it the search for known things that were not known by the author of this thesis as well as it had the investigation of unknown aspects that were tackled throughout the research. The investigation process in its generic format is depicted in Figure 3. The initial gathering of information as presented in section 2.1 and 2.2 are not demonstrated in the diagram below.

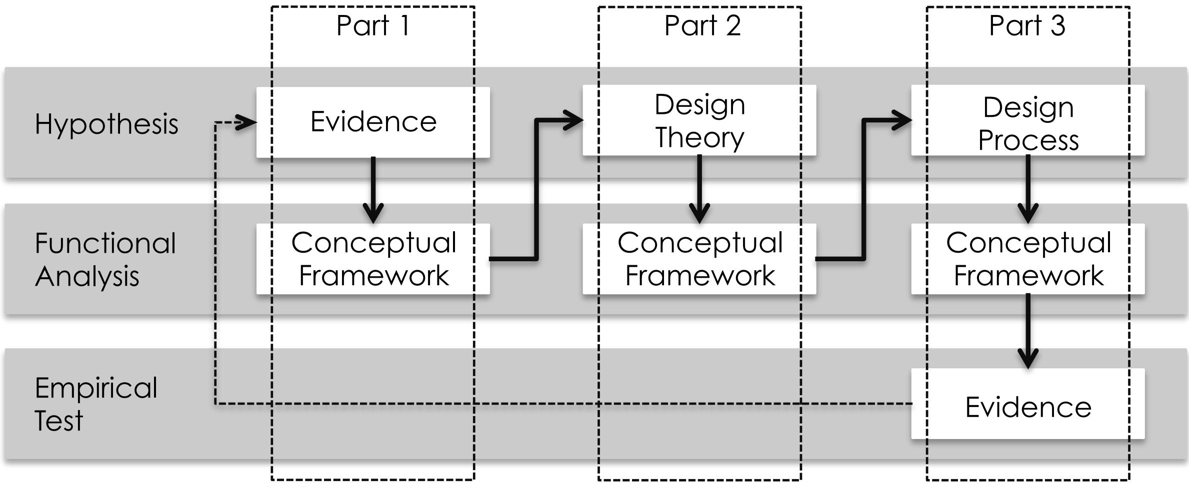

Figure 3 - Research Design

In this respect, the three phases of the analytical route were utilised to investigate the three research areas related to the problem, namely: evidence, design theory and the design process. The investigation followed a fuzzy process (rather than a sequential one) with many cycles of iteration as presented in section 2.1. The linear sequence represented in Figure 3, illustrates the analysis moving from abstract concepts to more practical processes; i.e. from the hypothesis to the empirical observation[7]. The three parts of the analytical process are described in the following.

2.3.1 Research Method Part 1

Part 1 referred to the hypothesis elaboration and functional analysis of evidence. The investigation was focused on the concept of evidence and sought to identify current philosophical definitions of evidence and its characteristics, as well as the role it plays within a knowledge system. The investigation was done through a literature review that started in the area of philosophy where the concept assumes a more abstract form. The search considered the implications that different ontological and epistemological approaches may have upon the characterisation of evidence. In addition, the areas of "Theory of Knowledge" and "Theory Building" were investigated in the search for improved understanding of what evidence accomplishes in a knowledge system. The investigation resulted in a conceptual framework that was used to support the characterisation of evidence within design in later stages of the research.

2.3.2 Research Method Part 2

Part 2 referred to the hypothesis elaboration and functional analysis of design theory. Here, a synthetic approach was used and the research was focused on identifying what design accomplishes and contextualising the role of evidence within the design theory domain. The investigation was done through the revision of the literature about design theory. A note must be made to the fact that there is no consensus in the literature regarding a theory of design. In this respect, current candidate theories were examined with a focus on the role of evidence within

[7] The research also led to learning cycles related to the application of different research methodologies, specifically the Method of Analysis. These are not represented in the design of the research, rather they are presented in the appendices as these learning cycles generated parallel contributions.

distinctive models. Only prescriptive[8] models of design were selected. The reasons for the selection of prescriptive models is based on the fact that research to develop descriptive models of design, to a great extent, have used protocol analysis (Feng and Zeng, 2009) as a research method. Whilst protocol analysis has proven useful in providing insights in design research, the method itself demonstrates limitations in providing an accurate depiction of design. By contrast, prescriptive methods are developed with a basis on the logical rationale underpinning the prescriptive proposition. The limitation of such methods is arguably based on whether or not such models can be applied (as the observation through protocol analysis is limited).

The selected models included those with application in practice as discussed by Asimow, (1962); Simon (1969); Markus (1969) and Marver (1970); Archer (1984); Forsberg and Hubka and Eder (1996); Forsberg and Mooz (1998); Gedenryd (1998) and Koskela *et al*. (2008); Suh (2001); Hatchuel and Weil (2003) and Lawson (2006). The approach used to resolve the lack of consensus amongst the selected candidate theories was to compare and contrast these models so to highlight the set of characteristics that are present in them. To do that, an assumption was made that the method of analysis and synthesis is the proto-theory of design (as discussed by Gedenryd, 1998 and Koskela and Kagioglou; 2006). All other theories were than compared to this method with the intent of identifying new features that were not addressed within the method of analysis. In addition to the theoretical comparison, a series of building design meetings were observed and the occurrence of the features of the method of analysis (as discussed in section 4.3) were used as the unit of analysis. The main source of evidence used was the observation of design discussions between designers and stakeholders. In this respect, actions, comments and decisions made that could be related to the features of the method of analysis and synthesis (Table 8) The context in which these meeting took place is further described in Section 2.2.3.2.

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[8] It is important to differentiate the use of the terms prescriptive and descriptive. In design, no definition was found in the literature that explains the difference between them. In relation to learning models, Ullrich (2008, p.37) argues that descriptive learning theories make statements about how learning occurs and devise models that can be used to explain and predict learning results. In design, for instance, that would involve discussions about creativity, wicked problems, and decision-making amongst others. According to Ulrich (2008), prescriptive theories are concerned with guidelines that describe what to do in order to achieve specific outcomes. In this respect, the term prescriptive, in this research, refers to models that attempt to prescribe a better or more appropriate pattern of activities in designing as opposed to simply describe the sequences of activities that typically occur.

Finally, once the features contained in the selected design theories were identified, the conceptual framework generated in Phase 1 was used to classify the occurrence of evidence within the design process. The investigation resulted in a conceptual model that supports the characterisation of evidence in design. Here, the analytical route was used.

2.3.3 Research Method Part 3

Part 3 referred to the investigation of evidence within the context of healthcare design. In this respect, empirical data was gathered through: a) a systematic literature review focused on identifying evidence related to the impacts of the built environment on health outcomes[9]; b) observations of design meetings related to the development of a major hospital in the UK. In this respect, the conceptual models generated in Parts 1 and 2 were used to interpret the emergence of evidence within design. Further details about data collection are presented in the following.

2.3.3.1 Systematic Review of the Impact of the Built Environment on Health Outcomes

A systematic literature review (SLR) was carried out to investigate categories of evidence used in the design of healthcare facilities. The focus of the review was on evidence indicating positive, negative or neutral impacts of the built environment (BE) upon health outcomes (HO). The review had two objectives due to the nature of the phenomenon investigated: a) to present the theoretical debate related to the phenomenon BE&HO; and b) to classify and synthesise the results of empirical studies investigating the relationship BE & HO, as follows.

Theoretical Review: The objective of the theoretical review was to present the theories offered to explain the particular phenomenon under investigation and compare them in breadth, internal consistency, and the nature of their predictions. In this respect, theories explaining the connection between BE & HO were explored. In the context of this research, understanding the "status" of theory in this field has a direct relationship with the classification of the evidence that is provided through empirical research.

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[9] The systematic review was considered as part of the empirical data collection because the evidence available in the articles has been used in the evidence-based design approach.

Evidence Mapping: The literature synthesis was focused on identifying empirical studies and summarising the results by drawing conclusions from the many separate investigations addressing related or identical hypothesis. In this respect, the review aimed at exploring the state of knowledge concerning the relationship(s) of interest and to highlight relevant issues that are unsolved in the field. These aspects are relevant to this research as they impact on the classification of evidence.

The adoption of a systematic approach to the literature review was aimed at adding rigour to the review process as well as setting boundaries for the searching process (considering the vast multidisciplinary field in which the research was done). The systematic process also gives room for improvement of the searching process. A more in depth discussion about SLR is presented in Appendix 1. Details about the aspects of SLR that were used in this research are presented in the following.

Familiarisation with the area of investigation: the starting point of the SLR about the impacts of the BE on HO was to establish the method to identify and restrict the area to be searched. For this purpose, the identification of 'key' publications presenting the state of the art in the field was essential. Three main sources were used: Devlin and Arneill, (2003); Ulrich and Zimring, (2004); and NHS Estates, (2005). From these publications, 293 academic journals publishing articles in the area were identified (see Appendix 2 for details). This information provided an initial overview of the areas of interest and fields of research investigating the impact of the built environment into health. The information gathered in this phase was used in the development of a framework for data collection.

Systematic steps of the searching process: the second aspect of the search was the establishment of the research steps to be systematically followed by the researcher. The research steps included (a) identification of relevant databases; (b) selection of key words; (c) definition of inclusion and exclusion criteria; (d) definition of quality criteria; (e) definition of framework for data collection.

- <u>The investigation of database availability and selection of available databases</u>: The selection of electronic databases in which to search followed these steps: screening available databases; selection of potentially useful databases by subject areas; initial search to evaluate usefulness of each pre-selected database (keywords used: health or hospital or patient AND architecture or environment or design AND research or data or evaluation). In total, 7 databases were searched as presented in Table 1.

Table 1 - Searched databases

Data base	Description
ASSIA – Applied Social Sciences Index and Abstracts (via CSA*)	Indexing and abstracting database covering health, social services, psychology, sociology, economics, politics, race relations and education. Updated monthly, ASSIA provides a comprehensive source of social science and health information for the practical and academic professional. Contains over 255,000 records from 650 journals in 16 different countries, including the UK and US.
CINAHL – Cumulative Index to Nursing Allied Health (via Ovid)	Bibliographic database which covers over 900 nursing, allied health and biomedical journals. Of particular use for physiotherapy and occupational therapy.
DAAI – Design and Applied Arts Index (via CSA)	A comprehensive database of design and craft journals covering 450 titles. It contains over 100,000 annotated references, as well as information on over 40,000 designers, craftspeople, studios, workshops, companies, etc.
Article First, ECO, Worldcat (via First Search - OCLC)	OCLC is a nonprofit, membership, computer library service and research organization dedicated to the public purposes of furthering access to the world's information and reducing information costs. More than 72,000 libraries in 170 countries and territories around the world have used OCLC services to locate, acquire, catalog, lend and preserve library materials. Available at: http://www.oclc.org/support/documentation/firstsearch/databases/dbdetails/details/ArticleFirst.htm
HMIC - Health management information Consortium (via Ovid)	Health Management Information Consortium – Consists of 3 databases, DH-Data, HELMIS, and Kings Fund Database. Abstracts are available on the following subject areas health service and hospital administration and management, public health, community care, service development and NHS organisation.
MEDLINE (via Ovid)	Contains bibliographic citations of biomedical literature, including all foreign languages. Covers the whole spectrum of medicine, referencing over 3700 journals from 70 countries.
NHS Estates – Safer Environment Database, efm-evidence, Bryan Lawson and Michael Phiri	Data base developed by the University of Sheffield

- The selection of keywords: The selection of keywords was based on the preliminary keyword list based on the scoping study about design and health outcomes. In that research, a discussion with a group of researchers involved in the subject area was used to refine the keyword list. The resulting list was used in this research and they were classified into health-related, research method-related, built environment related, outcome-related, design-related, and others. Table 2 presents the list of the selected key words.

Table 2 - Selected keywords

1 – Health	2 - Research	3 - Built environment
(Heal* OR Medical OR Patient OR Care OR Therap* OR Stress OR Recovery OR Treat* OR Diagnos*)	(Research OR Outcomes OR Data OR Evaluation OR (Evidence and based) OR Strategy OR Effectiveness OR Dimensions OR (Post and Occupancy) OR Evaluat*)	(Hospital OR Environ* OR Ambient OR Cent?? OR Facilities OR Setting OR Design OR Architecture OR (Built and environ*))
4 - Outcome	**5 - Design**	**6 - Others**
(Perspective OR Percep* OR Satisfaction OR Safety OR Friendly OR Social OR Interac* OR Behavi*r OR (User and Needs))	(Garden OR Noise OR Landscape* OR Windows OR (Way and Finding) OR Colo*r OR Music OR Light* OR Texture OR Acoustics OR Smell OR (Nature or Natural))	(Art OR Music OR PFI OR Lift OR PPP)

- The establishment of the criteria for the inclusion and exclusion of articles. The automatic criteria for inclusion or exclusion of studies considered that included references would have at least one of the keywords in each category, i.e. health, research, built environment, perception, design and others. The Boolean operator "and" was used between categories and "or" between words in each category. "*" was used for truncation. It is important to report that a short glossary of medical terms was developed in parallel with the establishment of the keywords. The development of a glossary was necessary due to the multidisciplinary nature of the field. The glossary is presented in Appendix 3. The result of the first search within six databases (ASSIA, CINAHL, DAAI, OCCL, HMIC and MEDLINE) resulted in 624 abstracts. The Safer Environment Database (NHS Estates 2005) was used as a second source of information. This database presents the abstracts of more than 500 papers related to the investigated subject.
- The establishment of quality criteria for the assessment of references. The manual criteria for inclusion or exclusion of studies were used to select the resultant references. The criteria used are highlighted in Table 3. The manual process of reference selection was based on reading the abstracts of selected articles. Additionally, a set of quality criteria was established aiming to assess the quality of the selected papers (Table 4).
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Table 3 - Manual inclusion criteria

N – Inclusion Criteria	N – Exclusion Criteria
01 – Hospital or Clinic setting (healthcare environment)	01 – Publications pre-1980 (except for recommended articles or with 50 plus citations)
02 – Qualitative or quantitative	02 - Literature reviews
03 – Theoretical or empirical	03 – Investigations related to offices spaces within healthcare facilities

Table 4 - Quality assessment criteria

Quality assessment criteria					
Element	Level				
	0-Absence	1-Low	2-Medium	3-High	Not applicable
Background	The article does not provide enough information to assess this criterion	Poor awareness of existing literature and debates. Under or over referenced Low validity of theory.	Basic understanding of the issues around the topic being discussed. The theory is weakly related to data.	Deep and broad knowledge of relevant literature and theory relevant for addressing the research. Good relation theory-data	This element is not applicable to the document or study.
Method	The article does not provide enough information to assess this criterion	Data inaccuracy and not related to theory. Flawed research design.	Data is related to the arguments, though there are some gaps. Research design may be improved.	Data strongly supports arguments. In addition, the research design is robust: sampling, data gathering, data analyses is rigorous.	This element is not applicable to the document or study.
Findings use	The article does not provide enough information to assess this criterion	The ideas are difficult to implement or consider as an input in designing the building.	It's possible to use the information available in the paper, but data needs to be deployed.	Data is ready for designers' consideration in designing the building.	This element is not applicable to the document or study.
Generalisation	The article does not provide enough information to assess this criterion.	Only to the population studied.	It is possible to generalise to population of similar characteristics.	High level of generalisation.	This element is not applicable to the document or study.

- <u>The establishment of a framework for data compilation</u>. Several attempts were made in relation to setting a framework for data compilation (Appendix 4). At this stage, the research took a different direction due to the impossibility of creating a framework that could represent causal-effect relationships. Consequently a framework was devised aiming at mapping the variables that have and have not been investigated in research. The map was developed using a MS Excel spreadsheet and the variables were classified as follows:

- Patients' condition: which included the illness, age, gender, and pre or post clinical intervention;
- Built environment setting, characteristics and features: this category included all different dimensions that can classify the BE from the type of healthcare building (e.g. hospital or primary care facility) to its minimum components (e.g. colour, texture, etc.).
- Health outcomes: Considering direct physical, physiological and psychological outcomes (e.g. depression and blood pressure) and indirect measures (e.g. length of stay and the reduction of the use of medicines). To demonstrate relationships between variables, a smiling face (☺) was used to show a positive impact, a sad face (☹) was used to show negative impact, (☺/☹) was used to show both positive and negative impacts, and the empty (▭) sign was used to show no positive or negative impact (neutral). The relevance of the outcome was not considered; an additional item related to publication quality was added based on the quality assessment criteria presented in Table 4.

Variables connecting the built environment and patient health outcomes were mapped in different levels of analysis. The analysis considered the elements and features identified in the selected abstracts and papers. In total, 196 features, elements and variables of built environment, health outcomes and patients condition were identified. These are discussed in Section 5 of this thesis.

2.3.3.2 Project Investigation

Empirical evidence was gathered to further explore the roles of evidence within design. In this respect, data from the conceptual design phase of a major healthcare project was used as a source of evidence as presented in the following.

The project for investigation is a £420 m project for the redevelopment of an existing secondary care hospital in the UK. The existing facility consists of a set of buildings that were built in different periods. The oldest building was built in the 1920s and its configuration is not appropriate for current medical practice. The project considered the redesign, relocation and co-location of services to be delivered in the hospital and the demolition and reconstruction of the hospital. Data about this project was collected through:

1. Documental investigation about the redesign of the services and facilities was carried out so to provide contextual understanding about the project being developed. Documents such as minutes of meetings and stakeholders forums, drawings and the Strategic Outline Case and Full Business Case were used as sources of contextual information;

2. Unstructured observation of design practice: In total, four full day stakeholders' meetings were observed. These meetings were related to the elicitation and classification (hierarchy) of requirements. Additionally, eleven 1 - 2 hour meetings between designers and stakeholders were observed with the same objective. Data collected from observed meeting was reported in the format of summary records as presented in Appendix 5. The observations were targeted at: a) identifying actions, comments and decisions that could be related to the method of analysis; and b) identifying he types of external evidence being used to justify decisions. This was done by observing actions, comments and decisions that could be related to the conceptual model of evidence discussed in section 3.4. The collection of data was restricted to the interpretation of the researcher only and examples of information that was considered as an indicative of evidence were:

- Veridical evidence: mention to a piece of scientific research or tested method to justify or explain a decision or a request for change;
- Potential evidence: mention to guidelines (e.g. HBNs and HTNs) or regulations to justify or explain a decision or a request for change;
- Anecdotal Evidence: mention to personal experience or reported testimony from a third party to justify or explain a decision or a request for change;

3 PHILOSOPHICAL ANALYSIS OF EVIDENCE

This section refers to Part 1 of the research and presents an overview about philosophy and the dualisms of reasoning. It discusses the different extremes of our reasoning for knowledge formation and gathering. These differences are relevant as they are related to what is accounted for evidence.

3.1 Introduction

Central to any piece of research is the philosophical statement that it makes. Embedded in all research there is a system of interconnected ideas and assumptions that provides foundations for certainty and that so often is not properly understood or made explicit. In this respect, there are a number of ways in which one could assemble the philosophical system of ideas and the objective of this section is to raise awareness regarding the most relevant debates related to philosophy of science.

The philosophical debate has many relevant contributors including Pythagoras, Aristotle, Descartes, Hume, Kant, Wittgenstein and Popper, to name a few.

Philosophy is the subject matter that addresses the structure of all existing interpretations of phenomena (Blackburn, 1999). Thus, it is as a subject embedded in research as it deals with interpretations of reality, or in other words, theories. Philosophical texts are therefore always abstract and theoretical and their main problem is to discuss ways for which truth is established. Truth is often defined as a correspondence between reality and predication (in its more sophisticated form it is between reality and theory, which is a system of statements about the world) (Teichmann &Evans, 1999).

Smith (2005) argues that philosophy traditionally includes four core fields: ontology, epistemology, ethics and logic. In this respect, ontology is the study of beings or their being (what is); epistemology is the study of knowledge (i.e. how we know); logic is the study of valid reasoning (how to reason); and ethics is the study of right and wrong (how we should act). In this study, only ontological and epistemological arguments are presented as they are related to the concept of evidence.

Philosophy deals with reality and predications about the world. However, in philosophical terms, this does not necessarily mean the planet we live in. The philosophical discourse considers the existence of several possible "worlds" such as the physical world (or the world of things) and the metaphysical world (or the world of abstract "things" such as processes and taxonomies) (Teichmann &Evans, 1999).

The physical world has been the subject of science in many areas of research such as natural research and its branches (i.e. physics, chemistry and biology). It accounts for any phenomena occurring in "real life". Metaphysics, on the other hand, refers to the world of ideas in Plato's discourse, i.e. everything that exists was created according to its "universal model" or, in modern terms, *abstract concept*. Metaphysics, according to The Oxford Dictionary of Philosophy (1996)[10] is applied to any enquiry that raises questions about reality that lie beyond those capable of being tackled by methods of science. The traditional examples will include questions of mind and body, substance and accident, events, causation, and the categories of things that exist.

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[10] "metaphysics" The Oxford Dictionary of Philosophy. Simon Blackburn. Oxford University Press, 1996. Oxford Reference Online. Salford University. 16 January 2006 http://www.oxfordreference.com/views/ENTRY.html?subview=Main&entry=t98.e1520

In this respect, metaphysics discusses the formation of the necessary qualities of theoretical frameworks (taxonomies) used to describe 'things'. As argued by Riemann (1866, as cited in Ritchey, 1991), the development of taxonomies should not be a practice emerging from synthesis. However, as discussed by Beaney (2003), since the Enlightenment the British philosophy has been strongly based on empiricism, resulting in numerous taxonomies that, despite serving a practical purpose, do not represent truth. Empiricism is one, amongst many, school of ontological thought as presented in the next section.

3.2 Ontology

The term ontology is derived from the Greek words 'ontos' (being) and 'logos' (theory or knowledge). It is a branch of philosophy dealing with the essence of phenomena and the nature of their existence. Therefore, to consider the ontological status of something is to ask whether it is real or illusory. Thus, the subject matter of ontology has many important philosophical positions to understand. The most important ones are realism (objectivist[11]) and anti-realism (subjectivist) (Miller, 2010).

The foundations of realism are grounded on the assumption that the world we perceive does exist outside of us and independently of us. Traditionally, realism more generally is associated with any position that endorses belief in the reality of something (Chakravartty, 2011). According to Miller (2010), there are two general aspects that characterise realism: the claim about existence and the claim about independence (for instance, the moon and the sun exist, they are silver and yellow independently of anything anyone happens to say or think about the matter). Therefore, empirical observations are possible, can establish truth and can be objective. The realistic school of thought assumes that social and natural reality exists independently of our cognitive structures: an extra-mental reality exists whether or not human beings can actually gain cognitive access to it (Johnson and Duberley, 2004).

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[11] The terms objectivistic and subjectivist ontology are presented in: Johnson, P. and J. Duberley (2004). Understanding Management Research. London, SAGE Publications Ltd.

On the other hand, the anti-realistic school of thought concerns are that the world does only exist in our mind and that our mind substantially shapes the world we live in. Mind and external world are intimately linked together and cannot be separated. Truth then becomes something that cannot be separated from the speaker and is therefore never objective but subjective. In this respect, a subjective (anti-realist) ontology assumes that what we take to be external, social and natural reality is merely a creation of our consciousness and cognition. Thus, reality is a projection of our cognitive structures (formed in metaphysics) with no independent status (i.e. true or false). All that exists is the phenomenal world (Johnson and Duberley 2004).

The epic debate between realistic and anti-realistic defenders can be illustrated through the example that follows: Descartes' statement "I think, therefore I am". This statement is an example of the realistic ontological point of view. For realists, the statement is objective as knowledge is gathered through sensorial experience. However, anti-realists challenge such an approach by enquiring how Descartes can prove that he exists to another person?

The realism/anti-realism debate is not further addressed in this study. The key point of this subject that is relevant to the development of this research is that there is great disparity of opinion between realists and anti-realists in regards to relying on senses to measure meta-framed [12] concepts to prove the occurrence of patterns and phenomenon occurring in the real world. Those questions related to 'how can we prove something' or 'how can we get knowledge from reality, whatever reality is', belong to the discipline of epistemology presented below.

3.3 Epistemology

> *Descartes: The method was to, in the first place, explore it by empirical observation. Look, but look carefully and systematically. To observe, however, is not to explain, and the new science seeks also to explain (Wilson, 2008 – Encyclopedia of Philosophy).*

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[12] The expression meta-framed concepts, in this study, means concepts created in the metaphysical world that as such do not exist, but they are used to describe 'things' that exist and make knowledge exchange possible, for instance the categorisation of animals as amphibians, birds, fish, invertebrates, mammals and reptiles. The category as such does not exist, what exist it the animal.

Narrowly defined, epistemology is the study of knowledge and justified belief. According to Goldman (2001) classical epistemology has been concerned with the pursuit of truth and relates to how an individual can engage in cognitive activity so as to arrive at true belief and avoid false belief. In other words, how to get knowledge from reality and justify it. Prior to engaging in discussing the existing epistemological schools of thought it is essential to discuss the concept of knowledge as it relates to the concept of evidence. This discussion is presented in the following.

3.3.1 Knowledge

Knowledge is a vast and truncated area. Its relevance to this study comes from the fact that evidence can be considered knowledge just as knowledge can be considered evidence. It also comes from the fact that the conceptualisation of knowledge is closely related/dependent to other rather complex concepts such as belief, truth and justification and therefore it must be defined.

Various types of knowledge exist (Goldman, 1967, 1976; O'Brien, 2006; Steup, 2011). According to O'Brien and Steup, there are three most relevant categories of knowledge: factual knowledge (or propositional knowledge – know-that), know-how (or ability knowledge) and knowledge by acquaintance[13]. In this section, focus is placed upon propositional (know-that) knowledge[14]. The following schema is adopted to facilitate discussion: 'S knows that p', where 'S' stands for the subject who has knowledge and 'p' for the proposition that is known[15]. The following scenario will also be used to support the discussion about knowledge.

> *"The case of barn facades: Henry drives through a rural area in which what appear to be barns are, with the exception of just one, mere barn facades. From the road Henry is driving on, these facades look exactly like real barns. Henry happens to be looking at the one and only real barn in the area and believes that there is a barn over there."*

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[13] This type of knowledge is also referred to as knowledge by discrimination or distinguishment by Goldman (1976).

[14] This research aims at qualifying propositional knowledge and investigates the consequences of its use within design practice. It acknowledges the fact that it is challenging, if not impossible, to separate know-that from know-how. However, for simplification purposes, these two categories will be treated separately.

[15] This schema was extracted from Steup (2011).

According to Goldman (1967, 1976), O'Brien (2006) and Steup (2011) three conditions must be fulfilled for Henry (S) to know the proposition 'p' that there is a barn over there. The conditions include justification, truth and belief and together they form the tripartite concept of knowledge known as Justified True Belief (JTB). As described by Steup (2011):

> *"False propositions cannot be known. Therefore, knowledge requires truth. A proposition that S does not even believe cannot be a proposition that S knows. Therefore, knowledge requires belief. Finally, S's being correct in believing that p might merely be a matter of luck. Therefore, knowledge requires… justification. Thus… S knows that p if and only if p is true and S is justified in believing that p.*

In this respect, truth is an ontological quality of the phenomena and its existence whereas justification and belief relates to the reason or reasoning for why the phenomenon is considered truth and as such it related to the individual 'S' not in the proposition 'p'. As discussed by Steup (2011) the role of justification is to ensure that S's belief is not unintentional. In this respect, two concepts of justification exist: **Evidentialism** and **Reliabilism**. Evidentialism refers to the possession of evidence[16] to satisfy the condition of justification whereas reliabilism refers to having a high objective probability of truth and that is accomplished if, and only if, a belief originates in reliable cognitive processes or faculties (Steup, 2011). In other words, Evidentialism depends on evidence without questioning its source, while Reliabilism relies on the level of probability that method used to gather evidence is accurate and reliable. This argument forms the basis of Gettier's (1963) suggestion that the JTB proposition is not sufficient to ensure the status of known to certain circumstances for two reasons:

> *"First, in that sense of 'justified' in which S's being justified in believing P is a necessary condition of S's knowing that P, it is possible for a person to be justified in believing a proposition that is in fact false. Secondly, for any proposition P, if S is justified in believing P, and P entails Q, and S deduces Q from P and accepts Q as a result of this deduction, then S is justified in believing Q (Gettier, 1963)[17]."*

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[16] Steup does not provide a definition of evidence as such, but relates it to 'internalism' i.e. something that must have internal consistency.

[17] An example of the second situation can be illustrated when a new theory is developed. In this case, all the evidence collected gave the status of known to the phenomenon until the very moment the new theory emerged.

Using the example of the barn façade, Goldman (1976) and Steup (2011) demonstrate that Henry's belief is justified through visual experience and that it originated in a reliable cognitive process (vision). However, it was only by coincidence (luck) that Henry looked at a real barn (as opposed to a façade only). Had he looked first at a façade, he would also have believed he saw a barn. In that case, Henry's belief was false and it would not qualify as knowledge because vision, in that particular context, would not be considered as a reliable cognitive process to discern barns from barn-façades.

Suggestions to solve the problem of justification are presented by Unger's (1968) theory of **non-accidentality analysis** and the **indefeasibility** approach proposed by Lehrer and Paxson Jr (1969). According to Unger (1968) and Goldman (1976) the non-accidentality theory suggests that: "*S knows that p, if and only If, it is not at all accidental that S is right about its being the case that p." Lehrer and Paxson Jr (1969) theory suggests that: "S's true belief is justified and this justification is not defeated, i.e. S's justification 'j' for believing that p is defeated if and only if there is some true proposition q such that the conjunction of q and j does not justify S in believing that p (as cited in Goldman, 1976)*."

According to Goldman (1976) both theories do not solve the problem as the concepts of non-accidentality and indefeasibility need further explanation and are not, in total, satisfactory. The main issue is related to the fact that for Henry to know he would have to be able to go through all the relevant candidate possibilities and have resources to differentiate between them[18]. That includes the possibilities related to the barn being real or just a façade, the different sources of evidence (vision, experiment, documental analysis of their construction, or any other possible source) and the condition of analysis (distance, reliability of documents, etc.). According to Goldman, to go through all candidate alternatives can often make the task impossible. The argument of both authors is related to the fact that in some circumstances, "first impressions (vision)" may seen reliable, when sometimes they are not.

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[18] In addition, as will be described in the scepticism section, this approach would fall within Agrippa's infinite regress argument, where a justification would need a justification that would need a justification and so on, infinitely. Furthermore, the idea of falsification as discussed by Popper (1972) will be explored in support of this issue.

In this respect, O'Brien (2006) argues that one alternative to Gettier's problem is to adopt a **fallibilist** approach. According to Hetherington (2005) Fallibilism **is the epistemological thesis that no belief (theory, view, thesis, and so on) can ever be rationally supported or justified in a conclusive way**. In other words, Fallibilism tells us that there is no conclusive justification and no rationale certainty for any of our beliefs or theses. For O'Brien (2006), fallibilists claim that we can have knowledge without conclusive reason: "*Thus, we can claim to know something even though the evidence we currently possess does not rule out the possibility that we may be wrong (O'Brien, 2006, p.15).*" The debate of fallibilists does not address, for instance, issues such as two contradictory pieces of knowledge and, according to this approach, this is to say that knowledge has a volatile, latent and dynamic characteristic and that we can never be certain of anything. This creates a condition where something will never be known and that everything is therefore "almost" known. Hetherington (2005) explains that the fallibilist discourse can often be misinterpreted as scepticism and despite the fact that all epistemologists would consider themselves fallibilists, most of them would deny being sceptical.

Finally, another alternative to Gettier's problem, as highlighted by O'Brien (2006, p.16), is based on the fact that we cannot justify our true beliefs if our reasoning involves beliefs that are themselves false. In Henry's case, the beliefs that "all that is there are barns" is a false belief. O'Brien (2006) argues that this alternative is also limited as some of Gettier's cases do not involve false beliefs or reasoning at all. For O'Brien (2006) a solution is presented in the work of Timothy Williamson that considers a new definition of knowledge.

As argued by O'Brien (2006), philosophers since the time of Plato have failed in providing a consensual definition of Knowledge and that is what Williamson considers as indicative of the inappropriateness of the approach adopted by traditional scholars. For Williamson (2000) the traditional tripartite concept of knowledge (i.e. justification, truth and belief) is the root cause of the problem. For O'Brien (2006), Williamson's attempt to provide a new epistemology based on knowledge consisting of the possession of a distinctive type of mental state that is epistemically basic is not well received in contemporary epistemology literature.

Discussion

Based on the above discussion it is possible to retrieve that:

- The definition of propositional knowledge in current literature is dependent on three interdependent concepts: Justification, Truth and Belief (JTB). For a proposition to be known, it must be true, justified and believed. Without meeting any of these criteria, a proposition is only a proposition.
- The JTB definition of knowledge is critiqued by Gettier as insufficient. The key points of criticism are: a) that false propositions can be justified; b) that epistemological limitations impose a limited degree of certainty to any justification; and c) truth and belief are connected concepts and belief can only exist if justified.
- An alternative consensual definition for propositional knowledge does not exist. In this respect, the issues presented by Gettier, represent the state-of-the-art debate around the problem of knowledge definition.
- Several attempts have been made to solve Gettier's problem. Alternative solutions include the theory of non-accidentality, indefeasibility and fallibilism. None of the alternatives solve Gettier's problem. However, despite the fact it does not solve Gettier's problem, fallibilism is the theory/concept adopted by epistemologists in current times.

In this thesis, the fallibilist proposition is adopted. That is to admit that knowledge has a volatile, latent and dynamic characteristic. Additionally, even though we can never be certain of anything, it is acceptable to define something as being known with a basis on inconclusive justification, belief and truth. In this respect, the state of being known remains until it is falsified by an additional new clarifying piece of information that is gathered.

3.3.2 Sources of Knowledge

It is an assumption in this thesis that the concept of evidence is dependent on the concept of knowledge. In this respect, everything that is known is evidence of something because it is known, i.e. evidence must be known to be evidence. Thus, to understand the sources of knowledge and how they impact in the creation of evidence is essential in the discussion addressed here.

Knowledge gathering belongs to the field of epistemology and there are several possible epistemological approaches. These approaches, according to Steup (2005) and O'Brien (2006), are based on the fact that our sources of knowledge and justification rely on **reason, perception**, **introspection**, **memory** and **testimony**. Different views on how we access knowledge form the foundations of contrasting and opposite schools of thought. The most relevant to the study are rationalism, empiricism and phenomenology. Rationalism admits that knowledge comes only from reason. Empiricism is the opposite i.e. knowledge comes from sense experience. Finally the subject matter of phenomenology is the study of consciousness as experienced from the first-person point of view. These approaches and the contra points that they bring are described below.

3.3.2.1 Reason

> *"The terms "a priori" and "a posteriori" are used primarily to denote the foundations upon which a proposition is known. A given proposition is knowable a priori if it can be known independent of any experience other than the experience of learning the language in which the proposition is expressed, whereas a proposition that is knowable a posteriori is known on the basis of experience (Baehr, 2006)"*.

***A priori* knowledge**, according to Blackburn (2001) and O'Brien (2006), refers to knowledge for which experience does not play a justificatory role. This would include mathematical truths, conceptual truths (e.g. the semantics of "all bachelors are single"); metaphysical claims and ethical truths. In this respect, O'Brien argues that experience does play a role in the acquisition of *a priori* knowledge. However, this role is indirect. For instance, one has to know mathematics to know that 2+2=4 or language/etymology to know the meaning of bachelors and single. In addition, as discussed by O'Brien some may argue that *a priori* knowledge is self-evident and certain. This is the opinion of Morton (2008, p.40) as, for him, *a priori* knowledge does not require evidence to be true. As explained by O'Brien, neither self-evidence nor certainty is a feature of *a priori* knowledge (not the least to all of *a priori* knowledge).

The idea of knowledge independent of experience forms the foundations of the rationalist school of thought (Steup, 2005). Also known as transcendental philosophy, rationalism has as its principal representatives Descartes and Leibniz. Rationalists consider that our senses give us an incorrect picture of the world, a picture that does not tally with our reasoning (Steup, 2005). Knowledge therefore can only be acquired through understanding (relevant) concepts (or ideas).

As discussed by O'Brien (2006) *a priori* knowledge provides, in Kant's terms, "analytical truths" whereas knowledge acquired through experience provides synthetic ones[19]. Analytical truths or propositions can be related, for example, to Aristotle's work about taxonomies (e.g. substance, qualities, quantities, relations, places, times, positions, states, actions and affections – Teichman and Evans, 1999). These 'categories' even though derived from 'reality' do not need evidence to sustain belief (Morton, 2003). For instance, the belief in the statement 'all bachelors are single' comes from its analytical rationale rather than evidence collected. In addition, as discussed by O'Brien (2006), rationalists also claim that there is synthetic *a priori* knowledge. Synthetic *a priori* truths are the product of intuition (as opposed to perception). For instance, we know *a priori* the concept of 12, but according to O'Brien (2006), it is through intuition (not experience) that we know that 7 + 5 = 12; 6 + 6 = 12, etc. To empiricists, this idea is debatable.

O'Brien (2006) goes further and discuss self-evidence and certainty as two features of *a priori* knowledge. In relation to *a priori* knowledge being self-evident, O'Brien (2006) agues that there are instances where that is not the case. For instance, whilst it is easier to know that 5 + 7 = 12 (self-evident), it is not so easy to identify such self-evidence in more complicated truths such as Pythagoras' theorem: the square of the longest side of a right-angled triangle is the sum of the squares of the two shorter sides. The same applies to certainty; there will always be doubt regarding the process, for instance, of adding numbers. In this case, the truth will depend on our *a priori* reasoning that is not infallible.

3.3.2.2 Perception

Perception is the process by which we acquire information about the world using our five senses of sight, hearing, touch, taste and smell (O'Brien, 2006). Perception forms the basis of Empiricism or British Philosophy that is the school of thought where

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[19] As argued by O'Brien: "We should not, however, equate the distinction between the empirical and the a priori with that between the analytic and the synthetic. The former is an epistemological distinction: it concerns the source of justification for our beliefs. The latter is one that is semantic: it concerns whether certain truths hold simply in virtue of the meanings of the relevant concepts (O'Brien, 2006, p.27)."

knowledge is tied to experience. Empiricists believe that we have absolutely nothing in the mind that we have not experienced through the senses (Steup, 2005).

Positivism[20] is one the most influential accounts of empiricism. Also known as the philosophy of Comte, it holds that the highest or only form of knowledge is the description of sensory phenomena (Steup, 2005). According to O'Brien (2006) there are four main schools of thought related to perception: Direct Realism, Indirect Realism, Rejecting Realism and Intentionalism.

The most relevant account of **Direct Realism** refers to scientific direct realism. This school of thought is positioned within a realist ontology (the world exists independently of us). In this respect, objects in the world have qualities that are dependent or independent of the perceiver. Independent qualities are classified as 'primary qualities' and include qualities such as shape, size, position, number, motion-or-rest, solidity, spin and mass. Secondary qualities, thus, are those that depend on the perceiver, such as colour, smell and felt-texture (O'Brien, 2006).

Indirect Realism also follows a realist ontology. However, it also embraces an ontology of non-physical objects. What we perceive is considered as sense data at first. Sense data is a cognitive description of what is perceived. For instance, the image of a bent pencil that is formed when submerged in water. The bent pencil does not exist as such in the real world (non-physical object), therefore it is a mental description of what is perceived (i.e. sense-data). Sense data is what is seen in cases of illusion and hallucination. Sense data can be classified as veridical and non-veridical. Veridical sense data, in the case of seeing a bent pencil, would be having a bent pencil in the real world, whereas the non-veridical sense data is the illusion formed by submerging a straight pencil in water (O'Brien, 2006). In the example of primary qualities presented above, shape, for instance, would be a questionable quality that also depends on our senses.

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[20] It is a common mistake to associate positivism with methodological approaches based on the exclusive use of quantitative data, although both quantitative and qualitative data can be used as a source of information. In this respect quantitative means that variables are linked to our reasoning and can be measured through length, breadth and depth for instance. On the other hand, qualitative data such as colour, smell and taste are linked to our senses perception and as such do not describe outer reality.

Perception is also described by schools of thought that reject a realist ontology. Within the anti-realist schools of thought that describe perception are idealism and phenomenalism (not to be mistaken with phenomenology). **Idealism** considers that physical objects consist in a collection of ideas. The world as we perceive it is the result of mind and sense data we perceive. In other words, the existence of physical objects is dependent on perceivers and God sustains the existence of non-perceived things. That is the most critiqued aspect of this approach. Similarly, **Phenomenalism** defends that statements about the physical world are statements about our possible experiences. The focus here is placed upon the 'possibility' of experiencing sense data that remains attached to the physical object and does not depend on God to exist (O'Brien, 2006).

Finally, the intentionalist theory of perception denies that sense data are involved in perception as we are in direct perceptual contact with the world (which is similar to direct realism). However, according to O'Brien (2006), the argument for dealing with illusion is different from direct realism. In this respect, there are three intentionalist schools: adverbialism, intentionalism and phenomenology. For O'Brien, **adverbialism** describes the verbs that explain perceptual experiences in terms of adverbial modifications. By doing that, we describe the manners in which we experience the external world rather than the objects in it. **Intentionalists**, on the other hand, defend the idea that there is a parallel between perception and belief; that is the intentionality of perceiving and it includes false beliefs (for instance, the "bent" pencil in the cup of water). There is no distinction between veridical and non-veridical cases; all that exists is the intentionality of perceiving or the intentional content of sense data. Finally, phenomenology argues that perceptual experience has a reference to the external world that is always dependent on a subjective form of the subject. Experience has an experiential quality (O'Brien, 2006). In this respect, the discipline of **phenomenology** is defined as the study of structures of experience, or consciousness (i.e. the study of appearances of things, or things as they appear in our experience, or the ways we experience things, thus the meanings things have in our experience (Smith, 2005).

Figure 4 presents an overview of the different ontological (existence) and epistemological (rational or empiric) approaches that have been discussed in this section. The author has added arrows to indicate the existence of "mixed" approaches that attempt to link cognitive frameworks to real world phenomena and vice-versa.

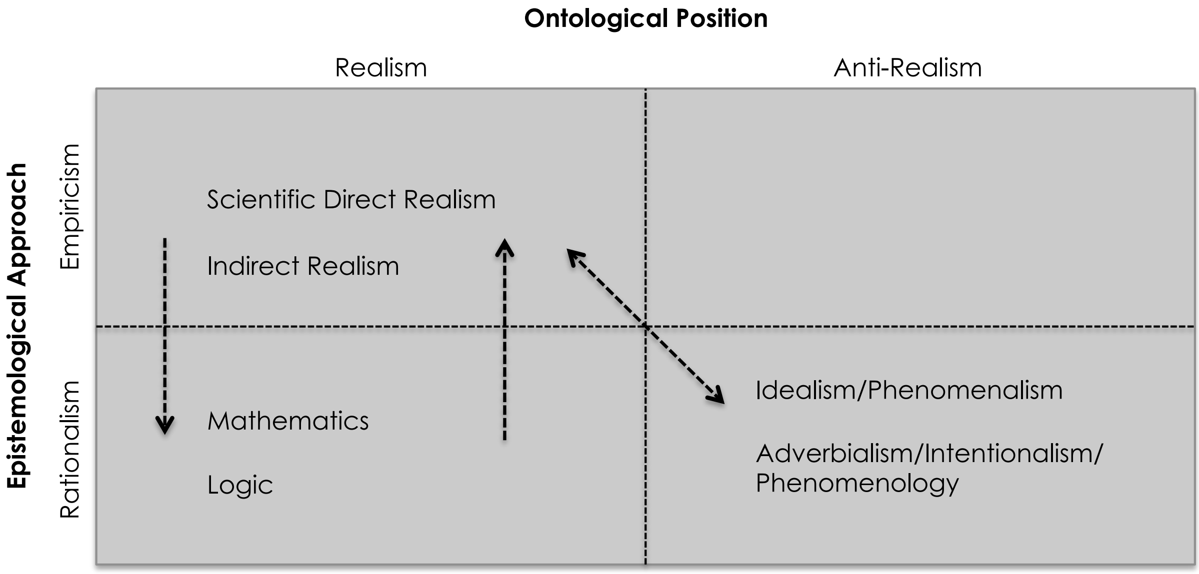

Figure 4 – Ontological and epistemological arrangement matrix (adapted from Johnson and Duberley 2004; and Lantelme 2005)

3.3.2.3 Testimony

Testimony is another way in which we can gather knowledge. According to O'Brien (2006) the debate about testimony is related to whether or not we can acquire justified beliefs and empirical knowledge from others without having perceived the relevant facts ourselves. Central to this debate is the reliability of the source of evidence and knowledge. Despite its relevance, testimony does not influence the way we perceive, rather it deals with how that perception is passed from one person to another, therefore testimony is not further discussed,

3.3.3 Skepticism

Philosophical skepticism (as opposed to ordinary incredulity) is the branch of philosophy that challenges our ordinary assumption that there is evidence available that can support discriminating world views as discussed by realists and anti-realists (Klein 2001). For Klein, ordinary incredulity is placed within a realistic ontological approach (i.e. evidence can be gathered) and doubt can be removed by discovering the truth. On the other hand, philosophical skepticism about a proposition derives from (anti-realistic) considerations that cannot be removed by appealing to additional similar propositions (Klein 2001).

Relevant to the discussion about evidence is the exploration of arguments discussed within skepticism. In this respect, two periods of skepticism can be identified: the ancient and the modern views. According to Vogt (2010) ancient skepticism is about belief rather than knowledge and the anciet debate is seen in current discussions about epistemology, philosophy of language and theory of action. For Vogt (2010) "*The core concepts of ancient skepticism are belief, suspension of judgment, criterion of truth, appearances, and investigation*" whereas important notions of modern skepticism involves the debate about knowledge, certainty, justified belief, and doubt play.

The skepticism debate often leads to epistemological discussions such as how can one know? These questions, according to Vogt (2010) turn into issues related to belief. For Vogt, it '*seems*' that the difference between knowledge and belief is based on differences in the degree of acceptance of a statement. Knowledge has a higher degree of certainty than belief. In this respect, the purposeful use of the verb 'seem' in the above sentence infers that there is belief (not knowledge) that Vogt differentiates knowledge from belief through the degree of certainty. Most important is the fact that both knowledge and belief are enough and an extremely necessary guide to action.

The early Greek philosophers developed distinctions between reality and appearances, knowledge and belief, and the non-evident and the evident (Vogt 2010). Many ancient philosophers, including Plato and Aristotle, contribute to the above discussion raised by scepticism in their work. In this respect, one of the most relevant arguments of ancient skepticism comes from Agrippa (Baptese and Brochier, 2004; Vogt, 2010). The contribution of Agrippa is known in ancient terms as the Five Modes and in modern terms as Agrippa's trilemma. According to Vogt the five modes discuss argument and proof as described in the following.

- ***Diaphônia:*** *The mode that argues from* ***disagreement****. With respect to some matter that presents itself, there is undecided (anepikriton) conflict, both among the views of ordinary life and the views held by philosophers. Due to this, we are unable to choose or reject one thing, and must fall back on suspension.*

- ***Eis apeiron ekballonta***: *Arguments that throw one into an* ***infinite regress****. That which is brought forward to make a given matter credible needs yet something else to make it credible, and so on ad infinitum. Since we thus have no starting point for our argument, suspension of judgment follows.*
- ***Pros ti:*** *Arguments from* ***relativity****. X only ever appears such-and-such in relation to the subject judging and to the things observed together with it. Suspension on how it really is follows.*
- ***Hypothesis:*** *Someone makes an* ***assumption*** *without providing an argument. A dogmatist, if thrown back into an infinite regress of arguments, just assumes something as a starting-point, without providing an argument (anapodeiktôs). We suspend over mere hypotheses - they could be false, opposite hypotheses could be formulated, and so on.*
- ***Ton diallêlon:*** *Arguments that disclose* ***circularity****. This mode is used when that which ought to confirm a given investigated matter requires confirmation (pistis—credibility) from that matter. We are unable to assume either in order to establish the other. We suspend judgment on both.*

Of the Five Modes, three are known as the Three Formal Modes and they constitute Agrippa's trilemma. These modes address the issues of proof and credibility. In modern terms the three modes are: Circular reasoning (*Ton diallêlon*); Infinite regress (*Eis apeiron ekballonta*); and Dogmatic assumption (*Hypothesis* or *Hupothesis*). The trilemma is relevant to the discussion of evidence as this way of reasoning implies that any conclusion in a debate is doubtful from the perspective of justifying our epistemic claims. The three arguments of the trilemma are presented in the following.

- **Circular reasoning:** One can use a circular argument to justify knowledge (e.g. a theory to justify its proof and vice-versa). In other words, this happens when the evidence which would be necessary to justify a conclusion that is under investigation pretends to get its validity from the conclusion itself. As it is impossible to use one to find the other, we suspend our judgment on both (Sextus Empiricus, I, §169 *as cited in* Baptese and Brochier, 2004). In this situation, the argument sacrifices its internal validity.
- **Infinite regress:** according to this mode, all justifications of certain knowledge have also to justify the means of their justification (epistemologically) and in doing so they have to justify again the means of their justification and so on (an infinite

regress). In other words, each proof needs justification and the justification needs proof that needs justification (infinitely). For instance, let us suppose the defence of some epistemic claim P. One option is to defend it on the basis of some further claim Q for which a justification is (sceptically) required. If R is invoked in support of Q then, short of some alternative strategy, an infinite regress process is in place. The difficulty of course is that only two alternatives present themselves: either to invoke P again in defence of R, but this invites the criticism of begging the question, or to carry *ad infinitum* the series of justifications.

- **Dogmatic assumption:** refers to the adoption of an (unquestionable) assumption (as given). The assumption is based, for instance, on experience, common sense, or fundamental principles, of which justification will not be certain. For instance, suppose that R justifies Q and Q justifies P, but R itself does not require any further justification, R is self-justifying. R, in other words, is an axiom.

3.3.4 Summary and Discussion

In this section, knowledge and its formation are discussed as key elements in the formation of evidence. Three sources of knowledge (reason, perception and testimony) and the associate academic debate related to them were presented and the key aspects relevant to this work is reported below.

- Reason as a source of knowledge is considered self-evident when it refers to solving problems that are disconnected from reality. For instance, mathematical truths (theorems) can be proven. Reason is based on *a priori knowledge,* i.e. generic ideas and concepts. In relation to problems that arise from reality, the debate is related to whether it is possible to explain phenomena/behaviour through rationale mechanisms.
- Perception as a source of knowledge has different interpretations. For realists, at the one end, there are direct realists that consider that the world exists independently of us and that the perceived characteristics of things can be dependent or independent of the perceiver. In both cases, observation is an objective exercise. At the other end, there are intentionalists arguing that the world exists independently of us, but the way we see things is dependent on the meaning that each individual will attribute to the thing seen. Meaning is formed through experience and it is a subjective rather than objective exercise. For anti-

realists, the world does not exist without us to perceive it. Sense data is meaningless without us to interpret it, therefore the world as we see it is created in our minds through a set of ideas.

- Testimony here is considered as a subcategory of knowledge source. This is because the original sources that form the basis of testimonies are perception or reason. The discussion around testimony raises issues around reliability related to the source of testimony that also applies to reason and perception.
- Scepticism was introduced here not as a source of knowledge but as the counter-argument that knowledge can never be gathered if dependent on justification, truth and belief. The three most relevant modes of scepticism are based on infinite regress, the use of assumptions (non questionable truths) and circularity.

In regards to knowledge, evidence plays a key role in supporting justification and is never *a priori*, but *a posteriori* knowledge (i.e. it depends on *a priori* knowledge and if formed with a basis on sensorial experience). A further discussion about evidence is presented in the next section.

3.4 Evidence

There are different ontological and epistemological starting points in different professional traditions that support the methods and enthusiasm with which professionals engage with evidence (Davies *et al*., 1999). In natural science, for instance, the consistent and continuous observation of natural phenomena is used as evidence to sustain inductive assumptions about the rules and laws of the universe. In general, evidence resulting from direct empirical observation can establish truth and can be objective (Johnson and Duberley, 2004). In social science however, the use of direct observation for evidence gathering may not be a straightforward mechanism, as the boundaries of social phenomena are, most often, not well delineated.

In science and in epistemology, the roles that evidence play has been a long term subject for debate. Early discussions around evidence can be seen in Plato's Meno dialogue. For Plato knowledge is acquired and sustained with a basis in evidence and that is what makes knowledge different from mere true belief (which just exists or is based on anecdotal evidence – i.e. based on individual or collective accounts). In this respect, knowledge reliability is greater when compared with true belief.

As seen in the previous section, from an epistemological point of view, the process of acquisition of knowledge refers to the process of finding **justification** (i.e. evidence) to sustain the acquired knowledge. This process will vary according to the different ontological positions that can be adopted. For an empiricist, for instance, evidence is gathered through empirical observations, as the world exists without our mind interfering in it. On the other hand, rationalists doubt the reliability of our senses as a way to gather knowledge. At the other end of the ontological spectrum, phenomenologists argue that knowledge is generated from individual interpretation of the outside world.

In this section the concept of evidence is discussed. The discussion starts with the etymology of the word evidence followed by its definition according to different authors. Related terms, functions and objectives as well as the elements that constitute evidence are presented. Finally, emerging issues related to evidence are highlighted.

3.4.1 Etymology

The earliest known meaning for the word evidence dates from the 1300's and refers to "appearance from which inferences may be drawn" (Harper, 2011). Such statement indicates that evidence is the starting process of an inductive process. Other meanings from later periods also exist and refer to proof, distinction, clearness, grounds for belief and obviousness (Harper, 2011). This latter concept indicates a relationship between evidence and justification. The meaning of evidence and its role within science and how it influences practice has provided stimulus for debates in, amongst others, the field of ontology and epistemology (Davies *et al*., 1999). This debate is briefly addressed in this section.

3.4.2 Definitions

It is very difficult to choose a definition of evidence that is scientifically valid. Many definitions of evidence exist that are related or dependent on the definition of knowledge. This similarity or dependency between these two concepts makes it a difficult (if not impossible) task to separate one from the other.

As seen in Section 3, justification, truth and belief are necessary features to classify something as knowledge. In this respect, justification and belief are achieved in the presence of evidence. However, evidence to be considered as such, must be known (i.e. knowledge). Such conceptual construction leads to sceptical arguments, such as the infinite regress and circular reasoning as shown in Aggripa's Trilemma. Thus, for the time being, the definition offered by the Oxford English Dictionary is used and revisited later, when more information is available to sustain a discussion.

> *"Evidence (noun) the available body of facts or information indicating whether a belief or proposition is true or valid".*

According to the dictionary, evidence then is something that indicates the status of truth of a proposition. However, the above definition is rather complicated as it uses five concepts in defining evidence: facts, information, belief, proposition and truth. Those concepts are relevant and are explained throughout this section. In the dictionary, evidence is considered as a *noun* (i.e. it has a status) or a verb. However, for the time being, the definition of evidence adopted in this thesis is: **evidence is a quality of knowledge used to sustain justification, truth and belief.** With such definition, evidence is not a *noun* or *verb,* but rather an adjective and as such has no status of being (i.e. '*is*' or '*is* not'). This definition is also revisited later in this section.

3.4.3 Characterisation of Evidence

It is not a coincidence or lack of research that this section is based, in its vast majority, on the work developed by Achinstein (1978). Extensive research conducted during the development of this thesis shows that there is consensus regarding his views about evidence, his acknowledgement of Gettier's problem and the criticism to Carnap's account of evidence and probability (discussed further in this section).

According to (Achinstein 1978) three types of evidence exist: potential, veridical and reasonable belief. Consider the following scenario and propositions as proposed by Achinstein (1978):

> *An individual's skin has yellowed and is examined by a doctor who promptly declares the patient has jaundice. Further tests carried out reveal later on that the patient does not have jaundice and that the yellow skin is the effect of a dye that the patient had been in contact with. From the above, the following propostions can be applied:*

1) Yellow skin was evidence of jaundice and still is;

2) Yellow skin was but no longer is evidence of jaundice;

3) Yellow skin is not and never was evidence of jaundice.

In this respect, the following discussion is proposed by Achinstein (1978) in regards to evidence:

1) Potential evidence: according to Achinstein potential evidence is the type of evidence that leads to truth, but on its own is not conclusive. For instance, a common symptom to many illnesses tells you that someone might be ill, but on its own, a symptom is not conclusive in defining whether the person is ill or not and what illness the person has got. In this case, according to Achinstein, whether it is true that the person does or does not have a symptom is not relevant. In this respect, Achinstein discuss four conditions of potential evidence. The categories (i.e. independency, objectivity, dependency, and regress) do not exist in the original work of Achinstein. These are proposed here to facilitate discussion.

- Independency: "*'e' can be potential evidence that 'h' even if h is false*" (e.g. yellow skin (e) can be evidence of jaundice (h) even if the diagnosis concludes that it is not jaundice). In this case, context is not relevant and the discussion is that all people with jaundice will have, amongst other symptoms, yellow skin.
- Objectivity: *"'e' can be potential evidence that 'h' independently of anyone's belief about 'e', 'h' or their relationship"*. Believing that someone has yellow skin and/or jaundice is irrelevant. However, belief is necessary to associate yellow skin and jaundice;
- *Dependency: "'e' can be potential evidence that 'h' if, and only if, 'e' is true"*. In this respect, people with yellow skin must exist in the world to be potential evidence of jaundice;
- Regress: 'e' is potential evidence that 'h', but 'e' is not evidence for itself. In other words, yellow skin is not proof that there is skin and it is yellow;

2) Veridical evidence: according to Achinstein, veridical evidence sanctions proposition (3) above. For 'e' to be veridical evidence of 'h' required that 'e' and 'h' both be true and that 'e's truth is related in an appropriate manner to 'h's. The following conditions applies:

- *Explanatory: "'e' is veridical evidence that 'h' only if 'e' is potential evidence that 'h' and 'h' is true"* (e.g. yellow skin is veridical evidence of jaundice if jaundice is the final diagnostic). In this respect, 'e' explains 'h' but 'h' not necessarily explains 'e'. Achinstein does not go further in describing 'explanatory relationship' but the examples provided by him indicates that there is a 'theory' or 'hypothesis' that is independent of 'e' and 'h' explaining the relationship or dependency between 'e' and 'h'. Therefore, the explanatory condition of veridical evidence is: " *'e' is veridical evidence that 'h' if 'e' is potential evidence that 'h', 'h' is true, and there is an explanatory connection between 'e's being true and 'h's being true"*. According to Achinstein (2010) potential and veridical evidence does not depend on what anyone believes, therefore they are objective concepts of evidence[21]. This definition matches the definition of knowledge based on the JTB concept of knowledge.

3) Epistemic Situation-evidence (Principle of Reasonable Belief)**:** according to (Achinstein 1978) "*If, in the light of background information 'b', 'e' is evidence that 'h', then, given 'b', 'e' is at least some good reason for believing 'h'*". In this scenario, even if 'yellow skin' is not potential or veridical evidence of 'jaundice' (i.e. the yellow comes from a dye), it is reasonable to think that yellow skin might be evidence because the fact 'b' (that yellow skin is known to be a symptom of jaundice – here, the explanatory connection) is a good reason to believe in jaundice until further evidence confirms that it is or it is not jaundice (as 'e' on its own is not enough to prove 'h'). In this category, context is relevant and it is demonstrated with the addition of the proposition "X" as related to someone (see examples below). The conditions that apply to the principle of reasonable belief (here named Probabilistic Justification) are:

- *"'e' is X's (i.e. someone's) evidence that 'h' only if X believes that 'e' is veridical evidence that 'h'; i.e., X believes that 'e' is potential evidence that 'h', that 'h' is true, and that there is an explanatory connection between the truth of 'h' and 'e'"*

[21] It is important to highlight the distinction between something being evidence that 'h' and someone's evidence that 'h'. As in the example, yellow skin can be (potential and veridical) evidence of jaundice without being the doctor's evidence (Achinstein, 2010, p.16).

- *“’e’ is X’s evidence that ‘h’ only if X believes that ‘e’ is potential evidence that ‘h’, that it is **probable** that ‘h’ is true, and that it is probable that there is an explanatory connection between the truth of ‘h’ and ‘e’”*
- *X believes that ‘h’ is true or probable (and does so) for the reason that ‘e’*

For Achinstein (1978), the concept of evidence is thoroughly subjective as the fact that ‘e’ is X’s evidence that ‘h’ is based on what X believes about ‘e’, ‘h’ and their connectivity and not on whether in fact ‘e’ is potential or veridical evidence that ‘h’.

With a basis on Achinstein categorisation of evidence, it is possible to highlight another characteristic of evidence that is not mentioned. That refers to a **latent status** of knowledge justified by the existence of uncertainty that can be seen in potential evidence and reasonable belief. In this respect, knowledge cannot be qualified as being ‘evidence’ or ‘not evidence’. *This status will be used later to partially explain the iterative characteristic of design.

Probability, Explanation and Strength of Evidence

Can probability be considered as evidence? According to Achinstein (1994; 2010) probability falls within the potential concept of evidence, if the truth-requirement of potential evidence is satisfied. Carnap (1950) *as cited in* Achinstein (2010) suggests the probability definition of evidence as: *‘e’ is potential evidence that ‘h’ if and only if the probabilty of ‘h’ given ‘e’ is greater than the prior probability of ‘h’. Conditions:*

‘e’ is potential evidence that ‘h’ if and only if $p(h/e)>p(h)$*;*

or, if ‘b’ is background information,

‘e’ is potential evidence that ‘h’ if and only if $p(h/e \& b) > p(h/b)$

In addition, Achinstein presents the explanation definition of evidence:

‘e’ is potential evidence that ‘h’ if and only if ‘e’ is true and ‘h’ would correctly explain ‘e’ if ‘h’ were true; and

‘e’ is veridical evidence that ‘h’ if and only if ‘h’ correctly explains ‘e’ (i.e. ‘e’ is potential evidence that ‘h’, and ‘h’ is true).

Without further explaining these categories here[22], Achinstein (2010) argues that these particular probability definitions are not sufficient to classify probability as evidence. He also analyses the explanation definition of evidence and concludes the same. However, a combined proposition (i.e. probability and explanation) is explored in the format below.

> *'e' is potential evidence that 'h' if and only if: 'e' is true; 'e' does not entail 'h'; p('h'/'e') > k; and p (there is an explanatory connection between 'h' and 'e'/'h'&'e') > k.*

As explained by Achinstein (2010):

> *"The fact that someone has yellow skin is potential evidence that he/she has jaundice only if it is probable that he/she has jaundice, given that he/she indeed has yellow skin, and it is probable that there is an explanatory connection between his/her having a yellow skin and jaundice, given that he/she has both. And whether these probability claims can be made depends on what background information is being assumed, and on the general relationship between probability statements and background information. What view is taken of this relationship will determine what evidence statements can be asserted.*

In relation to probability as a concept of evidence, Achinstein (1994) argues that higher probability is neither necessary nor sufficient for stronger evidence. For Achinstein (1994) four other factors, more relevant than probability, impacts on the strength of the evidence: **a) sample size** of the evidence (relative frequency of favourable evidence), **b)** total **number of tests**; **c) variety of evidence** (variety of conditions under which tests are made); and finally, **d)** the existence of an **explanatory connection** between the hypothesis tested and the evidence. According to Achinstein (1994, p.340):

> *"The probability of an hypothesis which attributes a property to an unexamined individual, conditional on the distribution of that property in a sample, approaches the relative frequency of the property in the sample as the size of the sample increases, as the 'variety' of the sample increases, and as the probability of an explanatory connection between the hypothesis and the test results increases."*

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22 These are provided in Achinstein (2010, p8-13).

3.4.4 Classification of Evidence in relation to the Source of Reasoning

According to Rieke and Sillars (1984) another classification can be applied to evidence that relates to the form of reasoning used to sustain argumentation. There are many forms of reasoning and the main ones are logic (syllogism or deductive reasoning), scientific (based on rational or empirical experiment, it involves both induction and deductive reasoning) and enthymeme (informal or rethorical syllogism – involves inductive and abductive reasoning) (Jeffrey and Burguess, 1981).

Common to these forms are the deductive, inductive and abductive forms of reasoning. According to Jeffrey and Burguess (1981), deductive reasoning starts from general premises that are considered true and moves to specific conclusions; Abductive reasoning involves choice in a situation that involves implicit knowledge (i.e. argument does not follow with certainty from its premises and concerns something unobserved). Finally, inductive reasoning involves making inferences from/based on prior observation. Different reasoning approaches can be used to support arguments generated from inductive reasoning (Jeffrey and Burguess, 1981):

- Analogy: refers to the comparison of two similar situations. The analogy is dependent on the perceivers' perception / accuracy of the similarity between the two cases;
- Generalisation: relates to the principle of induction where a series of instances are perceived and from them a general principle can be claimed;
- Cause: attempts to establish a cause and effect relationship between two events;
- Sign: asserts that two or more things are so closely related that the presence or absence of one indicates the presence or absence of the other;
- Authority: relies on the testimony and reasoning of a credible source (an expert).

From the above classification, Rieke and Sillars (1984) proposes four types of evidence (these are considered as part of the enthymeme form of reasoning): (a) anecdotal evidence consists of evidence based on a specific instance or occurrence of observation of the phenomenon; (b) statistical evidence is a numerical summary of a series of instances; (c) causal evidence consists of an explanation for the occurrence of the effect; and (d) expert evidence consists of the testimony of an expert. Here, the above classification is distinguished from evidence collected scientifically. Thus, for the purposes of this thesis the above classification was considered as part of a group named anecdotal empiricist evidence.

In relation to decision-making these types of anecdotal empiricist evidence have different levels of persuasiveness. According to Hornikx (2005) from higher to lower persuasiveness statistical, causal and expert evidence are more persuasive than anecdotal evidence. However, the same author argues that the quality of the evidence is a key factor that can influence the above-mentioned order of persuasiveness.

3.4.5 Roles of Evidence

As highlighted earlier in this section, the concept of evidence is related and dependent on the concept of knowledge. In this respect, the roles evidence play are associated to those related to knowledge formation. In other words, evidence is used to support and sustain knowledge justification, truth and belief. These roles were previously reviewed, earlier in this Chapter, and will not be further discussed here. However, these roles as related to evidence are presented below.

As discussed by Kelly (2006), the justification for what is thought as being known (i.e. evidence as that which justifies belief) is one out of three roles that evidence may play. Kelly (2006) discusses evidence as something that makes a difference to what one is justified in believing or what it is reasonable for one to believe. In other words, there is a cause-effect relationship, i.e. if something is believed; it is because there is something that supports its belief. This view is shared by O'Brien (2006) and Morton (2008).

The second role of evidence as discussed by Kelly (2006) relates to rationality. Kelly argues that knowledge gathered independently of sense experience is supported by its rationale status. The rationale status is therefore the evidence to sustain knowledge. In these two roles, evidence is conclusive (i.e. leads to conclusion). For example, a problem in geometry when solved generated the evidence that the theorems used for solving the problem are correct. Without further explanation at this point, this "demonstration" of solving a problem is also called synthesis. For O'Brien (2006) and Morton (2008) rationality is related to foundationalism. Foundationalism relies on "basic beliefs" (rationale ones) that do not require evidence[23]. We shall argue later that "synthesis" can be considered as evidence for rationale problems.

Finally, the third role as discussed by Kelly (2006) relates to evidence as a guide to truth. Regarding this role, evidence serves as a reliable sign, symptom, or mark that leads to truth but whilst on its own, would not be enough to sustain a conclusion. For example, in instances where a symptom is not enough evidence to support a diagnostic. Whilst Kelly (2006) discusses further roles of evidence, it is contended here that his further classification is embedded within these three categories. This view is parallel to Achinstein's view of potential evidence and also relates to the fallibilist theory as presented in O'Brien (2006).

In this respect, evidence can also be discussed as being directly related to knowledge reliability. Reliability is therefore dependant on the authenticity of the relationship between evidence and phenomena. Additionally, it is also dependant on the rigour of evidence gathering. Rigour is thoroughly discussed in the vast field of research methodology and comes from, amongst other qualities, the capability of research reproduction, impartiality of analysis and coherence. This discussion is further addressed in section 3.5.

3.4.6 Summary and Discussion

Despite the fact that evidence as presented in the dictionary as well as from the discussions about it do not relate the concepts of evidence to that of knowledge, it is clear that these two concepts refer to the same idea and are dependent on the same issues. These issues are related to the dependency of the concept, to the concepts of justification, truth and belief, as well as to Gettier's problem of knowledge.

In respect to the characteristics or categories of evidence, Achinstein proposes three types: potential, veridical and the epistemic situation-evidence. Potential evidence gives direction to truth but on its own is not conclusive. Veridical evidence on the other hand is conclusive and both are context independent. Finally, situation-

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23 The debate on whether or not rationalists relate their beliefs to sensorial experience, and therefore need evidence, was presented earlier in this Chapter.

evidence complements potential evidence, i.e. in the light of additional information, potential evidence reveals truth. Here, context counts.

In regards to the strength of evidence, it was discussed that higher probability is not a criteria for stronger evidence. Amongst the criteria that support stronger evidence are: sample size, number of tests, variety of tests and an explanation that links the evidence to the hypothesis tested. Evidence strength is further discussed in the following section.

Finally, evidence promotes different levels of persuasiveness in relation to decision-making (in particular evidence generated from non-scientific inductive process). In order, statistical, causal and expert evidence are more persuasive than anecdotal evidence as discussed by Hornikx (2005).

3.5 Theory Building

Without further discussion, it is an assumption in this work that the process for the generation of evidence is similar, if not the same, as the one involved in theory building. In this respect, as knowledge, a theory can only be valid in the presence of evidence and evidence is only relevant and coherent if there is a theory to support it. Thus, one would argue that understanding the theory-building domain can contribute to the better understanding of evidence.

Many dimensions must be considered in the development of theories. Amongst these dimensions are agency, culture, structure (DiMaggio, 1995) and evidence. For DiMaggio (1995), the multidimensional characteristic of theories is what makes contributions to them an extremely difficult process. According to Love (2000) one approach to deal with the multidimensionality is to take an abstract view of the problem, establish a framework for analysis and create a structure that enables elements of different subjects to be positioned relative to each other. This process, as suggested by Love, is not simple as the terminology within the field of theory building is ill defined and confusing. Thus, in this section, elements and features that can compose a framework to evaluate contributions to theories are discussed.

3.5.1 Definitions and Terms

In etymology, the term theory first appears in the literature in the 1590s meaning "conception, mental scheme". The English term is derived from L.L. theoria (Jerome), from Gk. theoria the meaning of which refers to "contemplation, speculation, a looking at, things looked at"; from theorein "to consider, speculate, look at"; from theoros "spectator"; and from thea "a view" + horan "to see" (see warrant). Theory referring to "principles or methods of a science or art (rather than its practice)" is first recorded in the 1610s and that of "an explanation based on observation and reasoning" is from the 1630s (Harper, 2012).

Many authors present definitions for the word theory in present times. Koskela (2000) argues that some associated terms, such as foundations, paradigm, first principles, system, model and doctrine are also related to the term "theory". Dubin (1969) argues that theory, model and system are identical and that they have an identical meaning. He also highlights that other writers, in social science, tend to view theory as fundamental explanation and model as representation of reality. Here, model and system were considered in this way. The number of concepts with the same or similar meanings is a symptom of ill-defined concepts. Despite the considerable number of different terms referring to the same concept, two are more significant due to the frequency of their occurrence: model and system (Koskela, 2000).

In this respect, candidate definitions for the term theory can be found in any field of knowledge. Here, definitions provided from experts in the fields of philosophy, theory building, design, social science, and management are considered for comparison and contrasting purposes. The examples below provide an overview of some candidate definitions.

> *"Theory, theoretical model, model and system stands for a closed system from which are generated predictions about the nature of man's world – predictions that, when made, the theorist agrees must be open to some kind of empirical test (Dubin, 1969)."*

> *"Theories are nets cast over what we call "the world": to rationalize, to explain, and to master it. We endeavour to make the mesh ever finer and finer (Popper, 1972)."*

> *"Theory is… an ordered set of assertions about a generic behaviour or structure assumed to hold throughout a significantly broad range of specific instances (Sutherland, 1976: 9)."*

"In social science history, as in most areas of knowledge, theory is not a tight set of logical deductions but is, rather, a loose collection of somewhat interrelated statements of varying levels of abstraction. These statements function as a summary of existing knowledge as well as arguments that goes beyond any known evidence (Flanigan, 1988)."

"By definition, theory must have four basic criteria: conceptual definitions, domain limitations, relationship building, and predictions. Theories carefully outline the precise definitions in a specific domain to explain why and how the relationships are logically tied so that the theory gives specific predictions (Wacker, 1998)."

"In its most basic form, a theory is a model. It is an illustration describing how something works by showing its elements in relationship to one another (Friedman, 2003)."

In addition to these definitions, according to Dubin (1969) and Whetten (1989), theories, in order to be complete, must contain four essential elements:

- **"What"** variables, constructs and concepts must be logically considered as part of the explanation of the phenomena of interest;
- **"How"** variables, constructs and concepts are related. For Dubin (1969) and Whetten (1989), What and How together constitute the domain or subject of the theory. At this point, causality is introduced (Koskela, 2000);
- **"Why"** the psychological, economic, or social dynamics **justifies** the selection of factors and proposed causal relationships These rationales are the "glue" that justifies the selection of factors and the proposed causal relationships (Dubin, 1969; Whetten, 1989). According to Koskela (2000) an explanation is also required.

Whetten (1989) highlights that, together, these three elements provide the essential ingredients of a theory: **description** (what and how) and **explanation** (why). Whetten (1989) does not include **prescription** in the "what" and "how" category. Thus, this category is added here.

According to Whetten (1989), the boundary of the theory is an important issue that is often the least developed area, therefore he includes the elements **"Who"**, **"Where"** and **"When"**. For Whetten (1989) these are temporal and contextual factors and as such contribute to understanding the range of situations where the theory has been tested. Whetten (1989) points out that, unfortunately, only a few theorists make explicit the focus on the contextual limits of their propositions:

"In their efforts to understand a social phenomenon they tend to consider it only in familiar surroundings and at one point in time (Whetten, 1989)."

As discussed so far, there are many elements that are necessary in the development of theories. Table 5, below, summarises the elements found in the definitions provided by the above-mentioned authors. From these definitions, it can be said that a theory is an explanation of phenomena that contains in itself an explanation for why it explains the phenomena. As such, the explanation must contain a selected number of concepts that are involved in phenomena and the rules that define the boundaries for inclusion and exclusion of concepts for which influence in the phenomena is relevant, irrelevant or non-existent. Each concept is explained individually and relationship mechanisms in between concepts are described or prescribed, thus supporting prediction. Veridical evidence must be collected to demonstrate that the described/prescribed relationships amongst specific parts or a whole works, thus validating the theory (i.e. predictions are accurate) in the contextual and temporal situation in which it has been tested.

Table 5 - Elements of a theory according to different authors

	Parts (what)	Relationships	Prediction	Evidence	Explanation	Rationale	Context
Dubin (1969)	■	■	■	■			
Popper (1972)	■	■			■	■	
Sutherland (1976)					■		
Flanigan (1988)		■			■		
Whetten (1989)	■	■	■		■		■
Wacker (1998)	■	■	■		■		
Friedman (2003)	■	■					

3.5.2 Functions

Several authors (e.g. Dubin, 1969; Hudson and Ozanne, 1988; Bacharach,1989; Meredith, 1998 and Koskela, 2005) argue that the key functions of a theory are **prediction** and **explanation**.

In this respect, Dubin (1969) discusses that there are two meanings for the prediction function: (1) that we can foretell the value of one or more units making up a system; or (2) that we can anticipate the condition or state of a system as a whole. In both instances the focus of attention is upon an outcome. Hudson and Ozanne (1988) add that with explanation or prediction we are usually interested in the similarities of a system. Bacharach (1989) argues that prediction tests the meaning of the explanations provided.

In regards to explanation, Dubin (1969) uses the term "*understanding*" to refer to the knowledge that explains the interaction between units of a system. However, according to Hudson and Ozanne (1988) understanding is a never ending process rather than an end. To them, with understanding, we are equally, if not more, interested in differences. Bacharach (1989) argues that explanation is used to establish meaning, i.e. to explain the prediction mechanism and how it relates to the investigated phenomena. According to Meredith (1998) understanding entails both explanation and prediction and more. Kaplan (1964)[24] *as cited in* Meredith (1998) illustrates this with the example of the ancient astronomers who made excellent predictions of the future positions of the planets; they could also explain the rationale behind the prediction but were unable to say why (understanding) that and not another mechanism was right.

According to Koskela (2005), prediction and explanation relates to the scientific functions of a theory. For this author, the functions of a theory can be further expanded and associated with their scientific and practical use (Table 6). Koskela (2005) augments to the previously discussed functions the predisposition that theories have to validate knowledge and provide direction to research. In respect to direction for research, Koskela argues that identified discrepancies between theory and empirical observation, in general, leads to new research and investigation.

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[24] In Kaplan, 1964. The Conduct of Inquiry. Chandler, New York.

In regards to its practical functions, Koskela (2005) argues that theories play a role in supporting methods and tools as an explanation is provided to why they work. The same role applies in relation to teaching, communicating and transferring knowledge across different fields. In addition to that, Cooper (2005) argues that theories help practitioners to identify the root cause of their problems. Once practitioners know "what is going on" they can try to establish practical ways (e.g. methods and tools) to interfere in a specific situation aiming to change it.

Table 6 - Functions of a theory according to its relation with its scientific and practical use

Scientific	Practical
Explanation	Supporting methods and tools
Prediction	Teaching
Validation	Communication
Direction of research	Knowledge transfer

In this paper it is assumed that the scientific function of a theory is to explain how and why phenomenon happen. In this process, knowledge is generated from both correct (known things) and incorrect explanations (yet to be known things). In this respect, knowledge development constitutes a function itself. On the other hand, in addition to the practical functions presented, theories (whether explicit or not, correct or not) form the basis of our arguments and decisions in the "real world" aiming to change, develop and create things.

3.5.3 Trade-offs

The process of building theories involves "solving" trade-offs and admitting limitations. For instance, due to intrinsic limitations, research will always be imperfect in relation to testing all possible or relevant contextual and temporal scenarios. Thus, a compromise related to the scope of the study that will generate the theory has to be made so as to progress the research. However, scope is only one aspect that generates trade-offs.

According to Weick (1979)[25] *as cited in* Sutton and Staw (1995), organizational scholars, like those in other social science fields, often are forced to make trade-offs between generality, simplicity, and accuracy. For DiMaggio (1995) this happens because theory building involves different purposes and embodies different values. In other words, a theory is the result of a hybrid combination of qualities that includes covering-law, enlightenment and process approaches (DiMaggio, 1995). As such, the process of developing logically consistent and integrated arguments becomes a challenge (Sutton and Staw, 1995). According to DiMaggio (1995), some of the challenging and common trade-offs experienced by theory developers include[26]:

Clarity versus de-familiarisation: quoting Plato's paradox, if you know what something is, there is no need for research and if you do not know you will not recognise it. Thus, theory building involves "de-familiarisation", which is the process of enabling a native to see its own world with a new "fresh" pair of eyes (DiMaggio, 1995). For instance, using different ontologies to investigate the same phenomena can promote similar or different understandings. According to DiMaggio (1995) both are essential 'old words' and neologisms. In this case, to confront a new reality can bring out our values from our subconscious and help us to reassess them.

Focus versus Multidimensionality: multidimensionality means to consider different characteristics related to the investigated phenomenon such as agency, culture, structure and several other abstract categories in its rhetoric (DiMaggio, 1995). For instance, a multi-dimensional take on building design will consider the views and needs of investors, different user groups, designers and contractors. A focused one will concentrate on one of them. DiMaggio (1995) highlights that focused theories have fewer and highly specialised readers and fewer interpretations (or different reception). Contrastingly, multidimensional ones attract more readers with different backgrounds and different interpretations or something to say. Thus, if on the one hand you limit the variables and relationships involved in the phenomenon, risking

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[25] In Weick, Karl E. 1979. The social psychology of organizing, 2nd ed. Reading, MA: Addison-Wesley.

[26] The viewpoint presented here is limited as DiMaggio (1995) adopts a subjective ontological point of view (i.e. the world is something created by the human mind). Therefore, balance and equilibrium is recommended since each person has a different background that will influence their understanding. The debate related to other ontological positions are not discussed here and the authors acknowledge this limitation.

developing something interesting, on the other you expand, and testing all relationships becomes challenging or impossible

Comprehensiveness versus memorability: If our job is to explain the world, rather than to note small but paradoxical statistical relationships, should not we focus precisely on the measures and processes that explain the most? DiMaggio (1995) confronts the problem related to levels of generalisation (i.e. can the same theory be applied in other contexts?). In this respect, the debate relates to the extent that a general theory can be accessed and validated or a specific one made relevant.

In relation generalisation, Meredith (1998) emphasizes the issues of **rigour** when developing a theory. For Meredith (1998) rigour is associated with the level of replicability of research and/or phenomenon. Meredith (1998) argues that on the one hand theories generated within a controlled environment could have limited generalizability, as the chances that the laboratory conditions exist in the real world are limited or non-existent. The same applies for those using cases studies, where the chance that the contextual and temporal setting where the theory was developed will never be the same in another case.

3.5.4 Summary and Discussion

This section proposes a discussion about theory building. This topic is relevant to the development of this thesis as knowledge and therefore evidence are generated as its theoretical support is presented. The discussion presented here is focused on highlighting the different terminology used to refer to theory, its functions and trade-offs.

In relation to available definitions, the review revealed that there is no consensus amongst academics conducting research in the area. In this respect, a definition was proposed that incorporates the shared and specific features considered within each studied definition. In relation to a phenomenon, that includes the relevant and irrelevant "parts" and the relationship mechanisms between those, its prediction capacity supported by evidence and the explanation for how evidence can be gathered, as well as the rationale behind the explanation and finally the context (generic or specific) in which the theory applies.

In terms of its function, the debate relates, in general, to scientific functions of theories. In this respect, explanation, prediction, validation and direction to research were highlighted as key functions. Without further discussion, theories are considered as a type of knowledge (theoretical knowledge) for which the JTB rules apply. In addition, practical functions of theories were discussed. These refer, in general, to theory building as a mechanism for knowledge exchange and justification/rationale for decision-making.

Finally, the process of theory building was discussed in relation to internal conflicting issues that lead to trade-offs. Key aspects where discussed, such as clarity, focus and comprehensiveness and their respective opposites. Rigour and replicability were also discussed as impacting on the generation of trade-offs in the development of theories. The definition, function and trade-off aspects of theory building, forms here a framework for the assessment of theories. These aspects are summarised below:

- **Completeness**: Were all relevant parts considered, and irrelevant ones systematically removed?
- **Usefulness**: Does the theory stimulate discussion and practical changes? Does it help to explain or predict an event?
- **Coherence**: Are the author's assumptions, explanations and justifications explicit?
- **Bias**: Have the relevant dimensions (lenses) been used to interpret the phenomena?
- **Replicability**: Can results from theory test be replicated?
- **Challenge**: Does the theory challenge the current thinking?
- **Novelty** and **Innovation**: Is it really a new theory? Is it a contemporary subject?
- **Validation**: are test mechanisms representative of investigated phenomena
- **Relevance**: How many times? How many places? How big is the population affected by the phenomenon?
- **Generalisation**: Is the theory abstract enough that it can be applied to different specific events?
- **Rigour**: Are methods and data collection reliable? Have different ontologies and epistemologies been addressed?

3.6 Conceptual Framework of Evidence

The discussions so far presented revealed that current definitions of knowledge, evidence and theory are non-consensual, ill-defined propositions where problematic issues remain unsolved. Despite the problems, a position has to be assumed that considers the current state-of-the-art debate related to evidence. Thus, this section presents a definition of the positions that are relevant to the classification of evidence coming from empirical investigations looking at the design of healthcare facilities in general and in particular to the effects of the built environment in healthcare settings on patients' health outcomes. The elements that compose the conceptual framework are presented below.

- **Ontological position:** refers to whether or not the world exists without us. The two possible classifications are realist and anti-realist.
- **Epistemological approach:** refers to how knowledge is gathered. There are two types of knowledge: *a priori* knowledge (independent of perception: mathematical and conceptual truths, metaphysical and ethical claims); *a posteriori* knowledge where its sources relies on perception, introspection, memory, reason and testimony. In this respect, two approaches are considered: rationalism (*a priori*) and empiricism (*a posteriori*). These are described below.

    - Rationalism: reason is the only mechanism that leads to knowledge. Knowledge is *a priori* and "independent" of empirical observation.
    - Empiricism: empirical observations using our senses (perception) constitute a reliable mechanism that leads to knowledge. However, there are different approaches to deal with the argument of illusion as presented in Table 7.

- **Evidence classification**: evidence can be classified in relation to its relation to generic truth. In this respect, two categories apply: potential and veridical. In regards, to the former, truth is a possibility whereas for the second it is certainty. Evidence can also be classified as situational when it is related to a specific and contextual analysis of a phenomenon where no general truth is sought. In relation to the form of reasoning, evidence can be classified as rationalist, scientific empiricist and anecdotal empiricist.

Table 7 – Ontological and epistemological approaches as related to the argument of illusion

Perception (realist ontology)	**Perception (anti-realist ontology)**
• Scientific Direct Realism: observed phenomenon has primary and secondary qualities. Secondary qualities are dependent on the observer's senses • Indirect Realism: perception generates sense data. Sense data of primary qualities leads to veridical sense data. Sense data of secondary qualities can lead to non-veridical sense data (illusion or hallucination).	• Idealism and Phenomenalism: objects (phenomena) are described through concepts that exist *a priori*. Description combines *a priori* concepts and sense data[27] • Adverbialism, intentionalism and phenomenology: similarly relies on *a priori* knowledge to describe phenomena, however focus of analysis is placed upon different issues: adverbialism is focused on how we describe experience; intentionalism is focused on the intention of perceiving; and phenomenology is focused on the meaning of experience as we experience the world.

- **Evidence strength**: the strength of evidence is dependent on the sample size, the explanatory connection between variables and concepts, and the variety of evidence that confirms or disconfirms the phenomenon and the number of tests carried out to confirm or disconfirm evidence.

Here, the criterion of knowledge status (known or unknown) is not considered and that relates to the fact that the concepts of knowledge and evidence are based on and must satisfy the criteria of justification, truth and belief. As discussed this proposition does not respond to Gettier's problem. It is also considered that no knowledge of evidence can escape the sceptical argument of circularity, infinite regression and dogmatic assumption. Therefore, this classification is not considered in the framework presented in Figure 5.

[27] As previously discussed, the difference between idealism and phenomenalism is in the argument of existence. For the former, non-experienced phenomena relies on God to exist (something exists if experienced) the latter focuses on the possibility of being experienced (if it is possible to be experienced, therefore it exists and does not depend on God). The argument of existence is not questioned here; therefore, these two categories have been grouped together.

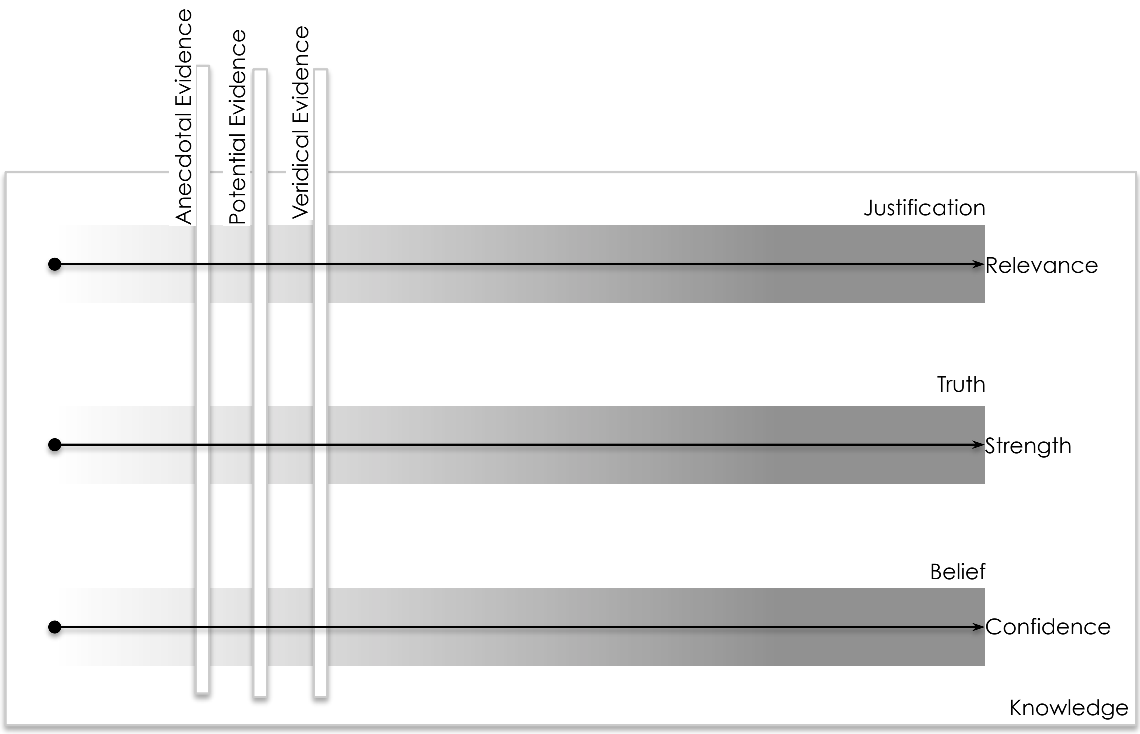

Figure 5 – Conceptual framework for assessing evidence in a knowledge formation system.

In the proposed framework, evidence and knowledge are inter-dependent concepts. Knowledge is a construct that is formed by the JTB idea. Thus, justification will be based on the relevance of the evidence provided and the context in which justification is required. The discussion proposed by Kelly (2006) the expression "something that makes a difference" for what here has been considered relevance. Truth relates to the strength of the evidence gathered and belief relates to the confidence in the evidence available as discussed by Achinstein (1994, 2010). The three types of evidence were organised in order of strength, being veridical evidence stronger than potential evidence that is stronger than anecdotal evidence. This is a generic model to be used in later stages of the research.

4 PRESCRIPTIVE DESIGN METHODS

From the previous section, evidence was defined and its characteristics explored. In this section the generation and uses of evidence within design are investigated. In this respect, cognitive and managerial process models of design are reviewed. The focus of the review is to identify how evidence is defined within the design field in comparison with its concept defined in philosophy.

Research about the cognitive process of design has its focus on understanding how designers think. The aim of such investigation, in general, is to map out the activities and the sequence behind the thinking process of design with the objective of developing systematic methods for improving the design activity. The main limitation of research in this area is the nature of the design process itself, as we do not have means to access the processes occurring in the human intellect. Epistemologically, sensorial experience is still a challenge and as a result, the field has been split. On the one hand, contradictory "descriptive" models developed through verbalisation marginally explain the routes adopted by designers to design. On the other hand, ‘advanced’ logical prescriptive models fail to justify the link between reasoning and practice.

In this respect, the routes of modern design science go as far back as the 1940s. Despite the fact that research conducted prior to this period exists, it was not until the end of the Second World War that a consistent and continuous production of research started to be developed (Hubka and Eder, 1996). This period is considered as the starting point of the movement for rationalizing and streamlining design as a cognitive and technical-scientific activity (Hubka and Eder, 1996).

Examples of research fields that have been explored include propositions of design theory such as those developed by Hubka and Eder (1988), Love (2000), Friedman (2003), Hatchuel and Weil (2003), and Koskela and Kagioglou (2006); engineering design methods as proposed by Asimow (1962), Hall (1962), Cross *et al.*, (1981), Archer (1984), Jones (1984), Cross (1989), Pahl and Beitz (1996), and Suh (2001); design and the decision-making process (e.g. Wallace and Burgess, 1995); issues involved in problem solving in design, as discussed by Newell and Simon (1972), Cohen (1995), Dorst (2003; 2006), and Thomson *et al.,* (2006); the creativity process within design (e.g. Gero, 2002); and the formation of expertise in design (e.g. Cross, 2004 and Lawson, 2004).

In this section, focus is placed upon prescriptive models of design. In this respect, the acclaimed seminal contribution made with the publication of “The Science of the Artificial” by Herbert Simon in 1969 is challenged. Simon (1969) described the design process as a goal-seeking system and as such it has influenced researchers in the design field since. The explanation provided by Simon has been challenged by Koskela *et al.,* (2008). According to Gedenryd (1998), a much older method, the method of analysis and synthesis developed by ancient Greek geometers, provides better foundations for design. Gedenryd attribute this finding to Alexander (1964) and Jones (1970) who studied and have been influenced by Polya (1964) and his knowledge as a problem-solving methodologist. Gedenryd (1998) starts the discussion about the relationship between design methods and the method of analysis and synthesis, however it was only in 2006 that Koskela and Kagioglou investigated this relationship further. Still, from Koskela and Kagioglou (2006) features of the method of analysis and synthesis were left uncovered. Thus, in this section, this method in particular and other methods are investigated in relation to the role that evidence plays.

4.1 The Method of Analysis and Synthesis

The method of analysis and synthesis was crucial as a method for discovery in geometry in ancient times (Panza, 1997). As such, this relevant method has been successfully applied in other fields to support their methodological approaches. For example, it is known that Isaac Newton used the method of analysis in Physics and Bernard Riemann in Biology.

The link between the method of analysis and discovery has recently triggered the discussion about this method as a proto-theory of design (see Koskela and Kagioglou, 2006 and Koskela *et al*., 2008). These authors claim that the method of analysis comprehensively embeds the features presented in most contemporary candidate theories of design. In this respect, this section is developed on the assumption that the method of analysis is a proto-theory of design and as being first in order it is presented ahead of contemporary candidates.

4.1.1 Analysis and synthesis: Ancient Description

Detailed descriptions of the method of analysis and synthesis from ancient times do not exist. As such, the reconstitution of this method is based on the interpretations of material that is related to the method of analysis such as in the works of Aristotle (*Analytics*, *Nichomachean Ethics and Physics)* and Euclides (*The Elements)*. There are several interpretations available such as those provided by Heath (1921) and Hintikka and Remes (1974) referring to the work of Pappus.

In this respect, the only available description of the method (as a method) is from a later period, around 300AD. This existing fragment of a description defines analysis and synthesis in the view of the Greek geometer Pappus as translated by Hintikka and Remes (1974).

> *"Now analysis is the way from what is sought - as if it were admitted - through its concomitants in order to something admitted in synthesis. For in analysis we suppose that which is sought to be already done, and we inquire from what it results, and again what is the antecedent of the latter,*

until we on our backward way light upon something already known and being first in order. And we call such a method analysis, as being a solution backwards.

In synthesis, on the other hand, we suppose that which was reached last in analysis to be already done, and arranging in their natural order as consequents the former antecedents and linking them one with another, we in the end arrive at the construction of the thing sought. And this we call synthesis.

Now analysis is of two kinds. One seeks the truth, being called theoretical. The other serves to carry out what was desired to do, and this is called problematical. In the theoretical kind we suppose the thing sought as being and as being true, and then we pass through its concomitants in order, as though they were true and existent by hypothesis, to something admitted; then, if that which is admitted be true, the thing sought is true, too, and the proof will be the reverse of analysis. But if we come upon something false to admit, the thing sought will be false, too. In the problematical kind we suppose the desired thing to be known, and then we pass through its concomitants in order, as though they were true, up to something admitted. If the thing admitted is possible or can be done, that is, if it is what the mathematicians call given, the desired thing will also be possible. The proof will again be the reverse of analysis. But if we come upon something impossible to admit, the problem will also be impossible."

This description of the method of analysis does not provide much to understand what in reality the method is. In this respect, the only way to reconstitute the method is to rebuild it from explanations provided by more contemporary descriptions. For instance, mathematician Polya (2004) explains that "…whilst analysis constitutes the elaboration of a plan, synthesis is the execution of the plan." In geometry, that refers respectively to the elaboration of a theorem and to the use of the theorem to solve a geometry problem. Thus, in the following section those features are presented through a compilation of interpretations given by those who attempted to use the method. The following description complements the description provided in Section 2.1.

4.1.2 Prior to Analysis and Synthesis

Before proceeding further, an important note about the problem-solving process is essential. According to Riemann (1866, as cited in Ritchey, 1991), three important foundations guide the process of gaining knowledge of any system:

- <u>Previous knowledge:</u> *knowing the existing/available natural laws and principles related to the system. It does not mean though that this knowledge should not be* *challenged. In reality, it is by challenging the current knowledge that most of the contributions to knowledge are made.*

Riemann (1866) does not highlight the importance of making explicit the ontology and epistemology used to generate previous knowledge. As discussed in Section 2, a change in the ontological and epistemological approach can also generate the promotion of knowledge and discovery.

- <u>System objective/function:</u> *the second foundation refers to knowing what the system to be investigated performs, does or accomplishes. For Riemann this knowledge can be obtained by empirical observation or experiment of the system in different situations.*

In relation to evidence, it was discussed that its role is to sustain the status of knowledge to a proposition. For that, propositions are tested in relation to justification, truth and belief "levels" that the evidence promotes.

- <u>System's construction:</u> *the third foundation relates to understanding which are the parts, components and elements of the system. This type of knowledge can be obtained by understanding the internal structure and processes of the system, especially the relationships between the parts and components.*

In respect to evidence and knowledge, the components that give them "status" are justification, truth and belief and how together they escape the argument of illusion, i.e. Gettier's problems. Despite the debate that these three components form an ill definition for evidence and knowledge, an alternative is not available. Therefore the search for another component or mechanism that brings them together is still not available.

The foundation for problem-solving is a point for reflection prior to when the application of the method of analysis starts. Although there is no known systematic rule for applying the method, the decision about which route to adopt for solving a problem should be considered first. According to Riemann (1866, as cited in Ritchey, 1991), two routes are possible:

- *Starting from the construction of the system, identifying its parts and components and then determining the relationship between each part and how they respond* *to external input[28]. By doing so, what the system does (in parts and as a whole) is identified by identifying its parts and how they operate. In other words* ***effects are identified from given causes[29]*** *and this is called the synthetic route.*

- *Alternatively, one can start by identifying what the system does and from there to identifying which parts are necessary to accomplish what the system does. In other words, that means* ***to search for causes of given effects*** *and this is called the analytic route. Riemann in his studies used this route.*

Riemann's view is aligned with traditional thoughts regarding the method of analysis. However, there is a third possibility. Descartes disagreed that only these two routes were possible. According to Timmermans (1999), Descartes highlights (here in generic terms) that the solution of a problem depends on everything that precedes and follows the solution. For Timmermans (1999) the method that Descartes advocates does not start from causes to effects nor from effects to causes, but from the primary idea of the dependency or relationship between cause and effect (known and unknown), starting from what is easiest to solve and moving to what is most difficult. In Timmermans's (1999) words:

> *"Descartes might not go backward from the consequences to the principles any more than it divided a complex whole into simple parts, but that it revealed the correspondences, order, or relations between different terms, known and unknown, consequences and principles, wholes and parts".*

The process to identify relationships as the first step of analysis, as approached by Descartes, is not explicit. However, Timmermans (1999) highlights that to make such a correspondence between known and unknown, Descartes considered it important not to make any distinction between known and unknown, i.e. the unknown must be considered to be of the same nature as the known as the description described below extracted from Timmermans (1999, p.445):

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28 The identification of parts requires the creation of taxonomies (identification and classification of parts). The elaboration of taxonomies and its relation to the method of analysis is examined further in this chapter.

29 It is extremely relevant to revisit the meaning of the word 'cause' in this context. Consider the example of a ball in movement. In this example 'cause' in the context of the method of analysis does not refer to searching for a fact "what has hit the ball so it causes it to move". Rather, the analyst would be looking for the law of inertia or the three laws of motion as proposed by Newton.

> *"By this means Descartes managed to get round the logical problem of analysis in a different way than the logicians did. It was a matter no longer of drawing an uncertain consequence from a recognized principle or deducing truth from falsehood but of bringing to light the relations (operations) that connected the terms that one was taking into account, without supplying any prior hypothesis as to their order or rank, truth or falsity."*

Ritchey's (1991) views of the works of Riemann's (1866) *and* Timmermans (1999) in his analysis of Descartes work, do not make reference to the method of analysis as described by Pappus. In Pappus's narrative "*as if were admitted*" the same approach as described by Descartes seems to be adopted by ancient geometers. In other words, the idea of starting from an assumption about the explanation of a conceptual relationship was already in the ancient method. Thus, the merit of Riemann and Descartes was to reincorporate this aspect of the method that, as explained by Koskela *et al*., (2008), was forgotten.

Finally, as highlighted by Holton (1998), Newton also contributed to the development of the method of analysis and synthesis. Conversely to Descartes, whose hypothesis was taken as assumptions discovered through intuition, Newton relied on experiments and observations to anchor the first principles in experience.

> *"…the investigation of difficult things by the method of analysis ought ever to precede the method of composition. This analysis consists of making experiments and observations, and in drawing general conclusions from them by induction [30], and of admitting no objections against the conclusions but such as are taken from experiments or other certain truths… By this way of analysis we may proceed from… effects to their causes… And the synthesis consists in assuming the causes discovered and established as principles, and by them explaining the phenomena proceeding from them, and proving the explanations (Newton, I., 2003)."*

According to Holton (1998), Newton's *crucial* addition to the process of analysis was to test propositions (that were assumptions in Descartes process) via observation and experimentation of the principles in practice: "*from the phenomena of motion to investigate the forces of nature, and then from these forces (e.g. the postulated universal gravitation) to demonstrate the other phenomena.*" This debate is further addressed in the next section.

[30] Here newton is considering induction as part of analysis.

In summary, three principles were presented that are key when investigating a phenomenon through the method of analysis and synthesis: to be aware of previous knowledge related to the phenomenon; to understand what is accomplished (effect); and to identify the existing parts and how they operate (causes). As described there are three routes that can be followed: the analytic route, i.e. seeking causes from given effects; the synthetic route, i.e. seeking effects from given causes; and the Descartes route (as it is called here), i.e. seeking relationships that link causes and effects, either through intuition (as by Descartes) or through experimentation (as per Newton). In the next sections the features related to the analytical and synthetic routes are further discussed.

4.1.3 Analysis

The debate about whether to start with analysis, synthesis or with the primary idea of the dependency between cause and effect is not addressed in this thesis. Here, an assumption is made that the three starting points are possible and we proceed by clarifying the features related to the method of analysis and synthesis.

From the previous description from Pappus *as cited in* Hintikka and Remes (1974) two types of analysis exist: theoretical and problematical. In theoretical analysis we attempt to establish the truth of theorems (for example, Pythagoras' theorem $a^2 + b^2 = c^2$) whereas in problematical analysis we aim at finding something that is unknown (Gaukroger, 1989) - for example, the length of a side of a right triangle. Thus, theoretical analysis deals with truth and falsehood, whereas problematical analysis deals with possible or impossible (Panza, 1997).

In this respect, the method of analysis has its origins in a rationalist science (geometry); that is to say that theoretical analysis is related to (the development of) knowledge *a priori* (Descartes *as cited in* Timmermans, 1999) whereas problematical analysis refers to knowledge *a posteriori*. In other words, problematic analysis generates 'evidence' for proposed theoretical truths (proof).

Theoretical analysis involves establishing a series of hypothetical [31]queries (axioms) to enable the linking of a more complex theorem to a series of interconnected simpler

[31] Hypothesis in the technical sense defined by Aristotle is an assumption of existence (Lee, H. D. P., (1935). Geometrical method and Aristotle's account of first principles. The Classical Quarterly **29**(2): 11).

(previously known and easier to solve) theorems. Riemann (1866, as cited in Ritchey, 1991), argues that the hypothesis is used to explain what is accomplished. If the hypotheses are confirmed to be truth we are led to a good understanding of the problems that can be solved. On the other hand, if we find something false, the analysis ends and synthesis is not necessary (Panza, 1997; Timmermans, 1999).

On the other hand, in problematical analysis the 'desired thing' is hypothetically considered/assumed to be known (it is given – for instance, in geometry a problem such as "given the sides a and b of a triangle, calculate its hypotenuse" – the geometer will use $a^2 + b^2 = h^2$) and we can reach either something that can be done (the calculation of the hypotenuse) where synthesis is necessary (i.e. to derive the theorem from the calculation of the hypotenuse) or we find something impossible to construct (for instance, if only the side "a" of the triangle was provided, then the calculation of the hypotenuse would be impossible). In other words, the geometrical figure to be constructed is considered as given and through analysis its parts and their relationships and the principles by means of which the figure can be constructed are found.

In this regards, Timmermans (1999) and Koskela *et al.* (2009) highlight the qualitative difference of the start and end points of analysis. According to Koskela *et al.* (2009), the starting point in both theoretical and problematical analysis consists of something unknown as if it was known – a hypothesis or the geometrical figure (even if the geometrical figure is unquestionably given, its constructability is unknown). In both cases, the end point is something known (i.e. truth) or can be done (i.e. possible). In this respect, Wallace (1993), in his investigation about Galileo's scientific method, argues that for Galileo, the starting point could be something known (in Enlightenment terms - a supposition[32]) or something "almost" known – a hypothesis.

The series/system of hypotheses here has a relationship with Plato's paradox of analysis (Meno's paradox): "Either we know what something is, or we do not. If we do, then there is no point searching for it. If we do not, then we will not know what to search for (Plato (80d). Meno.)" To escape the paradox, Socrates adopts the position that knowledge cannot be sought, but recollected. That means that when admitting something to be known, the known thing will need confirmation.

[32] Wallace (1983) uses the term '*suppositione*' (for supposition) which (even if not stated by Wallace) fulfills largely the JTB criteria of knowledge than hypothesis. The meanings attributed to both terms are described in Wallace (1983, p.624).

Here, we argue that such an approach escapes Plato's paradox of knowledge by rejecting the status "known" and "unknown" and adopting the status of "uncertain". By doing this, the method of analysis becomes a method of validation (or invalidation) of the hypothesis. Thus, it is only after analysis is concluded that the status "known" is granted. In this regard, analysis serves to determine how the unknown quantities of a problem depend on the given ('known') ones (Mäenpää, 1997).

Furthermore, the method of analysis has different modes of reasoning. Beaney (2003a) studying the concepts [33] of analysis distinguishes three main modes: **regressive** (or directional), **decompositional** (or configurational) and **transformative** (or interpretive) analysis. These modes are further described in the following.

The regressive mode of analysis is described by Beaney (2007) *as "the process of identifying the principles, premises, causes, etc., by means of which something can be derived or explained"*. Working back to principles (axioms) and previously proved theorems suggests that the regressive conception of analysis reflected in Pappus's account is central (Beaney, M., 2003b). In other words, regressive analysis is the seeking for causes of a given effect and cause of the cause and so on.

Mäenpää (1997) argues that the regressive mode of analysis is related to reduction (as in mathematical reduction)[34] and deductive reasoning. According to Mäenpää the method of reduction (*apagoge*) is a precursor to the method of analysis, and Hintikka and Remes (1974) only consider reduction in their translation. However, for Mäenpää examples of Greek mathematics shows that analysis also considers deduction. As stated by him, "*Pappus's description of synthesis as complementing analysis would be pointless if he regarded analysis as purely reductive, because this would make synthesis trivial and superfluous*".

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[33] By concepts Beaney means the different meanings given to analysis whereas by modes he means the different approaches.

[34] "*In mathematics, reduction refers to the rewriting of an expression into a simpler form. For example, the process of rewriting a fraction into one with the smallest whole-number denominator possible (while keeping the numerator an integer) is called 'reducing a fraction'* (Wikipedia, 2012 – entry: Reduction (mathematics))"

It follows that Galileo and his peers expanded this concept of regressive analysis. The concept of regressive analysis, as generated in mathematics, could not be seamlessly applied in "*scientiae mediae*" such as astronomy (Wallace, 1983). The key difference, as highlighted by Wallace was that suppositions could also be based on fictitious *suppositions*. Wallace also argues that there was confusion (even in some of Galileo's text) in relation to the ancient and present (at that time) meaning of the words resolution and composition (as referring to analysis and synthesis). For Wallace, "in mathematics *a resolution (analysis) is made when one first supposes that a theorem is true or a problem solved, and then on the basis of this supposition deduces consequence after consequence until he arrives at a manifest truth or falsity. If the original theorem is true, he will eventually come to a manifest truth, on the basis that only truth can come from truth if the matter and form of the reasoning is correct. Composition (synthesis) is the reverse…" (Wallace, 1983,p.627).* Galileo's view was not that. According to Wallace (1993) his view was that of *"Demonstrative Regressus" which, in practice, inverts the roles of analysis and synthesis.* That meaning (of *demonstrative regressus*) is seen presently in design science as discussed in section 4.1.1.17.

The configurational mode of analysis refers to the study of the functional dependencies among the constituents of a definite mathematical configuration. The configuration is a geometrical figure and consists of the given and the sought objects, assumed to be related to one another as specified by the condition – i.e. problem (Mäenpää, 1997). In geometry, it refers to the identification of parts (lines, angles, points, etc.) of a figure and the relationships between these parts. The concept of decompositional analysis in ancient times refers concomitantly to both "breaking down" and "finding relationships" between parts (e.g. the sum of the angles in a triangle is 180 degrees) (Beaney, 2003a). According to Byrne (1997), this double meaning has been lost in current time and only the 'breaking down" meaning is being adopted currently.

In this regard, Beaney (2003a) provides an example of a decompositional analysis with a basis on Plato's work as follows. If we consider "collecting" all animals that exist, a series of "configurations – breakdown" can be suggested to create groups. For instance, rationale and non-rationale; vertebrates and non-vertebrates. Whilst in regressive analysis the concept "animal" is first in the hierarchy and it is *a priori*, the decomposition into categories comes from observations *a posteriori*. The decomposition is dependent on the creation of taxonomies[35].

According to Mäenpää (1997), this configurational aspect of analysis was not explicit in Pappus's description. Thus, the determination of dependencies (in geometry) of the unknown quantities on the given one was a contribution identified by Descartes. This issues is also highlighted by Gedenryd (1998) who also presents a graphical representation of the difference in decomposition analysis before and after Descartes (Figure 6). Gedenryd argues that Descartes' hierarchical decomposition principle arranges the elements into a tree, whereas Pappus's version simply forms a linear chain. Mäenpää argues that this interpretation of configurational analysis shifts the focus of the analytical method from the analysis of a deductive connection to the analysis of a functional connection. This methodological aspect is also described by Riemann (1866, as cited in Ritchey, 1991).

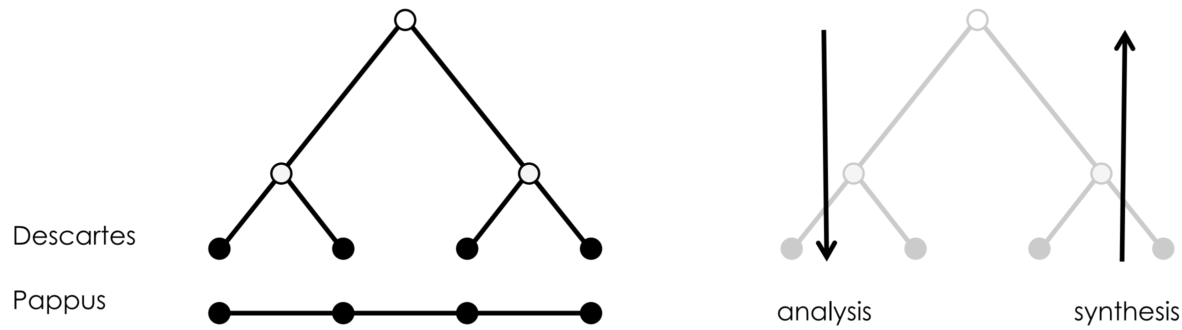

Figure 6 – Descartes and Pappus decomposition (Adapted from: Gedenryd, 1998)

Finally, **the transformative mode of analysis** usually takes place before the process of decomposition and relates to the 'translation' of the description of the original phenomena into their 'correct' logical form (for example, statements[36] in analytical philosophy) (Beaney, 2003). For Beaney this type of reasoning can be seen when a geometrical problem is 'translated' into the language of algebra or arithmetic so it

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35 Issues related to the creation of taxonomies are further discussed later in this section

36 Beaney, M. (2007). The analytic turn in early twentieth-century philosophy. The analytic turn: analysis in early analytic philosophy and phenomenology. M. Beaney, Routledge**:** 302. adds by clarifying that the aim of transformative analysis, in Russell's analytic philosophy, "*was to reveal the 'real' logical form of the proposition to be analysed, the constituents of the fully analysed sentence being assumed to correspond to, as to be structured in exactly the same way as, the ultimate simple constituents of the reality represented*".

can be easily solved. It is possible to argue that in science, when the scientist opts for a rationalist or empiricist approach, it results in the same transformative aspect of analysis. The same applies when one has to opt between using a scientific approach or a religious one to understand a problem. In both cases, the problem has to be 'translated' so it can be solved.

According to Mäenpää (1997) the transformative aspect of analysis involves the use of 'auxiliary constructions'. These necessary auxiliary constructions are invented to amplify the configuration in order to find the solution for nontrivial problems (Hintikka and Remes, 1974; Mäenpää; 1997). In other words, auxiliary lines are created when the problem does not provide enough information for its solution, thus by creating them, new relationships will also emerge (not present in the original problem) that may lead to solving the original problem. In the following, an example of the above is presented as described by Euclid *as cited in* Mäenpää (1997).

Proposition I: to construct a sought triangle on a given line segment satisfying the condition that the triangle is equilateral and constructed on the line segment (the solution is presented in Figure 7).

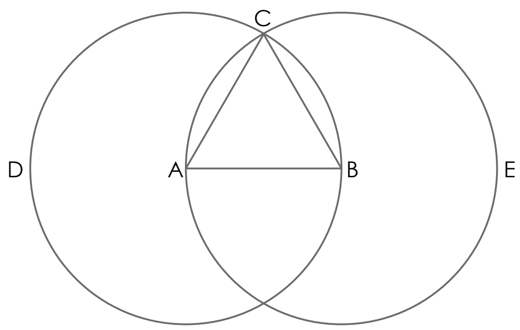

Figure 7 – Solution for proposition I

In this construction, Euclid constructs two auxiliary circles (not given) on the given line segment *AB,* one centred on point *A* and the other on point *B*, using *AB* as the radius. Subsequently he connects the points *A* and *B* to *C*, which is one of the intersection points of the circles. In the demonstration part of Euclid's synthesis, he shows that the condition of the problem holds by appealing to the definition of a circle. As *AC* and *AB* and respectively *BC* and BA are radii of the same circle, they are equal in length (Mäenpää, 1997).

Although the modes of reasoning provide some guidance regarding which move one should take to carry the analysis, they do not suffice as guidelines for solving the problem. This was a problem already known by Aristotle, Descartes and Polya (as described by Koskela *et al*., 2009) and Leibniz (as described by Holton, 1998). In current terms, this means that the process of analysis is heuristic (Timmermans, 1999). According to (Timmermans, 1999) the process of analysis can be considered heuristic[37] from a certain point of view:

> *"…analysis can be considered heuristic when, …, it is synthetic, that is, when it starts from something that, while a consequence, is also a simple, well known principle from another point of view that leads us to discover unknown things. Thus, without contradicting the definition of analysis as going from consequences to principles, we can use it as a method of discovery if the consequence from which we start is then seen from another point of view, a first or a priori idea from which we can draw new or unknown information (Timmermans, 1999)."*

In other words, from the standpoint of logic an analysis that starts from an unknown thing "as if it were known" and "goes backward" to a known thing does not lead to discovery (one cannot discover something that was already known). Rather, it leads to verification or justification of the status "known." From a mathematical standpoint, an analysis that considers the known and unknown through their relations, where the unknown becomes homogeneous and can accordingly be made to correspond to or be placed in an equation which is known, is obvious and clear (Timmermans,

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[37] "… in almost every field there are accepted truths, or conventional wisdom, that guide decisions and actions. And in almost every field, including medicine, many practitioners and their advisers are unwilling or unable to observe the world systematically because they are trapped by their beliefs and ideologies. Their observations are contaminated by what they expect to see, or because they aren't logical enough in their thinking. The result is that much conventional wisdom is wrong…" Pfeffer and Sutton (2006) – Hard facts, dangerous half-truths and total nonsense.p14.

The dictionary definition for heuristics is: noun [uncountable] formal "The study of how people use their experience to find answers to questions or to improve performance." Another, better, way of defining heuristics is by comparing it with algorithms. For example, a decision-making system that uses an algorithm will have a very well established rule for the decision to be made. Conversely, one that uses heuristics will not have such defined boundaries. In general, the direction for the decision comes from common sense and there is no guarantee that the optimal solution will be achieved. Well-known examples of heuristic rules include the "trial-error method" and solving a puzzle by starting it from the borders.

The term heuristics seems to be first linked to problem solving by scientist Herbert Simon in the 1950s. Since then, it has stimulated research also in other areas such as sociology and psychology. Heuristics is considered a method for discovery that is based in non-deductive methods (Rosa and Orey, 2005). For these authors, despite the fact that heuristics seem to utilize arbitrary suppositions, in reality, it follows a conceptual base, models and hypothesis that are necessary to the problem-solving process.

1999). The practice of algebra can also illustrate very well this approach where letters and symbols are used to represent the unknowns as if they were known.

In addition, the existence of iterative loops is also a characteristic of a heuristic process as there is no guarantee that a solution can be found in the first attempt (Polya, 2004). The process therefore is based on trial and error. This characteristic leads to decision-making situations when solving a problem. This is illustrated in the examples extracted from Polya (2004) below.

> *"If you are having difficulty understanding a problem, try drawing a picture (decision needed: what type of picture best represent the problem).*
>
> *If you can't find a solution, try assuming that you have a solution and seeing what you can derive from that (working backwards) (decision needed: which solution should I assume first and why).*
>
> *If the problem is abstract, try examining a concrete example (decision needed: which example is representative of the abstract problem).*
>
> *Try solving a more general problem first (decision needed: at what level of generality should the problem be formulated)."*

In this respect, according to Tversky and Kahneman (1974) finding parts and their relationships in analysis will lead the analyst to postulate inferences and formulate questions, such as: what is the probability that object A belongs to class B? What is the probability that event A originates from process B? What is the probability that process B will generate event A? Heuristics rules may work well under these circumstances, but in certain cases it will lead to systematic errors or cognitive biases[38]. An example of the circumstance mentioned above is the use of taxonomies in this trial and error manner. Taxonomy consists of the process of organising things in different groups or sets that show their natural relationships. However, there is a risk in developing taxonomies, as described by Holton, 1998:

> *"In every field of scholarship, 'successful' taxonomic systems are a minute fraction of the ever-growing total. At their best, hierarchical schemata of this kind convey the conviction of causal relationships and allow us to make confirming experiments and insightful extensions. At their worst, taxonomic schemes produce the very opposite effect; in the absence of some 'first principle' to which to rise and from which to derive an ordering*

[38] This issue is related to the issue of solving problems via the synthetic route as presented in Section 2.

matrix, they may simply fall back on the production of pigeonholes with plausible labels which invite one to disaggregate the incoherent vastness of possible observables. Since those labels were obtained in the first place through some intuitive perception of portions within the grand aggregate, the danger of a vivious circle is obvious. One can easily end up masking perplexity under the guise of parcelling out portions of it into the various corners of some lofty but arbitrary construction. (Holton, 1998 p.147)."

The formation of taxonomies was a topic very well discussed by *Aristotle*. In Analytics, Aristotle, *as cited in* Timmermans (1999), argues that "*the search for principles may proceed by induction* [39] *and that this procedure is not certain.*" However, as discussed by Polya (1990) the identification of emergent patterns based on observation (induction) cannot be disassociated from the elaboration or invention of the patterns (taxonomies). These 'patterns' are dependent on the beliefs of the perceiver and therefore are subject to error.

Aristotle, *as cited in* Timmermans (1999), provides an example for the situation above*: "some planets do not twinkle", and as an example of a general observation the fact that "all that does not twinkle is near". Aristotle explains that one thereby discovers a new 'fact' (the closeness of some planets). This fact may also be the 'cause' of the effect from which we started, that is to say, that those planets do not twinkle; but one cannot be sure that this new fact is actually the cause of the effect from which one started (Timmermans, 1999).*

In this respect, this capacity to observe and propose a definition for a pattern and its subcategories (taxonomy) is attributed to intuition (Polya, 1990). Polya argues that even mathematics relies on intuition (plausible reasoning as called by Polya). For him, one has to guess a mathematical theorem before you prove it. This process was also present in Kant's work (*as cited in* Holton, 1998) through apperception. For Kant apperception was the mental process by which a person makes sense of an idea by assimilating it to the body of ideas already possessed.

In addition to Polya's view, it can be argued that the theorem is guessed even before, when you consider it to be truth or known in the analytical process. Descartes, *as cited in* Holton (1998, p.141-142), also agreed that intuition is part of the method

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[39] The process of inferring a general law or principle from the observation of particular instances (opposed to deduction n., q.v.) (The Oxford English Dictionary, OED Online, accessed November 24, 2012).

for discovery. In this respect, Polya (1990) states that this is the point where mathematics, as any other human knowledge in the making, will depend on creativity.

In this respect, whilst intuition (or plausible reasoning) plays a recognition role in relation to the identification of patterns, the recognition without proof cannot be anything else but a proposition, conjecture or assumption only. The acceptance of this proposition as something known defines a process known as abduction (Gabbay and Woods, 2005). For Aristotle, *as cited in* Gabbay and Woods, abduction is a syllogism from a major premise, which is certain, and a minor premise, which is merely probable, to a merely probable conclusion. Conceived of in Peirce's way, abduction is a form of reasoning in which a new hypothesis is accepted because it explains or otherwise yields the available data. More broadly, the logic of abduction is a general theory of hypothesis formation (Gabbay and Woods, 2005). Here, it is contended that intuition, plausible reasoning, apperception and abductive reasoning are strongly related cognitive processes.

Finally, as highlighted by Panza (1997), Aristotelian analysis also involves deliberation. For Panza a deliberation starts with the fixation of an end and is concerned with the ways by which this end can be achieved. Now, to fix an end is just (or at least very similar to) considering something as being known or true. In the case of analysis, deliberation terminates with the determination of a possible action that has to be performed in order to produce a certain state of things. In synthesis, the pathway found is performed.

In this respect, Panza (1997) discuss the work of Aristotle further to link deliberation with choice. For him, the agent of a deliberation must be the subject who operates the choice (the analyst). However, deliberation cannot be applied to all problems. For Aristotle, the subjects of deliberation are those things for which the agent has influence upon or can modify. In this respect, mathematical truths and natural phenomena are not the subject of deliberation. Panza also highlights the fact that deliberation does not concern ends, but is only concerned with the means that are necessary to reach already fixed ends. Aristotle links deliberation with the philosophy of mathematics as a research approach ("every deliberation is research") and as such can be applied to any field (even though Aristotle does not make this statement explicitly). Here, the idea of deliberation is linked with the particular issue of dealing with the unknown. Thus, in the absence of knowledge or evidence (in its philosophical meaning), deliberation gives room to argumentation based on what is best available, i.e. anecdotal empiricist evidence.

To summarise, in this section features of the process of analysis were described. Firstly, the two distinguished types of analysis were presented, i.e. theoretical and problematical. The former is related to *a priori* knowledge and the latter *a posteriori*. In both cases, the process for finding a solution is argued to be the same. In this respect, the starting point is to assume something unknown as known reaching truth or falsity or considering something to be possible, therefore reaching feasibility or unfeasibility. In relation to reasoning, three modes of reasoning are recognised: regressive, decompositional and transformative. The application of these modes is not described as a sequential process; therefore it is assumed here that its application can follow a concomitant and random process that follows heuristic rules. A fourth type of reasoning, abduction, was also introduced and it relates to the formation of hypothesis and the starting point of analysis that are based on implicit knowledge. Finally, deliberation was discussed as a characteristic of the method of analysis so as to find means for fixed ends.

4.1.4 Synthesis

Great minds in science benefited from the methodological practice of synthesis. Newton, Descartes, Darwin and Einstein are, for instance, amongst those who successfully used the synthetic route in science. Other (not less prestigious) examples include the treatises of Aristotle, Aquinas, Spinoza and Kant. Synthesis is the complementary part of analysis and according to Holton (1998, p114) it plays an important role in current practice and research. For him, the current forms of synthesis can be observed through the emergence of a kind of 'global thinking' and the use of terms such as trans-disciplinary and interdisciplinary. The relevant track record of the method of synthesis makes it a relevant methodological approach.

Holton (1998) contends that the origins of synthesis are based on two different and opposite schools of thought, one being positivist and materialistic and the other being metaphysical and formalist. The origins are also ancient and go as far back as Thales, Pythagoras, Aristotle, Kepler and Galileo and they can be considered the precursor of the 'Newtonian Synthesis'. Newton's unification of the celestial and terrestrial physics makes him the foremost successful 'synthesist' (Holton, 1998). According to Holton, a more recent scientist applying the power of synthesis in the unification of knowledge from different fields was Einstein and the integration of the electromagnetic and mechanistic worldviews.

Despite its tested appropriateness, synthesis has also suffered from the epistemological dilution of its meaning and processes (Holton, 1998). According to Holton, the damage caused to synthesis is, however, considered much worse as considerably more attention has been given to analysis in comparison to synthesis. In general, synthesis is poorly described as the opposite of analysis and no further guidance is in general provided. Thus, the understanding of synthesis, as a methodological approach, is not comprehensively reported and/or properly understood. In this respect, the inversion of meanings between analysis and synthesis in comparison with the actual method (Pasini, 1997, p.37) is not uncommon in modern times.

Notably, Panza (1997) argues that analysis and synthesis are not opposite approaches as perceived in current times. For him the method is rather one single process. Panza argues that examples from ancient times demonstrate different types of separations and compositions that were operated in certain objects to change their relational status or obtain objects of the same logical nature. He also emphasizes that in ancient times neither synthesis, nor analysis entailed a passage from the particular to the universal or vice-versa or from objects to concepts or the other way around. Holton (1998) also emphasises that Plato was aware of such integrity and that analysis alone or synthesis alone would leave the work incomplete.

In this respect, Mäenpää (1997, p.225) argues that synthesis has an element of dependency in relation to analysis. For him, without an antecedent analysis, the synthesis has to proceed from the given objects to the sought ones and then demonstrate the condition through induction and without making systematic use of the sought objects and the condition. Thus, corroborating with Panza (1997) and Mäenpää (1997) here, it is assumed the conceptualisation (understanding) of analysis and synthesis as two complementary (but not opposite) processes.

Moreover, carrying out synthesis without prior analysis leads to the problem of induction that refers to the philosophical question of whether induction can lead to knowledge. According to Carnap (1945) and Vickers (2006) the problem of induction is related to the validity of any proposed system of inductive logic. For Carnap,

> *"the construction of a systematic inductive logic is an important preliminary step towards the solution of the problem. It is important because the exact formulation of rules of induction is what defines the systematic inductive procedures and without them the problem of the validity of these procedures cannot be raised in precise terms."*

On the other hand, a construction of an inductive logic, although it prepares the way towards a solution of the problem of induction, still does not by itself give a solution (Carnap, 1945).

Carnap (1945) goes further by saying that "*older attempts at a justification of induction tried to transform it into a kind of deduction*[40]*, by adding to the premises a general assumption of universal form*." In other words, the rules are created after to 'fit' the solution. Here, the relevance of analysis before synthesis is evident. In addition, Carnap argues that reducing induction to deduction with the help of a general ad-hoc principle is not possible. For Carnap (1945)

> *"…induction is fundamentally different from deduction, and any prediction of a future event reached inductively on the basis of observed events can never have the certainty of a deductive conclusion; and, conversely, the fact that a prediction reached by certain inductive procedures turns out to be false does not show that those inductive procedures were incorrect."*

Thus, it is assumed here that synthesis does involve a systematic inductive reasoning that is strengthened if preceded by analysis.

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40 Holton (1998) adds to this discussion by arguing that this deductive-inductive reasoning involves apperception. Holton does not say explicitly that induction is related to apperception, but he argues that induction depends on memory when discussing the following description of Newton: "*A merely reproduced manifold of representation would never… form a whole, since it would lack that unity which only consciousness can impact to it. If, in counting, I forget that the units, which now hover before me, have been added to one another in succession, I should never know that a total is being produced through this successive addition of unit to unit… (Newton, A103; see A78=B104).*" For Holton (1998) this passage shows the need for memory. He argues that "*things in the past representations must be recognized as related to present ones* (apperception). *And to recognize that earlier and later representations are both representing a single object, we must use a concept, a rule (A121, A126). In fact, we must use a number of concepts: number, quality, modality, and, of course, the specific empirical concept of the object we are recognizing.* Thus, the issue for Holton is that one cannot remember all the connections that are established explicitly (and implicitly) during induction.

In relation to this matter, Polya (1954) states that induction is a procedure that is related to experience and beliefs. For him, induction starts with the observation of phenomenon. It is through observation that conjectures (e.g. a general statement) that explain the observed phenomenon emerge by induction. However, conjectures elaborated through observations only can be, in general, insubstantial, even though based on the observation of reality. Once a conjecture is elaborated, the next step of induction is to prove or disprove the conjecture by testing/verifying it as many times as possible. The more tests are carried out the stronger is the support that the conjecture is true. Below, Polya states that the process for demonstrating and proving knowledge is the same, i.e. field independent.

> *"… Finished mathematics presented in a finished form appears as purely demonstrative, consisting of proofs only. Yet mathematics in the making resembles any other human knowledge in the making. You have to guess a mathematical theorem before you carry through the details. You have to guess the idea of the proof before you carry though the details. You have to combine observations and follow analogies; you have to try and try again. The result of the mathematician's creative work is demonstrative reasoning, a proof; but the proof is discovered by plausible reasoning, by guessing. If the learning of mathematics reflects to any degree the invention of mathematics, it must have a place for guessing, for plausible reasoning (Polya, G., 1954, p.vi)."*

However, a contra-point to the above argument exists. According to Holton (1998), until Albert Einstein, the predominant view envisaged was that truth could only be achieved by starting with analysis and then synthesis. In this regards, Holton (1998) advocates that Plato was aware of the fact that attempting synthesis without a previous analysis would not lead to truths. For Plato, to start from axioms and then arriving at a hypothesis whose truth was not assured would suffice to create self-consistent systems, although that would not lead to science (episteme). Descartes and Newton agreed with this path. On the contrary, for Einstein (as described in Holton, 1998), the formation of a hypothesis is an act of imagination that relies on intuition even in analysis, and as such is subject to errors.

Now, there seems to exist a relation between synthesis and, in current terms, the hypothetic-deductive method where a hypothetic (candidate) construction is tested (Holton, 1998). This compositional method for which instruction is the result rather than truth or discovery (as argued by Descartes) can be seen in the example provided by Kant (n.d.) *as cited in* Beanney (2009) below:

> *"There are two ways in which one can arrive at a general concept: either by the arbitrary combination of concepts, or by separating out that cognition which has been rendered distinct by means of analysis. Mathematics only ever draws up its definitions in the first way. For example, think arbitrarily of four straight lines bounding a plane surface so that the opposite sides are not parallel to each other (1). Let this figure be called a trapezium (2). The concept (2), which I am defining, is not given prior to the definition (1) itself; on the contrary, it only comes into existence as a result of that definition. Whatever the concept of a cone may ordinarily signify, in mathematics, the concept is the product of the arbitrary representation of a right-angled triangle, which is rotated on one of its sides. In this and in all other cases the definition obviously comes into being as a result of synthesis."*

It is clear from the above that the geometrical figure constructed by using '*four straight lines bounding a plane surface so that the opposite sides are not parallel to each other*' was named 'trapezium' after its construction was synthesized. However, one can argue that the concepts 'line' and 'parallel' were created first in analysis to so guide the construction in a specific way.

Now, Riemann (1866, as cited in Ritchey, 1991), describes that synthesis proceed from the construction of a system at first and, from it we seek to determine the laws of interaction between parts and response to stimulus (i.e. we infer effects from given causes). In other words, synthesis starts not from identifying what a system accomplishes but rather from how it is built. Thus, there is consensus that synthesis is a necessary step after analysis is completed (Newton, 2003; Riemann, 1866; and Otte and Panza,1997, p.xi). As described by Newton (2003), "*synthesis consists in assuming the causes discovered in analysis, and established as principles, and by them explaining the phenomena proceeding from them, and proving the explanations*."

Regarding the tasks to be done, Mäenpää (1997, p.202) argues that synthesis proceeds from putting together the given objects so to achieve the sought ones. This process can only be done if the functional dependencies uncovered in analysis are used. For Mäenpää this concerns problems. In the case of theorems, the task of synthesis was to convert the analysis into a demonstration of the proposition to be proved from ones known to be true. In other words, it refers to functional compositions of constructions of various types, like points, circles, and line segments in geometry. In this respect, we apply the analytic procedure in order to create a conceptual framework within which we can draw conclusions about the means by which a system solves its tasks. Indeed, we do this with the express purpose of establishing a solid foundation from which we can carry out a subsequent synthesis. This synthesis, in turn, acts to verify the conceptual model as an explanation. Equally, in analysis, this process is an iterative one (Ritchey, 1991).

Furthermore, Mäenpää (1997, p.215) argues that synthesis has two corresponding successive parts: construction and demonstration. For Mäenpää construction corresponds to resolution in analysis as it constructs the sought objects from the given ones. On the other hand, demonstration corresponds to transformation, as it deduces the condition from the transformed condition. In this respect, like theorems do not have sought objects and therefore their analysis has no resolution, the synthesis of a theorem does not have a construction, because there are no sought objects. Israel (1997, p.6) argues that Descartes was already aware of this relation as for Descartes analysis was considered more appropriate for metaphysical matters whereas synthesis is more acceptable in geometrical problems.

In this respect, synthesis, by contrast, employs a directly opposite method where the search is, as it were, *a posteriori* (though the proof itself is often more *a priori* than it is in the analytic method). It demonstrates the conclusion clearly and employs a long series of definitions, postulates, axioms, theorems and problems, so that if anyone denies one of the conclusions it can be shown at once that it is contained in what has gone before, and hence the reader, however argumentative or stubborn he may be, is compelled to give his assent. However, this method is not as satisfying as the method of analysis, nor does it engage the minds of those who are eager to learn, since it does not show how the thing in question was discovered (Descartes *as cited in* Holton, 1998).

Further features of synthesis are presented by Newton *as cited in* Holton (1998) in the following.

- "*Synthesis has its routes in the history of the field within which it produces coherence*." Here, the link and precedence from analysis is presented implicitly in the 'history of the field that produces coherence.'
- A first principle: any synthesis must consider a first principle on which to build a system. Newton, for instance, departed intuitively from the universal law of gravitation. "For an eventual success in the large sense, it would seem necessary to postulate explicitly the smallest number of independent statements, and

insofar as possible to exhibit the whole of parsimony and necessity among those postulates that do remain" (Holton, 1998, p.132).

- "*Inclusion and exclusion of elements. Any synthesis will be developed with the a priori selection of starting candidate elements or parts. Exclusion however, is not and cannot be an a priori conscious decision, but can only come at the end of a long series of unsuccessful attempts at inclusion*. *That is, exclusions are the result of the discovery of 'impotency principles'.*" Here, the heuristic and iterative characteristic of the process is described. Holton (1998, p.131) provides an example that synthesis is not an infallible process in regards to the exclusion of elements: *"The Newtonian laws, for instance, were proposed as governing the motion of objects having from atomic to galactic size. It was only in the 20th century that it was possible to exclude the atomic elements from that group. Such discovery triggered the development of the field known to us as quantum physics*."
- Cohesion of a general system: this refers to establishing the boundaries of a system. In the development of a taxonomy, for example, that means to understand the size of families and/or groups;
- Demystification and central 'image': according to Holton, to break with paradigms, beliefs and myths that have no scientific foundation. Some well known demystified beliefs in the history of science include earth as the centre of the universe and the Earth as a flat planet.
- Prediction: predictive capability is usually regarded as the ultimate test of how 'scientific' a synthesis is. Here, Holton acknowledges that the levels of predictability vary in the natural and social sciences.
- Cultural reach: according to Holton (1998), cultural reach is the final measure of a successful synthesis. For him, a synthesis that is relevant should become pertinent across different cultures.

According to Holton (1998) the use of synthesis *a priori* can only be successful within certain limits. In this section, the limitations of the Newtonian synthesis are presented according to Holton (1998).

- Assumption of unitary structure, and of elements for the Analysis and Synthesis process: the process of analysis and synthesis assume *a priori* the existence of some unity that is penetrable, or made otherwise manageable by the analysis of equivalent pieces, and that can be re-established through synthesis. In other words, characteristics that seem not to exist (Holton, 1998, p.135).

- Effects of the cultural framework: analysis and synthesis are related and affected by the analyst's cultural framework, knowledge and beliefs. In other words, the rules of an analysis today are not the same as the rules that have been used in the past. Because analysis and synthesis are related to the cultural framework, they will differ for different knowledge fields within the same culture. Here, without further discussion, we consider this feature as being influenced by paradigm shift and heuristics.

- The Problematic of Analysis and Synthesis in use: respectively, these approaches require decomposition and composition. However, Leibniz *as cited in* Holton (1998, p.137) argues that these methods (or method) does not provide guidance to identify the interfaces (boundaries) between distinctive components so that it would prevent one from dividing the problem into unsuitable parts, therefore making the problem more difficult.

- Unit of the method: Holton (1998) argues that most scientists tend to follow one or another part of the method of analysis and synthesis (pluralists or splitters in analysis versus monists or synthesizers in synthesis), and only a few consider its integrity. In this respect, Timmermans (1999) highlights that the end of the demonstrative method (which includes the complete loop between analysis and synthesis) is a perfect science, which is knowledge of things through their causes, whereas the resolutive method (which only includes analysis) is discovery and synthesis alone is demonstration (Mäenpää, 1997).

- Possible physiological aspects: Holton refers here to the different capabilities of the right and left halves of the human brain which would explain preferences for adopting analysis or synthesis as a strategic intellectual approach. In this respect, Holton speculates that there seems to exist a handover or exchange between the two halves where the right deals with more holistical issues and the left with more logical and detailed issues.

- Different forms of analysis and synthesis: here, Holton presents the effect different sciences have upon the application of the method of analysis and synthesis. For

Holton, the natural sciences can be characterised by more stable, controllable and replicable conditions during the collection of evidence. However, in social sciences, the 'world' of samples can rarely (if at all) be replicated and the separation between observer and observed successfully achieved, therefore, explaining the myriad of forms that Analysis and Synthesis can take in these different fields.

Finally, as a last attempt to generate further clarification, here we compare the identified features of synthesis with the features that form the process of carrying out analysis as presented in the previous section of this chapter. They include the types of analysis, the starting point of the process, the four modes of reasoning and certain characteristics of the process, such as iteration and the influence of heuristic rules in deciding the pathway to discovery. Thus, if the argument of "reversion of analysis" is correct and suffices to describe synthesis, the rationale presented in Table 8 should be arguably valid.

Firstly, with regard to the types of analysis and synthesis, whilst analysis has two types (theoretical and problematical), synthesis has only problematical synthesis. As discussed before, this is because inferring theorems through induction is not a rigorous enough approach.

Secondly, in relation to the modes of reasoning, two modes in analysis have their directly inverse modes in synthesis: regressive and decompositional and respectively progressive and compositional. The transformative mode in analysis does not have a reverse mode in synthesis. Rather, it has a related mode of reasoning that is the demonstrative mode. Similarly, abduction has no reverse and the strategy of reasoning is based on plausible reasoning, induction and intuition.

Lastly, in regards to the characteristics of analysis and synthesis: (a) *the starting point in analysis* is unknown but assumed to be known or given (abduction) whereas in synthesis the starting point is known and it is what is last in analysis; (b) the iterative nature is present in analysis and synthesis; (c) heuristic rules are used in both and in both they are influenced by the analyst/synthetist cultural framework; (d) analysis is considered more appropriate for issues of *a priori* knowledge whereas synthesis is better for *a posteriori* issues; (e) the act of deliberation is not explicitly presented in the literature related to synthesis, however we contend that deliberation is present in both analysis and synthesis; (f) analysis uses deductive reasoning whereas synthesis uses inductive.

Table 8 – Analysis and Synthesis as complementary methods[41]

	Analysis	**Synthesis**
Types of Problems	Theoretical: discovery of "the thing sought"	Not applicable as theorems have no construction (there are no sought objects) or done through induction (which is questionable)
	Problematical: resolution of "the desired thing"	Construction of the desired thing.
Modes of Reason	Regressive: infer causes (principles) from given effects (what the system accomplish)	Progressive: infer effects – concepts - from given causes – definition - (parts of the system)
	Decompositional: breaking down in parts and finding their relationships	Compositional / Construction: constructs the sought objects from the given ones
	Transformative: adding additional information to the problem so to reveal intrinsic relationships that are not evident from the given information	Demonstrative: deduces the condition from the transformed condition
	Abduction: fallibilist assumption	Inference through plausible reasoning, induction and intuition
Process characteristics	Starting point: the unknown is assumed as known (theoretical) or given (problematical)	Starting point: compilation of empirical evidence from a considerable large number of different but related phenomena.
	Iteration: the process is not infallible	Iteration: the process is not infallible
	Heuristic rules	Heuristic rules
	"*a priori*" – proof is independent of experience as principles / rules / axioms are based on rationale logic	*"a posteriori" – dependent on experience and on prior analysis*
	Deliberation: means to determined/given ends	Deliberation: means to undetermined / not given ends
	Deductive reasoning	Inductive reasoning

[41] The author recommends printing the above table separately to facilitating the reading of section 4.2.

4.2 Modern Design Methods and Analysis and Synthesis

In this section, current prescriptive design methods are reviewed and their process characteristics compared with the characteristics of the method of analysis identified in section 4.1. In this respect, there are many descriptive models of design available and the criteria for selection of the chosen models was: (a) their relevance as perceived by the author and informal consultation carried out with peers conducting research in the field of design and product development; (b) that the models would be related to different areas fields of design including: engineering design, general theory of design, software design, mechanical engineering, architectural design, system engineering and industrial design[42]; and (c) from different periods of time. It is important to highlight that the meaning of the terminology used in the investigated theories varies considerably and differs significantly from the method of analysis and synthesis as demonstrated in the semantic investigation carried out by Koskela *et al* (n.d.)[43]. Here, the comparison involves the semantic investigation of the transcripts of the chosen model; From the original texts, only a few passages were selected to demonstrate the interpretation given and each passage from the original text is identified as P1, P2, P3, …, Pn. The author seeks to compare suggested processes through the explanation provided by the investigated authors and its relation with the method of analysis. The framework for comparison refers to the types of problems, the modes of reasoning and the characteristics of the process as summarised in Table 8 in Section 4.

4.2.1 Morris Asimow

Morris Asimow was a systems engineer and part of the founding group that investigated the move towards a systematic method for design practice in the 1960's. According to Heylighen *et al*. (2009), Asimow described the design process as being composed of a vertical (managerial) structure that involves a sequential phasing of

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[42] The selected authors, their fields and year of contribution are: Morris Asimow (engineering design – 1960s); Herbert Simon (general theory of design and software design – 1960s); Thomas Markus and Thomas Maver (architectural design – 1970's); Leonard B. Archer (mechanical engineering design – 1980s); Vladimir Hubka and W. Ernst Eder (mechanical engineering – 1980s and 1990s); Kevin Forsberg and Hal Mooz (systems engineering – 1990s); Nan Suh (engineering design – 2000s); Armand Hatchuel and Benoit Weil (industrial design - 2000s); and Brian Lawson (architectural design – 2000s).

[43] In Koskela et al., (n.d.) the author was responsible for carrying out the research about design terminology in relation to the terms 'analysis' and 'synthesis'.

activities (e.g. the definition of needs, feasibility study, and preliminary design over detailed design and production planning to actual production) and a horizontal structure (cognitive) in the form of an analysis-synthesis-evaluation-communication cycle that is common to all phases in the managerial structure.

Following the same idea, Asimow (1962) considers analysis and synthesis as important processes in designing. Asimow emphasises the problem identification and formulation as a relevant part of the process of analysis. This is due to the fact that the process of finding a solution for the problem is part of the process of problem identification and both interact. Once the problem is identified or enough understanding about it has been gathered, the designer is able to propose appropriate solutions. To Asimow, synthesis relates to solving the interface between identified partial solutions. Creativity plays an important role in finding those connections. In this respect, the aspects of the ancient method recognized in Asimow's method are presented in the following passages as extracted from Asimow (1962).

> ***P1.*** *"Engineering design is a purposeful activity directed toward the goal of fulfilling human needs, particularly those which can be met by the technological factors of our culture."*
>
> ***P2.*** *"The starting point of a design project is a hypothetical need which may have been observed currently on the socio-economic scene. It may be phrased in the form of a primitive statement resting on untested observations; it may have been elaborated into a sophisticated and authenticated statement based on market and consumer studies. The need may not yet exist, but there may be evidence that it is latent, and that it can be evoked when economic means for its satisfaction becomes available."*
>
> ***P3.*** *"Before an attempt is made to find possible solutions for the means of satisfying the need, the design problem should be identified and formulated. It is strange how strong the temptation is to seize mentally on some concept of hardware that seems to provide a feasible solution before the real problem is well understood, and thereafter to patch up the concept in perilous ways as deficiencies in the solution begin to appear. The temptation should be resisted, for it tends to lead to a mental rut, which blocks the truly creative effort that should follow after the problem is grasped. In effect, we consider the ultimate solution to be a black box, the contents of which remain unknown. The information we have available comes from the results of the preceding step, particularly the specifications of desired outputs, and from relevant technical knowledge about environments, resources and general engineering principles. With this information an activity analysis is performed whereby*

the design problem is given a technical formulation. The question, which must be asked before this step may be considered complete is whether the resulting engineering statement of the problem is sufficiently relevant and adequate to commit the ensuing steps to the design. If the decision-maker is not confident enough, he will reject the statement and require another performance of the activity analysis step. Indeed, new information, developed in this step, may reduce the confidence in the validity of the preceding need analysis step and require further study at that level. This iterative nature, involving repetition of steps or parts of steps, is characteristic of design. Design is too complex a process to admit of an uninterrupted progression without backing up now and then to correct or rework previous results. New information is constantly developed by the design work itself which previously was either overlooked or unknown. This new information changes the confidence levels on which prior decisions were made. If the deterioration in confidence levels is enough to destroy the basis for a particular decision, the decision-maker will require that the affected step be reworked until the necessary level of confidence is restored" p.20.

P4. *"Synthesis refers to the fitting together of parts or separate concepts to produce an integrated whole. The synthesis step formally begins after the design problem is well understood, although some notions about possible solutions may have already been suggested during the prior steps. The point to be emphasized is deceptively obvious; concentration on possible solutions should not begin until the design-problem has been studied and identified, and a reasonably good working formulation of the problem set down. As with prior steps, there is an iteration process, a feedback. The solutions, which are conceived and matched against the background of the problem statement, yield new insights and items of information about the preceding steps which can then be corrected if necessary"p.20, 21.*

P5. *"It is the synthesis step which most characterises the project as a design undertaking. This, more than any other step, requires inventive and creative effort. Creativity is therefore a very essential ingredient of engineering design. In the context of design we offer the following as a definition of creativity: a talent to discover combinations of principles, materials or components, which are especially suitable as solutions to the problem in hand. None of the individual elements, which comprise the synthesis, need be new or novel. Developing new and novel elements is more the object of research than of design. After a new principle is discovered by the researcher, the designer is often assigned the task of evolving some new components that are advantaged, for the first time made possible by the new principle. In doing so he will generally combine the new principle with several old ones to achieve the final result" p.21.*

P6. *"(1) Need. Design must be a response to individual or social needs which can be satisfied by the technological factors of our culture.", "(2) Physical Realizability. The object of a design is material goods or service which must be physically realizable.", "(3) Economic Worthwhileness. The goods or service, described by a design, must have a utility to the consumer that equals or exceeds the sum of proper costs of making it* *available to him.", "(4) Financial Feasibility. The operations of designing, producing, and distributing the good must be financially supportable.", and "(6) Design Criterion. Optimality must be established relative to a design criterion which represents the designer's compromise among possibly conflicting value judgements that include those of the consumer, the producer, the distributor, and his own (Asimow, 1962 as cited in Hansen, 2008)."*

P7. *"…Thus, the three elements that concern us in critical decision making, as it appears in the design process, are the alternatives, the benefits, and the difficulties of implementation… To help in resolving the issue, we seek and apply relevant evidence" p. 57.*

From the above passages it is possible to identify the following features present in the method of analysis and synthesis (Table 9 presents an overview of the identified features):

Types of problems

- The explanation provided in P1 and P2 indicates that Asimow considers both theoretical and problematical types of analysis. In P2, he mentions assuming a hypothetical need (unknown or uncertain) as the starting point. In P1 Asimow states that those needs can be met, in general, by technology and here this is associated with the resolution of the desired thing (a conversion of needs into a technical system of some sort) and therefore a problematical analysis. In P4, Asimow demonstrates the need for synthesis as the 'fitting together of parts'. Finally, in P6 Asimow attempts a series of generic principles for which design must meet.

Modes of reasoning

- <u>Regressive</u>: as discussed above, in P2 and P3 the designer should start with revisiting the problem until it is clear so as to regress to the identification of what should be accomplished by design.
- <u>Decompositional</u>: the decompositional mode of reasoning is very discrete in P5. Asimow states that creativity involves the discovery of 'combinations of principles', thus admitting that the problem is composed of distinguishable parts.
- <u>Transformative</u>: In P3 Asimow suggests that the information about the problem feeds into an activity (functional) analysis and the problem is transformed (given)

into a technical formulation. This is seen as characteristic of the transformative mode of reasoning in the ancient method.

- Progressive: In P4 the construction of a solution that started from the identification of the problem progresses by adding the parts that solve the problem.
- Compositional: this mode of reasoning is explicit in P4 where Asimow refers to 'fitting together parts' (in synthesis). The same argument appears in P5.
- Demonstrative: in P5, Asimow stresses that it is the synthetic half that is mostly recognised as design. Similarly to Polya (1954) in mathematics, for Asimow, finished design presented in a finished form appears as purely demonstrative, consisting of proofs only.

Process characteristics

- Starting point: In P2 it is clear that the starting point (of analysis) is something unknown (a hypothetical need). This idea is reinforced in P3 where the "ultimate solution… remains unknown". In P4, the start of synthesis is something known (i.e. 'the design problem is well understood').
- Iteration: Asimow explains in P3 that there is no guarantee that the activity analysis can be correct at first and as such, if necessary, the problem (or part of it) will be revisited. Iteration is also characteristic of the synthetic route as explained in P4. Asimow mentions that that happens via two ways, new insights (in terms of alternative solutions) or new pieces of information about the preceding steps (activity analysis).
- Deliberation: In P6, need is linked to individuals or the society. Thus, the designer cannot interpret a need isolated from consumers, users, or society. Thus, deliberation must take place in analysis and synthesis, so as to attain the goals and solutions from all parts involved. However, the link with deliberation is not explicit from Asimow. The same can be assumed from principles (2), (3), and (4) as three types of stakeholders (need-design-business) are implicit. Choice (decision-making) is explicit in P7, thus characterising deliberation.
- Deductive reasoning: the approach suggested by Asimow denotes a deductive approach. Asimow, in P3, even refers to the temptation of using an inductive approach, but clearly demonstrates knowledge about the problem of induction: '… temptation … to provide a feasible solution before the real problem is understood, and … patch up the concept … as deficiencies … appear.'

Table 9 - Comparative investigation of analysis and synthesis and Asimow (1962)

	Analysis	Asimow (1962)	Synthesis	Asimow (1962)
Types	Theoretical	P2	NA	NA
	Problematical	P1; P6	Solution	P4
Modes of Reason	Regressive	P2; P3	Progressive	P4
	Decompositional	P5	Compositional	P4; P5
	Transformative	P3	Demonstrative	P5
	Abduction	NI	Induction	P2
Process characteristics	Starting point	P2; P3	Starting point	P4
	Iteration	P3	Iteration	P4
	Heuristic	NI	Heuristic	NI
	a priori	NI	*a posteriori*	NI
	Deliberation	P6	Deliberation	P6; P7
	Deductive reasoning	P3	Inductive reasoning	NI

NI: Not Identified

From the above discussion, it is possible to characterise Asimow's process as being based on both the analytical and synthetic approaches in comparison with the method of analysis and synthesis. It is important to highlight that, in P4, Asimow demonstrates awareness in relation to the steps prior to analysis and synthesis as suggested by Riemann (1866, as cited in Ritchey, 1991).

4.2.2 Herbert Simon

The cognitive aspects of the design activity as presented in engineering design methods can be generally described as an attempt to model how designers think during designing. One of the assumptions behind this attempt is that a fundamental model exists and the designer can be trained to follow it.

A milestone in research regarding this theme can be fixed in the 1960's when Herbert Simon published the first edition of his book 'The Science of the Artificial' (Simon, H. A., 1969). In this book, Herbert Simon makes explicit the differences between the research of natural and artificial (human made) things. The author argues that for the first, research relates to how things are, while in the second, research relates to how things ought to be.

Despite the consideration of analysis and synthesis within design, Simon does not make reference to the ancient method and the debate related to the method of analysis and synthesis when referring to it. His interpretation of design, explained within the problem-solving paradox, has analysis and synthesis as part of his conceptual framework. For Simon (1969) analysis and synthesis refers to means-end analysis. Simon explains analysis and synthesis by analogy with a goal-seeking system. The main points of his analogy are the constant absorption of information and perceptions of the world(s) and the use of logic of any kind to build up design solutions. The aspects of the ancient method recognized in Simon's theory are presented in the following passages as extracted from Simon (1988).

> ***P1***. *"For this reason problem-solving systems and design procedures in the real world do not merely assemble problem solutions from components but must search for appropriate assemblies."*
>
> ***P2***. *"The condition of any goal-seeking system is that it is connected to the outside environment through two kinds of channels: the afferent, or sensory, channels through which it receives information about the environment and the efferent, or motor, channels through which it acts on the environment. The system must have some means of storing in its memory information about states of the world information - afferent, or sensory, information - and information about actions - efferent, or motor, information. Ability to attain goals depends on building up associations, which may be simple or very complex, between particular changes in states of the world and particular actions that will (reliably or not) bring these changes about… Except for a few built-in reflexes, an infant has no basis for correlating his sensory information with his actions. A very important part of his early learning is that particular actions or sequences of actions will bring about particular changes in the state of the world as he senses it. Until he builds up this knowledge[44], the world of sense and the motor world are two entirely separate, entirely unrelated worlds. Only as he begins to acquire experience as to how elements of the one relate to elements of the other can he act purposefully on the world."*

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[44] Here, knowledge has no status of truth as described in Section 2 and it only represents the knowledge from the point of view of what has been experienced.

P3. *"The 'inner environment' of the design problem is represented by a set of given alternatives of action. The alternatives may be given in extenso: more commonly they are specified in terms of command variables that have defined domains. The 'outer environment' is represented by a set of parameters, which may be known with certainty or only in terms of a probability distribution. The goals for adaptation of inner to outer environment are defined by a utility function - a function, usually scalar, of the command variables and environmental parameters - perhaps supplemented by a number of constraints (inequalities, say, between functions of the command variables and environmental parameters). The optimization problem is to find an admissible set of values of the command variables, compatible with the constraints, that maximize the utility function for the given values of the environmental parameters. (In the probabilistic case we might say, 'maximize the expected value of the utility function', for instance, instead of 'maximize the utility function')."*

P4. *"To design such a complex structure, one powerful technique is to discover viable ways of decomposing it into semi-independent components corresponding to its many functional parts. The design of each component can then be carried out with some degree of independence of the design of others, since each will affect the others largely through its function and independently of the details of the mechanisms that accomplish the function."*

P5. *"One way of considering the decomposition, but acknowledging that the interrelations among the components cannot be ignored completely, is to think of the design process as involving, first, the generation of alternatives and, then, the testing of these alternatives against a whole array of requirements and constraints."*

P6. *"Now the real worlds to which problem solvers and designers address themselves are seldom completely additive in this sense. Actions have side consequences (may create new differences) and sometimes can only be taken when certain side conditions are satisfied (call for removal of other differences before they become applicable). Under these circumstances one can never be certain that a partial sequence of actions that accomplishes certain goals can be augmented to provide a solution that satisfied all the conditions and attains all the goals (even though they be satisfying goals) of the problem."*

P7. *"For this reason problem-solving systems and design procedures in the real world do not merely assemble problem solutions from components but must search for appropriate assemblies. In carrying out such a search, it is often efficient to divide one's eggs among a number of baskets - that is, not to follow out one line until it succeeds completely or fails definitely but to begin to explore several tentative paths, continuing to pursue a few that look most promising at a given moment. If one of the active paths begins to look less promising, it may be replaced by another that had previously been assigned a lower priority."*

From the above passages it is possible to identify the following features present in the method of analysis and synthesis (Table 10 presents an overview of the identified features):

Types of problems

- The description provided by Simon (1988) indicates that solution is found mostly through synthesis. Simon states that solutions for problems are assembled from available alternatives (components) and that there are 'assemblies' that are more appropriate then others as manifested in P1. In P5 the same approach is presented in "design process … involving, first, the generation of alternatives …" In P3 a problematical approach is briefly mentioned and referred to as 'outer environment' of design (i.e. known and forcibly known – through probability – parameters). In this respect, the outer environment parameters as a goal are superseded by existing constraints, again demonstrating a synthetic approach.

Modes of reasoning

- <u>Decompositional</u>: in P4 the use of decompositional analysis to break down in parts so as to facilitate the resolution of the problem is evident. However, the criteria for breaking down are not mentioned in this or any other passages. In this respect, In P5 Simon contradictorily admits that interrelations amongst components cannot be ignored.
- <u>Progressive</u>: in P3 progressive reasoning is evident in "…the goals for adaptation of inner to outer environment are defined by a utility function".
- <u>Compositional</u>: Simon states that the ability of attaining goals depends on building associations in P2, revealing a compositional aspect within his method.
- <u>Demonstrative</u>: the demonstrative mode of reasoning is present in P5 – "testing of these alternatives against… requirements and constraints." In this passage, the alternatives represent a transformed condition from the original problem for which tests will reveal their performance.
- <u>Induction</u>: in P2, the use of induction (more precisely, the problem of induction) is present in Simon's reference to the use of memory to store the results of different attempts that 'bring changes about'. In the same passage, plausible reasoning is implicit in the last sentence as the recognition aspect of this process is built on experience.

Process characteristics

- Starting point: in P3, the design problem is set in the given alternatives of action that is characteristic of a synthetic approach.
- Iteration: the iterative characteristic of Simon's model is eminent in P6 where he states that one can never be certain that the solution will attain the desired goal. Simon does not make explicit that one should return and revisit the problem, but from the overall description, it seems, this occurs within the process.
- Heuristic: in P7 Simon suggests that one should seek the alternatives that 'look most promising at a given moment'. The criteria for the selection of the most promising alternative is not present in this passage, but Simon (1988, p80) states that choices follow algorithms or heuristic rules.
- Deliberation: despite deliberation not being mentioned explicitly within Simon's model, a process that involves choice is implicit in P1 and P7.
- Inductive reasoning: Simon's approach is characterized by inductive reasoning. It is clear in P3 that the design problem refers to a set of given alternatives (given effects) and the search for a solution will proceed from there. The same approach appears in P5.

Table 10 – Comparative investigation of analysis and synthesis and Simon (1969; 1988)

	Analysis	**Simon (1969; 1988)**	**Synthesis**	**Simon (1969; 1988)**
Types	Theoretical	NI	NA	NA
	Problematical	P3	Solution	P1; P5
Modes of Reason	Regressive	NI	Progressive	P3
	Decompositional	P4; P5	Compositional	P2
	Transformative	NI	Demonstrative	P5
	Abduction	NI	Induction	P2
Process characteristics	Starting point	NI	Starting point	P3
	Iteration	NI	Iteration	P6
	Heuristic	NI	Heuristic	P7
	a priori	NI	*a posteriori*	NI
	Deliberation	NI	Deliberation	P1; P7
	Deductive reasoning	NI	Inductive reasoning	P3; P5

From the above discussion, it is possible to characterise Simon's process as being based on the synthetic approach in comparison with the method of analysis and synthesis.

4.2.3 Thomas Markus and Thomas Maver

The model devised by Markus (1969) and Maver (1970) is cited many times in the design process literature. Both were founding members of the Design Methods Group formed in 1966 that, as mentioned before, was seeking for more systematic methods of design. Their model is based on the paradox of problem solving and has directly or indirectly influenced other researchers. It was not possible in this research to access the original publications from Markus (1969) and Maver (1970), thus, the description of their method that follows is from secondary sources.

According to Lawson (2006) the model developed by Markus (1969) and Maver (1970), represented in Figure 25, follows the same assumption, i.e. analysis and synthesis as part of the design process. For these authors, there is a process which refers to the thinking process and is constituted by analysis, synthesis, appraisal and decision. This process happens as the solution develops from its concept to a more concrete level in the detailed design phase.

According to Markus (1969) and Maver (1970), *as cited in* Lawson (2006), analysis is related to the identification and classification of relationships between objectives to be achieved. In other words, it is the exploration (in detail) of the design problem. Synthesis, on the other hand, is related to finding an answer to the design problem. In this respect, Lawson (2006) argues that Marcus and Maver represent the design process as a series of decisions that are organized in three hierarchical levels: (a) outline proposals; (b) scheme design; and (c) detail design. The result of these phases is design documentation. In this respect, each phase has four processes: (a) analysis; (b) synthesis; (c) appraisal; and (d) decision. As described by Lawson (2006), this model does not consider the existing iteration between analysis and synthesis that other models present. Lawson also highlights that the process of synthesising a solution might bring some clarification regarding the original problem, which is revised leading to the elaboration of another solution. The three phases of their model (see Appendix 6) are sequential and a loop only exists between synthesis and appraisal.

Without having access to meanings of analysis and synthesis as defined by Markus (1969) and Maver (1970), the author can only infer what is perceived as being related to the ancient method. In this respect, their model seems to follow a synthetic-only approach as presented in the following.

Types of problems

Overall, the model developed by Markus (1969) and Maver (1970) falls within synthesis, in particular, an approach focused towards the solution. The clue for this inference is in the proposed managerial stages (i.e. outline, scheme and detail design) that only consider the production of solutions.

Modes of reasoning

- Progressive: as represented in Figure 25, solutions are proposed and assessed progressively from lower levels of detail (outline) to high levels of detail (detail design). Here, the process is characteristically inductive and based on the proposition of solutions upfront.
- Demonstrative: the depicted process is also of a demonstrative nature as it is acknowledged that the output of each phase is design documentation.

Process characteristics

- Iteration: this characteristic is restricted to synthesis and appraisal, which denotes the result of analysis, and is not revisited in the process. The model also denotes that there is no return to the problem, once a decision is reached and the design has moved from one phase to the other.
- Deliberation: the clue for this characteristic is in the word 'decision'. It is not clear though if this is an individual process or a collective one.

Table 11 presents an overview regarding the comparative investigation of analysis and synthesis and the design process as proposed by Markus and Maver (1969; 1970).

Table 11 - Comparative investigation of analysis and synthesis and Markus and Maver (1969; 1970)

	Analysis	Markus and Maver (1969; 1970)	Synthesis	Markus and Maver (1969; 1970)
Types	Theoretical	NI	NA	NA
	Problematical	P3	Solution	P1; P5
Modes of Reason	Regressive	NI	Progressive	P3
	Decompositional	P4; P5	Compositional	P2
	Transformative	NI	Demonstrative	P5
	Abduction	NI	Induction	P2
Process characteristics	Starting point	NI	Starting point	P3
	Iteration	NI	Iteration	P6
	Heuristic	NI	Heuristic	P7
	a priori	NI	*a posteriori*	NI
	Deliberation	NI	Deliberation	P1, P7
	Deductive reasoning	NI	Inductive reasoning	P3, P5

NI: Not Identified

4.2.4 Leonard Bruce Archer

Leonard Bruce Archer is one of the UK's foremost relevant contributors to the development of research related to systematic design methods. In this respect, in 1969 Archer proposes a prescriptive model that influenced research in the design field. Archer (1984) argued that there was no consensus regarding whether the design process should contain four, five or six phases. In this respect, Archer developed a six-phase model containing: (a) programming; (b) data collection; (c) analysis; (d) synthesis; (e) development; and (e) communication. According to Archer the process is iterative because difficulties and obscurities emerge throughout the process. Archer (1979) adds to the description by arguing that design also has a commutative[45] aspect that increases the obscurities. This model is illustrated in Figure 26 and further grouped in Figure 27 (Appendix 6) and the steps are described in the following according to Archer (1979; 1984).

- Programming: establishment of crucial issues and proposal of course of action;
- Data collection: collection, classification and storing of data;
- Analysis: identification of sub-problems, preparation of design specifications, reappraisal of proposed programme and estimation;
- Synthesis: preparation of outline design proposals
- Development: development of prototype design(s), preparation and execution of validation studies
- Communication: preparation of manufacturing documents

These steps were grouped into three phases: analytic, creative, and executive as described below. Further quotes follow to assist the investigation of this method in relation to the features of the method of analysis and synthesis.

> ***P1.*** *"…the special features of the process of designing is that the analytic phase with which it begins requires objective observation and inductive reasoning, while the creative phase at the heart of it requires involvement, subjective judgement, and deductive reasoning. Once the crucial decisions are made, the design process continues with the execution of working drawings, schedules, etc., again in an objective and descriptive mode. The design process is thus a creative sandwich. The bread of objective and systematic analysis may be thick or thin, but the creative act is always there in the middle (Archer, 1984)."*

> ***P2.*** *"There can be no solution without problems; and no problem without constraints; and no constraints without a pressure or need. Thus, design begins with a need. Either the need is automatically met, and there is no problem, or the need is not met because of certain obstacles and gaps. The finding of means to overcome these obstacles or gaps constitutes the problem. If solving the problem involves the formulation of a prescription or model for subsequent embodiment as a material object (and requires a creative step), then it is a design problem (Archer, 1984, p.59)."*

> ***P3.*** *"In practice, of course, the designer cannot define the factors in his particular problem… A single design is a complex of a thousand or more sub-problems. Each sub-problem can be dealt with in a characteristic way… But although each sub-problem can be resolved so as to produce*

---

[45] The terms commutative (adj) comes from mathematics and refers to the condition where a group of quantities connected by operators gives the same result whatever the order of the quantities involved, e.g., $a \times b = b \times a$.

an optimum solution, or even a field of acceptable solutions, the hard part of the task is to reconcile the solutions of the sub-problems with one another. Often, where the optimum solution of one sub-problem compels the acceptance of a poor solution in the other, the designer is forced to decide which of the two must take priority. This entails putting the whole complexity of sub-systems into an order of importance… (Archer, 1984, p.62)"

P4. ***"****In the design field it can truthfully be said that, having prepared a problem for a computer, the answer quite often will become so obvious to a skilled designer that he can dispense with the computer's service altogether. It will not always, but since he is very rarely asked to prove that his is the best answer, if it works it will usually suffice … (Archer, 1984, p.63)."*

P5. *"… it is demonstrable that the assumptions upon which even the quantitative considerations are based can never be wholly value-free" [5] models (Archer, 1979)." Archer also criticized the 'alien mode of reasoning' presented to designers by "mathematical and logic*

In addition, Archer (1984) relates design with heuristics and cybernetics (the science of communications and automatic control systems in both machines and living things). By heuristic, Archer (1984) quotes Polya's (2004) model that considers plausible rather than exact reasoning. According to Archer (1984) plausible reasoning is more appropriate to solving design problems. Although Archer (1984) does not explain in detail the relation of heuristics and cybernetics, he states that the method of solving design problems brings both.

From the above we can infer:

Types of problems

In P1, Archer argues that the "analytic phase" starts with objective observation and inductive reasoning. This is contradictory as his narrative indeed shows that design starts with observation and induction, thus characterising a synthetic approach. Similarly, in P2 Archer argues that design begins with a need that is identified through progressive reasoning, i.e. moving from the solution to the need. Contrastingly, in P4 the description provided denotes the use of a problematical analysis approach. In this passage, Archer describes the preparation of a problem rather than the solution. In P5, Archer argues that this mode of reasoning is alien to designers.

Modes of reasoning

- Decompositional: In P3 the consideration of sub-problems indicates the break down of the original problem.
- Abduction: In P6 the use of assumptions as a basis for quantitative considerations indicates abductive reasoning.
- Progressive: In P2 – from solution to problem to constraints to need.
- Compositional: the use of 'reconcile the solution' in P3 indicates a compositional mode.
- Demonstrative: In P1 Archer mentions the production of drawings and schedules that are characteristic of the demonstrative mode of reasoning. In P2, "the formulation of a prescription has a similar interpretation.
- Induction: Archer says: 'subjective judgement' and 'deductive reasoning' after the demonstration (as above), so indicating the process in induction rather than deduction.

Process characteristics

- Starting point: In P1 the starting point is observation and induction. Contrastingly in P2, the starting point is a need. Here, we understand that designing starts with observation and it ends with the identification of the need.
- Iteration: Iteration is not evident in the passages but explicit in Figures 7 and 8.
- Deliberation: In P1 the use of 'subjective judgement' and 'crucial decisions' indicates that deliberation is part of the process. This is also present in P3 in 'forced to decide'.
- Inductive reasoning: In P1, the process starts with objective observation and inductive reasoning and that is comparable to the use of inductive reasoning in the synthetic route.

Table 12 presents an overview regarding the comparative investigation of analysis and synthesis and the design process as proposed Archer (1979; 1984).

Table 12 - Comparative investigation of analysis and synthesis and L.B. Archer (1979; 1984)

	Analysis	L.B. Archer (1979; 1984)	Synthesis	L.B. Archer (1979; 1984)
Types	Theoretical	NI	NA	NA
	Problematical	P4; P5	Solution	P1
Modes of Reason	Regressive	NI	Progressive	P2
	Decompositional	P3	Compositional	P3
	Transformative	NI	Demonstrative	P1
	Abduction	P6	Induction	P1
Process characteristics	Starting point	NI	Starting point	P1
	Iteration	NI	Iteration	NI
	Heuristic	NI	Heuristic	NI
	a priori	NI	*a posteriori*	NI
	Deliberation	NI	Deliberation	P1; P3
	Deductive reasoning	NI	Inductive reasoning	P1; P2

NI: Not Identified

From the above, Archer's process is mostly inductive and therefore follows the synthetic route as it refers to means more than to ends.

4.2.5 Vladimir Hubka and W. Ernst Eder

In regards to the design process, Hubka and Eder (1996) provide an extensive and detailed model that attempts to open the traditional 'black box' of design (for the full model see (Appendix 6). Their model is focused on the 'transformation' of inputs into outputs according to the problem identified. For that, Hubka and Eder suggest a generic (field independent) structure for 'technical systems' that must be considered whilst designing. The selected passages that support the description of their process are presented in the following.

P1. *"Designing means transforming the given problem statement into a full description of a technical system. The direct content of the design process consists of thinking out (conceptualising) and describing the structures of the technical system." (Hubka and Eder, 1996)*

P2. *"Designing usually takes place in answering to a perceived need. Especially in engineering, designing is goal-directed. Goals include attempting to resolve an issue, usually to achieve satisfaction for the customers. Trying to find a set of reasonably logical steps and progressions that can suggest ways to rationalize designing would thus make sense." (Hubka and Eder, 1996)*

P3. *"Designing is an activity of humans (individuals, groups and teams) together with their assisting tools (e.g., computers), performed using information, under direction and with goals delivered from management, in a working environment. All these factors affect the quality of the designed product. Responsibility rests with the designers, but information is needed by and from many others. Designing as a process accepts input information about the task and the requirements for its output. Designing delivers as its output a set of instructions for implementing or manufacturing the designed system. The next direct customer for this output information is typically a manufacturing planning department, and its manufacturing facilities." (Hubka and Eder, 1996)*

P4. *"During designing, a system may need to be broken down (decomposed) into sub-systems. Each sub-system can be regarded as a different design problem. In analogy to computer programs, we speak of design projects being nested -- a subroutine within a subroutine, e.g., problem solving called many times within designing, or evaluation and decision making called many times within either designing or problem solving. The process of designing is normally recursive -- a subroutine calling itself, e.g., problem solving calling problem solving for a sub-problem, or a design process calling a second design process for a less complex sub-system, going downwards in a hierarchy of complexity. Designing must also be iterative -- exploring forward into more advanced (usually concrete) design stages, to repeat (backwards) for review, expansion, completion and correction. Opportunistic actions can and should be taken at any time when a likely avenue opens, but designers should not just go off at any tangent. … Designing must also be iterative - exploring forward into more advanced (usually concrete) design stages, to repeat (backwards) for review, expansion, completion and correction." (Hubka and Eder, 1996)*

P5. *"Nested in the design process is a group of frequently occurring operations which we collectively call problem solving… This group consists of defining a problem, searching for solutions, evaluating and deciding among candidate solutions, and communicating -- either to the next more detailed level, or to a sub-problem, or to an implementation process. Searching for solutions can involve literature and other existing knowledge and information, from own or outside sources, advisory systems, information banks, knowledge-based systems, and other artificial intelligence (AI) applications, but it can also imply thinking of new or* *transferred applications. Evaluating can use analysis and its tools, including computer programs such as finite elements (FEM), boundary elements, computational fluid dynamics, circuit analysis, system simulations and so on. Reasons for evaluating include checking to make sure that the proposed system is unlikely to fail, comparing proposed systems to find the best for the situation, and/or comparing a candidate system to an ideal to establish its potential quality. Evaluation needs criteria, statements about acceptable performance related to the properties -- tolerance limits, maxima or minima. Some objective evaluation criteria will contain numbers or 'mathematicizable' relationships, but others will be (more or less) subjective, depending on human judgment. Evaluation criteria should appear in the design specification, but only a limited selection of these criteria is applicable at any design stage. Decision processes may point out possibilities for optimization and improvement of a candidate system, but their main purpose is selection. Decision theory… has been developed for that purpose, to make evaluative decisions more rationale, providing that the criteria and goal functions can be simplified and formulated in mathematical and/or symbolic terms." (Hubka and Eder, 1996)*

The interpretation of Hubka and Eder's process in relation to the ancient method of analysis is presented below.

Types of problems

In regards to the types of analysis and synthesis, Hubka and Eder suggest a model that emphasizes the construction of the desired system. In P1, for instance, they refer to the conceptualisation and description of the structures of the technical system and in P2 to answer a perceived need. By this means, their route of design is synthetic. Contradictorily, in P4 Hubka and Eder suggest that the system (not the need) has to be broken. The breaking of the system implies that parts of the problem - 'a different design problem' - can be achieved through parts of the system, so indicating an element of problematical analysis. Also in P5 characteristics of the desired thing are said to be investigated revealing problematical analysis.

Modes of reasoning

- <u>Decompositional</u>: as discussed above the breaking down of the system in P4 implies the breaking down of the problem, thus revealing a problematical analysis.
- <u>Transformative</u>: in P5 the authors say that 'objective criteria will have… mathematicizable relationships…' so indicating the transformative mode of analysis.

- Progressive: progressive reasoning is present in Figure 30 as the authors relate the assembly of the system (taking into consideration the processes, the functions, sub-systems and components) that together should provide the solution.
- Compositional: in P4 the breaking down of the solution presupposes *a posteriori* assembly. In P5 the testing of the system is mentioned as a way to identify problems within parts.
- Demonstrative: in Figure 29 the absence of outputs that are different from design specifications and instructions denotes demonstrative reasoning.
- Induction: in P4 Hubka and Eder refer to taking opportunistic action when a 'likely avenue opens'. Our interpretation is that this process involves induction or plausible reasoning, i.e. the spontaneous / intuitive recognition of a pattern. In P5 tests (simulative tests) are run to check the likelihood of failing, so demonstrating inductive reasoning.

Process characteristics

- Starting point: in P5 the authors argue that all that is available (pre-knowledge) about the problem or related to it (including solutions) should be collected from the beginning of the design, indicating a synthetic route start.
- Iteration: in P4 it is explicit that design is an iterative process (in the synthesis).
- *A posteriori*: in P5 the authors refer to using 'existing knowledge' to search for the solution that characterises knowledge *a posteriori*.
- Deliberation: although not explicit, in P3 Hubka and Eder admit that the design process can be individual and collective (groups and teams). Thus, it is assumed that some sort of deliberation would exist in their model. Also in P5 the authors mention the comparison of proposed systems, so indicating deliberation.
- Inductive reasoning: in P5, the authors mention the use of simulative tests as a way to forecast problems. Simulation relies on statistical methods that are built upon inductive reasoning.

Table 13 presents an overview regarding the comparative investigation of analysis and synthesis and the design process as proposed by Hubka and Eder (1996).

Table 13 - Comparative investigation of analysis and synthesis and Hubka and Eder (1996)

	Analysis	Hubka and Eder (1996)	Synthesis	Hubka and Eder (1996)
Types	Theoretical	NI	NA	NA
	Problematical	P4; P5	Solution	P2; P5
Modes of Reason	Regressive	NI	Progressive	Figure 30 (**Error! Not a valid result for table.**)
	Decompositional	P4	Compositional	P4; P5
	Transformative	P5	Demonstrative	Figure 29 (**Error! Not a valid result for table.**)
	Abduction	NI	Induction	P4
Process characteristics	Starting point	NI	Starting point	P5
	Iteration	NI	Iteration	P4
	Heuristic	NI	Heuristic	NI
	a priori	NI	*a posteriori*	P5
	Deliberation	NI	Deliberation	P3; P5
	Deductive reasoning	NI	Inductive reasoning	P5

NI: Not Identified

From the above discussion, the design process of Hubka and Eder (1996) prevalently follows the synthetic route with features of the analytical one.

4.2.6 Kevin Forsberg and Hal Mooz

In relation to design, Forsberg and Mooz (1998) discuss and contribute to the development of the "Vee" model. NASA has originally developed the concept of the "Vee" model in the 1950s. Its application within the aerospace industry was related to the fact that "everything had to be created from scratch, or commercial products had to be adapted for use in an environment for which they were never intended to be used" (Forsberg and Mooz, 1998). Therefore, the model was conceptualised for solving problems related to reliability and performance such as the 12 failures in launching the Corona satellite (Forsberg and Mooz, 1998).

The main idea of the "Vee" model is to establish client requirements and performance specifications at the beginning of the development process. In this process, the methods for measuring (verifying and validating) the achievement of requirements and performance are also considered. Although the "Vee" model can be applied in different ways and in different contexts (e.g. evolutionary or incremental approaches - Forsberg *et al*., 1998) its basic concepts are generic and can be presented as follow:

> ***P1.*** *"This depiction [the 'Vee model - Figure 31, 30 and 31 - Appendix 6] is requirements-driven, and starts with identification of user requirements. When these are understood and agreed to, they are then placed under project control, and through decomposition the system concepts and system specification are developed. The decomposition and definition process is repeated over and over until, ultimately, lines of code and piece parts are identified. Agreement is reached at each level, and the decisions are placed under project configuration management before proceeding to the next level. When the lowest level is defined, we move upward through the integration and verification process on the right leg of the 'Vee' to ultimately arrive at the complete verified and validated system. At each level there is a direct correlation between activities on the left and right sides of the 'Vee' – the rationale for the shape. Everything on the left and right legs of the 'Vee' are sequentially placed under configuration control, and hence this has been designated the 'core' of the 'Vee'." (Forsberg and Mooz, 1998)*

> ***P2.*** *"Decomposition and Definition. The 'Vee' chart provides a three-dimensional view of the technical aspect of the project cycle. At each level, moving into the depth of the paper (perpendicular to the surface) there are a number of parallel boxes illustrating that there may be many Segments or Configuration Items (CIs) that make up the system at that level of decomposition. Also at the System level, on the left of the chart, the number of parallel boxes illustrates that alternate concepts should be evaluated to determine the best solution for the User's needs. At the System Requirements Review (SRR), the choice is approved and a single concept is baselined for further definition." (Forsberg and Mooz, 1994)*

> ***P3.*** *"As project development progresses, a series of six baselines are established to systematically manage cohesive system development. The first is the 'User Requirements Baseline'. The second is the 'Concept Baseline'... The third is the 'System Performance Baseline' (or Development Baseline)... The fourth is the 'Design-To' Baseline' (or Allocated Baseline)... The fifth is the 'Build-To' Baseline' (or preliminary Product Baseline)... The sixth is the 'As-Built' Baseline' (or Production Baseline)..." (Forsberg and Mooz, 1994)*

> ***P4.*** *"The left side of the core of the 'Vee' … the Control Gates define significant decision points in the project cycle. Work should not progress beyond a decision point until the Project Manager is ready to publish and*

control the documents containing decisions agreed to at that point." (Forsberg and Mooz, 1994)

P5. *"… there is no prohibition against doing detailed work early in the cycle. In fact, hardware and software feasibility models may be required at the very first stage (User Requirement Analysis and Agreement) in order to clarify the User Requirements Statement, and to ensure that the User is not asking for an unachievable result…. Early application of involved technical and support disciplines is an essential part of this process." (Forsberg and Mooz, 1994)*

P6. *"While technical feasibility decisions are made in the off-core activities only decisions at the core-level are put under Configuration Management at the various Control Gates. Off-core activities, analyses, and models are performed to substantiate the core decisions and to ensure that risks have been mitigated or determined to be acceptable. The off-core work is not formally controlled, and will be repeated at the appropriate level to prepare justification for introduction into the baseline definition." (Forsberg and Mooz, 1994)*

P7. *"The multiple arrows descending from the bottom of the left side of the core of the 'Vee' indicate that there can, and should be, sufficient iteration downward to establish feasibility and to identify and quantify risks. Upward iteration with User Requirements (and levels leading to them) is permitted, but should be kept to a minimum unless the user is still generating requirements. The User needs to be cautioned that changes in requirements during the development process will cause positive or negative changes in the predicted cost and schedule and may cause the project to be not cost or schedule effective… Modification of User Requirements after PDR should be held for the next model or release. If significant changes to User Requirements must absolutely be made after PDR, then the project should be stopped and restarted at the start of a new 'Vee', reinitiating the entire process. The repeat of the process may be quicker because of the lessons learned, but all steps must be redone. Time and project maturity flows from left to right on the 'Vee'. Once a Control Gate is passed, iteration is not possible backward…" (Forsberg and Mooz, 1994)*

P8. *"Test philosophy and planning are part of the Verification and Validation Plans identified earlier and are developed in conjunction with the system decomposition process… are all part of the oversight function of System Engineering that should ensure the tests will produce the tangible evidence necessary to prove System Verification. Descending down the left side of the 'Vee' represents Decomposition and Definition. Ascending the right side of the 'Vee' is the process of Integration and Verification. At each level, there is a direct correspondence between activities on the left and right sides of the chart. This is deliberate. The method of verification must be determined as the requirements are developed and documented at each level. This minimizes the chances that requirements are specified in a way, which cannot be measured or verified. Even at the initial and highest level, as User Requirements are translated into system requirements, the system verification approach* *must be determined that will prove that the system does what it is required." (Forsberg and Mooz, 1994)*

P9. *"Verification is the process of proving that each product meets its specification ('Have we built the system right?'). Validation is the process of demonstrating (as opposed to proving) that the product satisfies the User Needs, 'regardless' of what the system specification requires ('Have we built the right system?')." (Forsberg and Mooz, 1994)*

The interpretation of the 'Vee' model in relation to the features of analysis and synthesis is presented in the following.

Types of problems

In P1 it is evident that both problematical analysis and solution in synthesis are carried out: "starts with the identification of user needs… decomposition… the system concepts and system specification…". In this case, these two sides are linked together. This feature is also present in P8. Six baselines are mentioned in P3 for which the system to be developed must adhere to – this refers to the resolution of the desired thing.

Modes of reasoning

- Regressive: in P1 and P8 the authors indicate that there is a search for what the system should accomplish (the concept).
- Decompositional: the need and the solution that satisfy the need are broken down through decomposition (P1). This feature is also present in P2
- Transformative: the passage in P6 indicates that there is a core-level and an off-core level. Here, the process only considers the core-level as critical thus transforming the complex problem into a simpler one. Contrarily to the method of analysis and synthesis, transformation is done through removing information rather than adding. This is a new characteristic perceived as falling under the transformative feature that needs further investigation.
- Progressive: in P1 and P8 there are indications that tests are carried out to validate the achievement of the performance established within the concept.
- Compositional: in P2 there is reference to different levels of system composition.
- Demonstrative: the verification and validation of the system discussed in P1, P8 and P9 relate, in our interpretation, to the demonstrative character of synthesis.

Process characteristics

- Starting point: in P1 the starting point of analysis is the search for the system concept that leads to the starting point of synthesis.
- Iteration: the discussion about iteration is addressed in P7. For the authors, iteration is represented 'perpendicularly to the paper' as depicted in Figure 31. Vertical (descending) iteration is also considered but should be avoided, as it would impact on other characteristics of the design process such as time. If the needs have changed, then a new 'Vee' (analysis and synthesis) should be started.
- Deliberation: in P1 the authors say that "agreement is reached at each level and decisions made", thus denoting the use of deliberation. The same argument is present in P4.
- Inductive reasoning: in P5 the authors admit that inductive reasoning is possible up front, but this is only a secondary resource to support the clarification of the concept (up front) via analogy. The authors state that the final product may have nothing that is related to the solutions used at the start of the process.

Table 14 - Comparative investigation of analysis and synthesis and Forsberg and Mooz (1994; 1998)

	Analysis	**Forsberg and Mooz (1994; 1998)**	**Synthesis**	**Forsberg and Mooz (1994; 1998)**
Types	Theoretical	NI	NA	NA
	Problematical	P1; P3; P8	Solution	P1
Modes of Reason	Regressive	P1; P8	Progressive	P1; P8
	Decompositional	P1; P2	Compositional	P2
	Transformative	P6	Demonstrative	P1; P8; P9
	Abduction	NI	Induction	NI
Process characteristics	Starting point	P1	Starting point	NI
	Iteration	P7	Iteration	P7
	Heuristic	NI	Heuristic	NI
	a priori	NI	*a posteriori*	NI
	Deliberation	P1; P4	Deliberation	P1; P4
	Deductive reasoning	NI	Inductive reasoning	P5

NI: Not Identified

To this point, the 'Vee" model seems the one which brings together most of the elements in both halves of the method of analysis and synthesis. In this respect, three new characteristics were identified that are not present in the method of analysis:

- Inductive reasoning as a secondary resource to support problematical analysis;
- Internal iteration within each step of the 'Vee' and the avoidance of iteration between steps;
- An inverse transformational approach that excludes off-core requirements.

4.2.7 Nam Suh

(1)[46] The development of the axiomatic approach is based on the assumption that design can (and must) be based on a systematic basis (Suh, 2001). For Suh, the opposite of using a systematic design approach is designing with a basis in experience. Despite the importance of experience, experience only will lead the designer to a cycle of trial and error that, frequently, is not efficient or effective[47].

(2) For Suh (2001, p3) "*Design is an interplay between 'what we want to achieve' and 'how we want to achieve it'. 'Therefore, a rigorous design approach must begin with an explicit statement of 'what we want to achieve' and end with a clear description of 'how we will achieve it.' … 'When the product does not fully satisfy the FRs, then one must either come up with a new idea, or change the FRs to reflect the original need more accurately. This iterative process continues until the designer produces an acceptable result.*'

(3) Suh (2000) uses the concept of '*design domains*' to systematise the thinking process related to design. In this respect, Suh (2001) argues that there are four 'domains' in which design evolves, these are: Customer, Functional, Physical and Process domains. The interplay of design activities (see Figure 34 - Appendix 6)

[46] In relation to the work of Nan Suh, a different approach was adopted. Thus, in addition to the quotes as extracted from Suh's work each paragraph that explain his method is numbered and interpreted as in the previous sub-sections.

[47] Suh's point of view regarding systematic versus experience based design: "How should we design? In the past, many engineers have designed their products (or processes, systems, etc.) iteratively, empirically, and intuitively, based on years of experience, cleverness, or creativity, and involving much trial and error. Although experience is important because it generates knowledge and information about practical design, experimental knowledge alone is not sufficient, as it is not always reliable, especially when the context of the application changes. Experience must be augmented by systematic knowledge of design, or vice versa (Suh, 2000, p.4).

happens within domains through mapping customer attributes[48] (CA), functional requirements (FR), design parameters (DP) and process variables (PV)[49] as described below.

> ***(4) "Functional requirement:*** *Functional requirements (FRs) are a minimum set of independent requirements that completely characterize the functional needs of the artefact in the functional domain. By definition, each FR is independent of every other FR at the time the FRs are established."*
>
> ***(5) "Constraint:*** *Constraints (Cs) are bound on acceptable solutions. There are two kinds of constraints: input constraints and system constraints. Input constraints are imposed as part of the design specifications. Systems constraints are constraints imposed by the system in which the design solution must function."*
>
> ***(6) "Design parameter:*** *Design parameters (DPs) are the key physical variables (or other equivalent terms in the case of software design, etc.) in the physical domain that characterize the design that satisfies the specified FRs."*
>
> ***(7) "Process variable:*** *Process variables (PVs) are the key variables (or other equivalent terms in the case of software design, etc.) in the process domain that characterize the process that can generate the specified DPs."*

The activities carried out within each domain is described by Suh (2001) in the following:

> *(8) "The customer domain is characterized by the needs (or attributes) that the customer is looking for in a product or process or systems or materials. In the functional domain, the customer needs are specified in terms of functional requirements (FRs) and constraints (Cs). FRs, according to Suh (2001) must be defined in a solution-neutral environment. To satisfy the specified FRs, we conceive design parameters (DPs) in the physical domain. Finally, to produce the product specified in terms of DPs, we*

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[48] Also called customer needs.

[49]Key concepts related to the axiomatic design approach as discussed by (Suh, 2001) include:

- **Axiom:** Self-evident truth or fundamental truth for which there are no counterexamples or exceptions. An axiom cannot be derived from other laws or principles of nature.
- **Corollary:** Inference derived from axioms or from propositions that follow from axioms or from other propositions that have been proven.
- **Theorem:** A proposition that is not self-evident but that can be proved from accepted premises or axioms and so is established as a law or principle.

develop a process that is characterized by process variables (PVs) in the process domain (Suh, 2000, p.10)."

Despite not being depicted in his model, the iterative process between the domains is described by Suh. Table 15 shows an example of the domains' characteristics as applied in different fields of design.

Table 15 – Domains characteristics for different designs (Suh, 2001)

	Customer Domain {CA}	**Functional Domain {FR}**	**Physical Domain {DP}**	**Process Domain {PV}**
Manufacturing	Attributes that customers require	Functional requirements specified for the product	Physical variables that can satisfy functional requirements	Process variables that can control design parameters
Materials	Desired performance	Required properties	Microstructure	Processes
Software	Attributes desired in the software	Output specification of program codes	Input variables algorithms, modules, program codes	Subroutines, machine codes, compilers, modules
Organisations	Customer satisfaction	Functions of the organisation	Programs, offices, activities	People and other resources to support programs
Systems	Attributes desired of the overall system	Functional requirements of the system	Machines, components, subcomponents	Resources (human, financial, etc.)
Business	ROI	Business goals	Business structure	Humans and financial resources

(9) According to Suh (2001) the process designers will follow when interplaying amongst the design domains are:

"*1. Know or understand their customer's needs;*

2. Define the problem they must solve to satisfy the needs;

3. Conceptualize the solution through synthesis;

4. Perform analysis to optimize the proposed solution;

5. Check the resulting design solution to see if it meets the original customer needs (Suh, 2001, p.3)."

(10) According to Suh's axiomatic approach, analysis (as in the ancient method) is done after the conception of a solution that is found through synthesis[50]. In Suh's words:

> *(11) "… we must think of all the different ways of fulfilling each of the FRs by identifying plausible DPs. Sometimes it is convenient to think about a specific DP to satisfy a specific FR, repeating the process until the design is completed. Databases of all kinds (generated through brainstorming, morphological techniques, etc.), analogy from other examples… extrapolation and interpolation, laws of nature, order-of-magnitude analysis and reverse engineering… can be used." (Suh, 2001, p18)*

(12) In general terms, the axioms constitute general design rules ("*generalizable principles that govern the underlying behaviour of the system being investigated*") that supports decision-making in design (Suh 1990). For Suh (2001) axioms can be derived into corollaries and theorems that work as design rules that prescribe precisely the bounds of their validity. It is evident that from Suh's point of view, all requirements can be deployed into smaller units so to become an objective DP and synthesis is used to do so.

(13) In this respect, two are the main axioms of design according to (Suh 2001): the Independence axiom and the Information axiom. The Independence axiom proposes that all FRs must be independent whilst designing. The information axiom suggests that information content of the design must be minimised. In other words, that means that the best design solution for a system will be the one where there are no dependencies between its FRs and the design content is reduced. For Suh (2001), design axioms are created through the identification of common elements that are present in all good designs. However, Suh (2001) does not describe how this task is performed.

From the above it can be inferred:

Types of problems

According to Suh's process (2) the problematical type of analysis and the synthesis of the solution are parts of the design process. In (3), (4), and (8) both types are also

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50 The investigation of whether the axiomatic approach relates to the method of analysis is discussed by Koskela and Kagioglou (2007) and Koskela et al., (n.d.).

evident with the distinction between functional and physical domain. Similar to the method of analysis, the process starts with the identification of what the system is expected to perform. However, contrary to the ancient method, a link between analysis and synthesis seems non-existent. In (11) this is evident as Suh suggests the use of plausible reasoning. In (12), it is not explicit, but the design axioms may fulfil the role of linking analysis and synthesis. However, this needs further investigation.

Modes of reasoning

- Decompositional: the decompositional mode of reasoning is present in the independence axiom (13). In this respect, there are dependent FRs that must be considered independent whilst designing.
- Progressive: as in (2), (6) and (8), the inductive process is characterised by linking given causes (FRs) to effects (DPs) that are identified through induction.
- Demonstrative: design parameters constitute the characterisation of the problem (condition) that satisfy the identified need (see 6).
- Induction: in (10) analysis happens after synthesis, characterising the inductive approach within that stage, i.e. the system that is put together is tested to verify if it achieves the required performance.

Process characteristics

- Iteration: in (3) iterations between domains is described as a feature of the problematical analysis and the synthesis of the solution.
- Heuristic: for Suh, heuristic rules (design axioms) are used to guide decision-making (see 12). Without further justification we consider the design axioms as presented by Suh as being heuristic rules.
- Inductive reasoning: overall, the process as described by Suh seems to rely more on inductive than deductive reasoning. It is understood that the axioms for design are not a design specific, rather they are general principles, thus limiting the analytical activity.

Table 16presents an overview regarding the comparative investigation of analysis and synthesis and the design process as proposed by Suh (2001).

Table 16 - Comparative investigation of analysis and synthesis and Nan Suh (2001)

	Analysis	Nan Suh (2001)	Synthesis	Nan Suh (2001)
Types	Theoretical	NI	NA	NA
	Problematical	(2); (3); (4); (8)	Solution	(2); (6); (8)
Modes of Reason	Regressive	(2); (3); (4); (8)	Progressive	(2); (6); (8)
	Decompositional	(13)	Compositional	NI
	Transformative	NI	Demonstrative	(6)
	Abduction	NI	Induction	(10); (11)
Process characteristics	Starting point	NI	Starting point	NI
	Iteration	(2)	Iteration	(2); (11)
	Heuristic	(12)	Heuristic	(12)
	a priori	NI	*a posteriori*	NI
	Deliberation	NI	Deliberation	NI
	Deductive reasoning	NI	Inductive reasoning	All

NI: Not Identified

4.2.8 Armand Hatchuel and Benoit Weil

The C-K Design theory of Hatchuel and Weil (2002; 2003) and Hatchuel *et al.*, (2004) is based upon ideas of a joint-expansion of 'a space' of concepts and 'a space' of knowledge that leads to the creation of new concepts and knowledge formation. In this respect, these authors do not provide a definition for knowledge and do not acknowledge the existing debate about the definition of knowledge as discussed in section 3.

For Hatchuel and Weil, design happens through the processes of disjunction, partition, conjunction and expansion of concepts and knowledge. Hatchuel and Weil argue that design process involves the 'manipulation' of existing knowledge ('K') and the proposition of new ideas (concepts – 'C') that has no status in K. In other words, the propositions are not known to be true or false. Thus, design is accomplished only and only if the propositions have a true status in 'K'. The manipulation happens through the definition of restricting and expanding 'partitions'

For Hatchuel and Weil (2003) restricting and expanding partitions is the result of adding properties to a concept 'C'. If the property added is known in K, thus this property will restrict the expansion of the concept. On the other hand, if the property added is unknown, that allows for an expansion of the concept, that if proven true will generate an expansion of 'K'.

These 'expansions' (as named by Hatchuel and Weil, 2003) occur as a result of four processes involving C and K: K to C (disjunction); C to K (conjunction); C to C (enrichment of C through the creation of additional consistency rules) and K to K (self expansion of knowledge with a basis on existing knowledge).

> ***P1.*** *Disjunction: "How does design reasoning start? By setting a problem to be solved? This sort of formulation provides no useful information whatsoever about design reasoning. What makes this reasoning specific is that the 'problem' implies that a concept must be formulated, which is not the case for most of the problems we meet. Obviously, if we say: 'I'm looking for my keys and have no idea where they can be,' there is a problem to solve but no need to draw up a concept. The keys in question do not need to be designed and I will recognize them as soon as I see them. On the other hand, if we say that we want to design 'easy-to-find keys', we are formulating a concept with all the properties mentioned above… We call the operation that consists in going from K⇒C and enabling a concept to be formulated the C-K disjunction. What conditions are required for the … proposition to be a C-K disjunction: (a) all the terms of this proposition must belong to K propositions; (b) the proposition must not have a logical status, otherwise it would be knowledge, K." (Hatchuel and Weil, 2002)*
>
> **P2.** Conjunction: "*C-K conjunction is symmetrical to disjunction. It marks the moment when we think that we have finished designing … 'easy-to-find keys'. How can this moment be defined? It happens when we consider that we know what 'easy-to-find keys' are! In other words, when a proposal such as: 'an easy-to-find key possesses properties P1, P2...Pi...Pk' is true in K. When such a proposition is accepted, the design reasoning can be stopped; also, 'easy-to-find key' is no longer a concept, but has become a proposition in K. And it can even be given a name: 'the XXX Key is an easy-to-find key with properties Pi....' We call the operation that goes from C⇒K and transforms a concept into knowledge the C-K conjunction. A design reasoning process can lead to several conjunction operations from a single disjunction, as there are several ways of making 'easy-to-find keys'." (Hatchuel and Weil, 2002)*

P3. *"Design is the process by which K ⇒C disjunctions are generated, then expanded by partition or inclusion into C ⇒K conjunctions." (Hatchuel and Weil, 2003)*

P4. *"Proposition: the space of concepts has a tree based structure: Proof: A space of concepts is necessarily tree-structured as the only operations allowed are partitions and inclusions and we have to assume at least one initial disjunction (this a classic result in graph theory). Several design theories have used the tree structure to represent design reasoning [9] but they misinterpreted it as a decomposition process. A tree structure appears because we can only add or subtract properties. Yet adding properties to a concept seems to decompose a concept into sub-concepts: this is an illusion, as in design the tree is necessarily an 'expansion' of the concept." (Hatchuel and Weil, 2003)*

P5. *"Definition of restricting and expanding partitions: If the property we add to a concept is already known (in K) as a property of the entities concerned, we call it a* ***restricting partition****; if the property we add is not known in K as a property of the entities concerned, we have an* ***expanding partition****. In other words, restricting means detailing the description with already known attributes, while expanding means adding a new topology of attribute." (Hatchuel and Weil, 2003)*

P6. *"Design as a process generating the co-expansion of two spaces: spaces of concepts C and spaces of knowledge K. Without the distinction between the expansions of C and K, Design disappears or is reduced to mere computation or optimisation. Thus, the design process is enacted by the operators that allow these two spaces to co-expand. With each space helping the other to expand. This highlights the necessity of four different operators to establish the whole process. Two can be called 'external': from C ⇒K and from K ⇒C; and two are 'internal': from C ⇒C and from K ⇒K." (Hatchuel and Weil, 2003)*

P7. *"K ⇒C: This operator adds or subtracts to concepts in C some properties coming from K. It creates 'disjunctions' when it transforms elements from K into a concept. This also corresponds to what is usually called the 'generation of alternatives'. Yet, concepts are not alternatives but potential 'seeds' for alternatives. This operator expands the space C with elements coming from K." (Hatchuel and Weil, 2003)*

P8. *"C ⇒K: this operator seeks for properties in K that could be added or subtracted to reach propositions with a logical status; it creates conjunctions which could be accepted as 'finished designs' (a K-relative qualification). Practically, it corresponds to validation tools or methods in classical design: consulting an expert, doing a test, an experimental plan, a prototype, a mock-up are common examples of C ⇒K operators. They expand the available knowledge in K while being triggered by the concept expansion in C." (Hatchuel and Weil, 2003)*

P9. *"C ⇒C: this operator is at least the classical rules in set theory that control partition or inclusion. But it can be enriched if necessary by consistency rules in C." (Hatchuel and Weil, 2003)*

P10. *"K ⇒K: this operator is at least the classical rules of logic and propositional calculus that allow a knowledge space to have a self-expansion (proving new theorems)." (Hatchuel and Weil, 2003)*

Thus, from the above, it can be inferred that:

Types of problems

According to Hatchuel and Weil's model, the design process follows an analytical route and has both theoretical and problematical types of analysis. In P1 and P3 they discuss the discovery and elaboration of the thing sought and desired. In P10 they discuss the expansion of knowledge, thus further characterising the theoretical type of analysis. In P2 and P5 the concept is considered as found (a proposition) and from there it starts to be resolved, i.e. theoretical analysis.

Modes of reasoning

- Regressive: in P1 and P4, design starts with a problem and the formulation of the problem is done via regressive reasoning (i.e. the designer should look for the concept that defines the problem).
- Decompositional: decomposition is present in P4. Interestingly, Hatchuel and Weil consider that the concept of tree structure is misinterpreted as being decompositional. In fact, they misinterpret the concept. In a tree structure system, not only a system is decomposed into its smallest unit as the relationships (branches) are maintained.
- Abduction: in P2 the concept found has no status in K (so it is something not known) but on that basis it is assumed as known, thus indicating an abductive approach.
- Induction: in P9 the authors relate the C⇒C operator to set theory. In set theory, sets are recognized as such through inductive/plausible reasoning.

Process characteristics

- Starting point: the starting point is something unknown (P1; P2).
- Heuristic: the axiom of choice is defined within set theory (P9), thus heuristic is seen as part of the C⇒C (operator) inductive process.
- Deliberation: the same argument presented above is valid for deliberation. In other words, since C⇒C involves choice, thus deliberation is part of the process (P9).
- Inductive reasoning: the expansion of concepts (P7) and knowledge (P10) from knowledge denotes an inductive process.

Table 17 - Comparative investigation of analysis and synthesis and Hatchuel and Weil (2002; 2003)

	Analysis	**Hatchuel and Weil (2002; 2003)**	**Synthesis**	**Hatchuel and Weil (2002; 2003)**
Types	Theoretical	P1; P3; P10	NA	NA
	Problematical	P2; P3; P5	Solution	NI
Modes of Reason	Regressive	P1; P4	Progressive	NI
	Decompositional	P4	Compositional	NI
	Transformative	NI	Demonstrative	NI
	Abduction	P2	Induction	P9
Process characteristics	Starting point	P1; P2	Starting point	NI
	Iteration	NI	Iteration	NI
	Heuristic	NI	Heuristic	P9
	a priori	NI	*a posteriori*	NI
	Deliberation	NI	Deliberation	P9
	Deductive reasoning	NI	Inductive reasoning	P7; P10

NI: Not Identified

4.2.9 Bryan Lawson

Lawson's contribution comes through the criticism of the models developed by Markus (1969), Maver (1970) and Darke (1978). According to Lawson (2006) the cognitive design process not only involves analysis and synthesis, but also the negotiation process between problem and solution (Figure 35 - Appendix 6). For Lawson, the key aspect of design is the difficulty of delineating the design problem. For him, solutions assist the finding of problems (and this is what he calls 'negotiation'). Further aspects related to key points identified by Lawson (2006) are presented in the following.

> **P1.** *"Our final attempt at a map of the design process shows this negotiation between problem and solution with each seen as a reflection of the other (Figure 35). The activities of analysis, synthesis and evaluation are certainly involved in this negotiation but the map does not indicate any starting and finishing points or the direction of flow from one activity to another. However, this map cannot be read too literally since any visually understandable diagram is probably far too much of a simplification of what is clearly a highly complex mental process."*
>
> **P2** *"The process involves finding as well as solving problems. … the designer must inevitably expend considerable energy in identifying problems. It is central to modern thinking about design that problems and solutions are seen as emerging together, rather than one following logically upon the other. The process is thus less linear than implied by many of the maps … but rather more argumentative. That is, both problem and solution become clearer as the process goes on."*
>
> **P3.** *" … there is no natural end to the design process. There is no way of deciding beyond doubt when a design problem has been solved. Designers simply stop designing either when they run out of time or when, in their judgement, it is not worth pursuing the matter further."*
>
> **P4.** *" … we learn about design problems largely by trying to solve them."*
>
> ***P5.*** *"Eberhard (1970) as cited in Lawson 2006… there are two ways in which designers can retreat back up the hierarchy of problems, by escalation and by regression. … escalation leads to an ever wider definition of the problem. … This behaviour is only one logical outcome in practice of the notion that analysis precedes synthesis and data collection precedes analysis. As we have seen, in design it is difficult to know what problems are relevant and what information will be useful until a solution is attempted. '…design consists of analysis, synthesis and evaluation linked in an iterative cycle … designers are often solution focused and work by generating ideas about whole or partial solutions. These solutions are sometimes developed and sometimes abandoned."*

P6. *"The design process: (1) the process is endless; (2) there is no infallibly correct process; (3) the process involves finding as well as solving problems; (4) design inevitably involves subjective value judgement; (5) design is a prescriptive activity; (6) designers work in the context of a need for action."*

P7. *"…analysis involves the exploration of relationships, looking for patterns in the information available, and the classification of objectives. Analysis is the ordering and structuring of the problem. Synthesis on the other hand is characterised by an attempt to move forward and create a response to the problem – the generation of solutions."*

From the above, we infer that:

Types of problems

According to Lawson's model, the design process follows an analytical-synthetic route and has both problematical type of analysis and solution through synthesis (P2, P3 and P6). However, as discussed in the end of this section, the process proposed by Lawson seems to follow an inductive approach rather than a deductive one.

Modes of reasoning

- Regressive: the use of regressive reasoning is considered in P5.
- Decompositional: in P5 the term 'escalation' is used in a similar way for what is meant by the decompositional mode of reasoning.
- Demonstrative: in P6 design is considered as a prescriptive activity, thus revealing the demonstrative characteristic of synthesis.
- Induction: there is evidence in P4 of looking into solutions and recognizing in them new problems that were not previously identified.

Process characteristics

- Iteration: in P5 iteration is recognised as part of synthesis, i.e. problem information is collected, and then solutions proposed lead to revisiting the problem.
- Deliberation: deliberation is perceived in analysis and synthesis. In P2 and P6, the words 'argumentative' and 'subjective value judgements' are the clue for this characteristic.
- Inductive reasoning: as previously mentioned, inductive reasoning is evident in P4.

Table 18 - Comparative investigation of analysis and synthesis and Lawson (2006)

	Analysis	Lawson (2006)	Synthesis	Lawson (2006)
Types	Theoretical	NI	NA	NA
	Problematical	P2; P3; P6	Solution	P2; P3; P6
Modes of Reason	Regressive	P5	Progressive	NI
	Decompositional	P5	Compositional	NI
	Transformative	NI	Demonstrative	P7
	Abduction	NI	Induction	P4
Process characteristics	Starting point	NI	Starting point	NI
	Iteration	NI	Iteration	P5
	Heuristic	NI	Heuristic	NI
	a priori	NI	*a posteriori*	NI
	Deliberation	P2; P6	Deliberation	P2; P6
	Deductive reasoning	NI	Inductive reasoning	P4

NI: Not Identified

In relation to Lawson's point of view regarding the design process, Lawson's explanation related to what is meant by analysis and synthesis seems similar to the ancient method, however the description of the tasks within his explanation relates to synthesis more that analysis. In this respect, in P1 evaluation is seen as being an independent process rather than the result of synthesis. Also, Lawson describes different design tactics to deal with problem finding. In this regard, all the tactics described are based on synthesis. Finally, it is also argued by him that data collection precedes analysis. Because Lawson does not provide detailed information about how data is collected, here we related this to Riemann's idea of knowledge prior to analysis and synthesis.

4.2.10 Empirical Observation in Healthcare Facilities Design

This sub-section presents the interpretation of the data acquired via observation in eleven design meetings (as described in section 2.2.3.2) that were held between design team members (DT) and client representatives (CR). An additional source of evidence was the drawings and the briefing document as proposed by the DT. The interpretation of the results in relation to the method of analysis and synthesis is presented below.

Types of problems

- The interpretation of data obtained from the observations is that the problematical type of analysis occurs more often in the specific phase of design observed. In this respect, in meetings 1, 2, 4 and 5 reference was made to the developed brief. The preparation of the brief (or programme) is considered here as related to theoretical analysis because it seeks to define (with a basis on needs) the artefact (building) to be designed. In all meetings, the focus was to review the design that was developed as if checking if the parts and components were right.

Modes of reasoning

- Regressive: as indicated above, the reference to the briefing document is interpreted as a regressive process. In this respect, the design solution proposed is linked back to the needs (demand) established in the brief.
- Decompositional: in several passages (e.g. meeting 1 – where is imaging located? Meeting 4 – where are secretaries coming from? Meeting 10 – where is the cash-point, disposal rooms and car park?) indicate that there are parts and relationships between them. The example from meeting 10 for instance (location of cash-point) revealed a relationship between the coffee area (used to generated revenue) and the cash machine. The assumption made was that people would not voluntarily go to the coffee area unless attracted by another activity such as withdrawing money and/or paying bills.
- Abduction: in meeting 1, CR1 indicate that the numbers used to develop the proposal were incorrect. Still, the design was developed. That is interpreted as an

abductive act. The design team assumed the numbers as correct and developed the design based on that assumption.

- Compositional: the 'evidence' of the compositional feature of design does not come from a particular meeting as such, but from the overview of how meetings were held. Groups of stakeholders were consulted separately in each meeting. However, within the design proposal there were spaces shared by different stakeholders' groups (e.g. the open plan office shared by therapy nurses, clinical nurses and McMillan nurses).
- Demonstrative: in all meetings the DT members explained how the solutions were addressing the needs, thus indicating the demonstrative aspect of design.

Process characteristics

- Starting point: the starting point was considered as following the analytical route. In this respect, the brief represents the formalisation of what is considered as known (even through, there is no certainty that the brief is correct or it can be done).
- Iteration: the need for iteration was identified in all meetings as the design solutions, as members of the DT left the meetings with a list of design tasks for the correction of the proposed design solution.
- Deliberation: as per the above, the objective of the meetings amongst DTs and CRs were to deliberate about means and ends in all meetings.

Table 19 presents an overview regarding the comparative investigation of analysis and synthesis and non-participant observations of design meetings.

Discussion

From the above discussion, it is possible to characterise the observed design process as having both the analytical and synthetic approaches in comparison with the method of analysis and synthesis. In addition to the link with features of the method of analysis and synthesis other observations were made as presented below.

- CRs were senior members of clinical and non-clinical staff responsible for carrying out activities within the current/existing hospital. In this respect, it was observed that CRs constantly referred back to their experience and practices to assess the design proposal being developed (this issue is further discussed in Section 5.3).

Table 19 - Comparative investigation of analysis and synthesis and observation of design meetings

	Analysis	Design Meetings	Synthesis	Design Meetings
Types	Theoretical	NI	NA	NA
	Problematical	I	Solution	NI
Modes of Reason	Regressive	I	Progressive	NI
	Decompositional	I	Compositional	I
	Transformative	NI	Demonstrative	I
	Abduction	I	Induction	I
Process characteristics	Starting point	I	Starting point	NI
	Iteration	I	Iteration	I
	Heuristic	NI	Heuristic	NI
	a priori	NI	*a posteriori*	NI
	Deliberation	I	Deliberation	I
	Deductive reasoning	NI	Inductive reasoning	NI

I: Identified; **NI**: Not Identified

- The design solutions were presented in the format of technical drawings representing the proposed building. The scale of representation used at the stage of investigation was 1:500. In this respect, it is important to highlight that at this scale, constructive details (e.g. specification of materials) were not available and the discussions were focused on general aspects of the design such as room function, size, occupancy capacity and location.
- An interesting aspect observed is that the design was developed to fulfil the need of the programme as well as to promote change in behaviour of staff. For instance, it was mentioned that a specific layout configuration (with reduced area) was suggested as a way to avoid the 'congregation' of nurses.
- In relation to composition, it was observed that it does not refer only to the 'putting together' of solutions but also the design problems. For instance, the development of the shared office had many requirements such as access to natural light for all members of staff, space flexibility to accommodate unplanned

increase/decrease in the number of staff occupying the room, the need for reduced noise levels and privacy for holding confidential conversations between staff and patients. The proposed solution (at the point of observation) was an open plan office with floor to ceiling windows within approximately 2/5 of the perimeter of the room, that had enclosed small meeting spaces contained by sound proof glass partitioning walls and furnished with noise absorbent materials and furniture.

- Finally, the brief was used as a 'problem freezing mechanism' of design. In other words, the design had to answer the problems as stated in the brief and the discussions held within the meetings were to assess whether or not the design proposal was doing so. Changes in the brief were not discussed in design meetings involving DTs and CRs but within meetings held between the DT and the project management team. That was done that way because changes in the brief could lead to changes in the estimated budget. Thus, discussions were organised in clusters such as functional discussions and business discussions.

4.2.11 Discussion

To this point, prescriptive modern methods of design were reviewed and the features contained in them compared to the features of the method of analysis and synthesis. Here, this information is cross-analysed and emerging ideas are highlighted. The compilation of results from individual modern models is presented in Table 20 below.

General overview

From the comparative analysis between the ancient method of analysis and modern methods, it can be said that:

- All features within the ancient method are present in the modern ones, with the exception of reference to *a priori* knowledge and *a posteriori* knowledge.
- Modern methods have more features of the synthetic route than the analytical route.
- The problematical type of analysis and synthesis through solution are features present in all methods. However, it seems that, predominantly, synthesis (inductive reasoning) is used to assist problematical analysis (this aspect was identified and highlighted by Forsberg and Weil (1988).

Table 20 – Analysis, synthesis and modern design methods – cross analysis

ANALYSIS	Theoretical	Problematical	Regressive	Decompositional	Transformative	Abduction	Starting Point	Iteration	Heuristic	*A priori*	Deliberation	Deductive Reasoning
Morris Asimow	■	■	■	■	■		■	■			■	■
Herbert Simon		■		■								
Markus and Maver		■		■								
Leonard Archer		■		■		■						
Hubka and Eder		■		■	■							
Forsberg and Mooz		■	■	■	■		■	■			■	
Nan Suh		■	■	■				■	■			
Hatchuel and Weil		■	■	■		■	■					
Lawson	■	■	■	■							■	
Observation		■	■	■		■	■	■			■	
SYNTHESIS	NA	Solution	Progressive	Compositional	Demonstrative	Induction	Starting Point	Iteration	Heuristic	*A posteriori*	Deliberation	Inductive Reasoning
Morris Asimow	□	■	■	■	■	■	■	■			■	
Herbert Simon	□	■	■	■	■	■	■	■	■		■	■
Markus and Maver	□	■	■	■	■	■	■	■	■		■	■
Leonard Archer	□	■	■	■	■	■	■				■	■
Hubka and Eder	□	■	■	■	■	■	■	■		■	■	■
Forsberg and Mooz	□	■	■	■	■			■			■	■
Nan Suh	□	■	■		■	■		■	■			■
Hatchuel and Weil	□	■				■			■		■	■
Lawson	□	■			■	■		■			■	■
Observation	□			■	■	■		■			■	

- The most commonly identified modes of reasoning that are present in modern methods are: decomposition (by unanimity); this is followed respectively by demonstrative and induction fewer occurrences; progressive, compositional, and regressive modes have a few mentions; the transformative mode and the abduction mode are modes with minimum appearances in modern methods.
- Finally, in terms of process characteristics, Iteration and deliberation (in synthesis more than in analysis) appear often in modern methods.

Detailed comments

The start and end points: in the ancient method of analysis and synthesis the start and end points of analysis are considered qualitatively different. At the starting point of analysis, we don't know if the analysed 'thing' is possible or can be done, whereas the end point is something already known. According to the investigated authors the starting point of analysis within design is a need, a goal, a problem or the establishment of functional requirements. In general, the starting point of something not known is not explicit. However, it often can be implied. Therefore, the current conception does not fit very well with the ancient method of analysis and synthesis.

The types of analysis: as mentioned above, there are two forms of analysis: theoretical, for establishing the proof, and problematical, for finding a solution. In synthesis, the way forward is through the proposition of a solution after analysis is completed. The problematical type of analysis within design may be associated with the way that the designer will establish the principles or rules that explain the most i.e. the established need, concept and design solution. This does not mean that the need, concept and the design solution should be fixed. On the other hand, the theoretical type of analysis within the design process means that a specific or contextual situation can both be explained (by the adopted general principles) and solved, because the general principles provide the rationale to solve it. Again, this does not necessarily mean that the explanations (solution) and the proof represent the best answer for the problem. Solution in synthesis is the demonstration of the proposal and how it solves the problem.

In this respect, two issues emerge regarding problematical and theoretical analysis (and synthesis) within the design process: firstly, the aim of problematical analysis is to find the structure, order, rationale that explains the most. Secondly, the rationale adopted should explain the relation between problem and solution (in designing, the concept and the product or the need and the concept). Thus, the statement of the product concept in the design process can be understood as a 'generic' solution for the 'perceived need' (problem). In establishing the concept, the designer 'goes back' to clients and customers needs as an attempt to identify priorities, constraints, conflicts and rules related to the investigated problem. Then the designer moves forward, either through a creative leap or systematically, and the result is a concept, i.e. a candidate solution. In proving that the concept provides a valid solution, the designer analyses the concept solution into the smallest elements, and synthesizes them back into the final design, simultaneously taking care that all the client requirements are being met. Therefore, in spite of differences in vocabulary, the idea of two streams of activities, one towards the solution and the other towards a proof of the solution, is evident in the ancient method of analysis as well as in the current view of the design process.

Iteration: The method of analysis does by no means ensure that a solution can be found. Rather, the method leads to an iterative approach: we may be compelled to return to the problem and revise it, and start afresh (Figure 8). There are two possible reasons for the lack of a solution for a problem: the problem may be impossible or the solution was not discovered / invented yet.

Figure 8 - Iteration in the method of analysis and synthesis and in the design process

Looking within design, the iterative process between analysis and synthesis can be viewed in both i.e. backwards between problem and solution, as well as forwards between solution and proof (Figure 8). Thus, despite there being no reference to the ancient geometers the iterative method is evident both in the ancient method of analysis and the current view of the design process.

Decomposition: Even if not explicitly discussed in Pappus' account, a decompositional (also called configurational) analysis is usually involved in the method of analysis. In the context of geometry, the question is about investigating from which parts (lines, angles, points, etc.) a figure is made up, and what relations exist between those parts (e.g. opposite, complementary). In fact, it is in this meaning of breaking down into parts that the term analysis is today most often used. However, to bring to light the current conceptualisation in design, the following were considered.

It is clear that there are similarities between the ancient and current views of decomposition. However, in design, designers are not just looking for 'what is there' but also for 'what is not there'. The concept (or solution) may consider the addition of benefits e.g. through making explicit, visible or more evident in the concept something that could be there implicitly (Levitt, 1990; Kotler, 1998). Another difference, as pointed out by Koskela and Kagioglou (2006), might be the fact that the modern view sees the decomposed parts as independent, whereas the ancient approach also covered the relationships between the decomposed parts.

The two directions of analysis: The two directions considered in the ancient method of analysis and synthesis are: backwards for the solution, and forwards for the proof. Looking backwards for the solution the analyst is looking for the general rules or principles related to the problem (in geometry, axioms). Looking forward to the aim is to prove that the solution or the axioms can be used to solve the problem.

In design, this feature can be considered as looking back for causes by their effects. For instance, considering 'the perceived need' as an effect, the analyst will be looking for the cause or causes of that need; for example, people need flexible rooms because the use of the rooms is changing frequently and the use is changing frequently because products and processes are in constant development. Therefore, products and process development may explain the necessity for flexibility.

However, looking at engineering design methods, it seems that the process of analysis consists of regression, i.e. regressive inferences. In this respect, the admission of hierarchies, steps, priorities, goals and sub-goals, refers to the identification of the constituent parts of the problem. Therefore, it is obvious that regression takes part in the design process as in the method of analysis and synthesis. However, it is not clear how the designer infers the sequence of inferences from the 'perceived need'. Also, how regression and decomposition comes together is an issue that is not addressed in depth. Lastly, inferences forward are rarely mentioned in the design literature. An exception can be found in Forsberg *et al*. (1996).

In conclusion, through the investigation conducted here, it must be concluded that most of the features of the ancient method of analysis and synthesis have been considered within the current views of analysis and synthesis in design. However, it seems that analysis and synthesis as a method within current systematic design methods lacks completeness and structure. On the one hand, regarding completeness, the main point is related to the failure to utilising all main forms of reasoning as well as both directions of them. On the other hand, it is not made clear where the start and finish is for analysis and synthesis.

Moreover, in science, analysis has a specific meaning and relates to a specific method; however, currently it has been used as a synonym of examination, investigation and interpretation, therefore, causing confusion. In addition, within the design field, despite many descriptions regarding the process (or method) of analysis and synthesis, none of them refers to the original method, thus distorting the use of all prior knowledge accumulated around analysis and synthesis. Finally, similar research was carried out in relation to the method of analysis and production management theories and the findings corroborate the results presented in this section as presented in Appendix 8.

4.3 Evidence and the Method of Analysis and Synthesis

To this point, the concepts of knowledge and evidence have been discussed and the prescriptive design process presented as containing the features of the method of analysis and synthesis. In this respect, firstly it has been discussed that the concept of knowledge depends on justification, truth and belief. Also, that knowledge is a conceptual proposition that has an inconsistency: the Gettier's Problem. Secondly, it is argued here that evidence is a type of knowledge that supports sustaining the JTB concept and that there are three types of evidence: potential, veridical and situation-evidence. Accordingly, evidence being a form of knowledge, its formation is a matter discussed within the field of epistemology. Lastly, we have discussed prescriptive methods of design and identified that the features of the method of analysis and synthesis are present in the description of modern design methods, thus, confirming the assumption that the method of analysis is a stronger theory to represent the design process.

In this respect, according to Koskela *et al*. (n.d.), the use of evidence within the design process is key. For these authors, the method of analysis and synthesis (as in the ancient method for solving problems in geometry) embeds the features of the design process as described in contemporary design science and product development literature. Although these authors do not use the term evidence, they argue that designers, through the process of analysis, assume/choose a path to follow in search of a solution for a problem. This process of assuming a direction is usually based on evidence of some sort indicating that the designer is following the right direction. If the evidence and assumption were correct, then the analysis is successful. The proof (evidence) that the solution does work is generated in synthesis. In this case, at first, evidence is used as a guide to truth or to the solution of the design problem. Afterwards, the evidence generated is the proof that the solution was reached. In this regard, the discussion that follows is an interpretation based on the discussions held so far. To start the discussion, the hierarchical decomposition aspect of analysis and synthesis as proposed by Descartes (Figure 9) is revisited and reinterpreted.

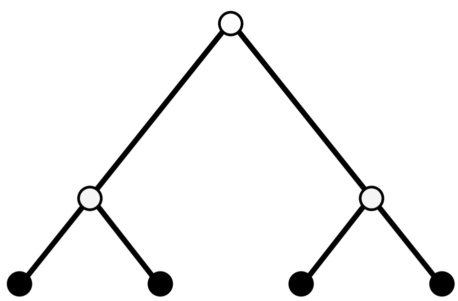

Figure 9 – Descartes' hierarchical decomposition (adapted from Gedenryd, 1998)

To assist the discussion, Figure 9 is interpreted as a design solution where each node represents a sub-component of the concept and the solution; thus, each component is the result of a combination of at least two sub-components and all together they form a system that is the resolution of the desired thing and accomplishes what was sought in the first place. The links between sub-components represent the relationships between the parts and the whole. The whole set of components and the relationships forms the design solution.

Undeniably, the similarity with a theoretical system (as presented in Section 3.5) is evident. In this respect, the design proposition can be considered as a theoretical construction that explains what, why and how a system (will) operate in the way it does (a proof *a priori* - a theory of the system). It fulfils the explanation and prediction functions of the 'theoretical' system developed. On the other hand, the construction of the artefact (or its tests through prototyping) will confirm that the 'theoretical" model was correct (or not), thus generating the proof (*a posteriori*). The same can be said about planning the production of the artefact, i.e. the plan can be tested *a priori* and *a posteriori*. Thus, Descartes' model, interpreted as a design model, should have two lines when representing design: one representing the *a priori* relationships and the other the *a posteriori* solutions. Dashed lines are used to represent the iterative characteristic of the design (i.e. the problem and the solution can be revisited). The following configuration is presented in Figure 10[51]. In relation to evidence, *a priori* knowledge is related to rationalist *episteme* and *a posteriori* on an empiricist or phenomenological one.

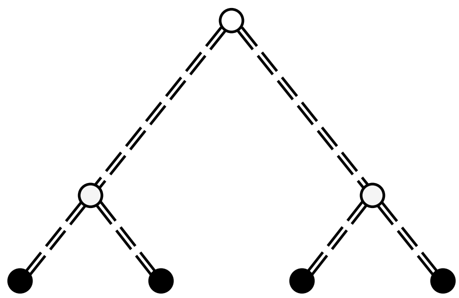

Figure 10 – Hierarchical decomposition interpretation of design

[51] The fact that any representation is limited is acknowledged. However, the use of diagrams to represent the design process is perceived as beneficial in supporting the discussions.

In this respect, lets separate the *a priori* and *a posteriori* systems. In a traditional scenario, the production of the artefact starts only when the design is finished. By finished we consider that the *a priori* proof was reached as represented in Figure 11. Here, the continuous line shows that the proposed theoretical design proposal works and the designed artefact should accomplish (with a determined probability) the task that it was set for. In this respect, at this stage a design proposal is, in part or as a whole, **potential evidence** that the task will be accomplished by the proposed system – independently of whether the system is the right one or not. In this respect, the design problem sets the boundaries for the conditions in which the artefact should operate. However, there is no guarantee that the problem that triggered the design problem was properly understood. In other words, the system may work as designed but it does not mean it is the right system. Paraphrasing Polya, just as mathematics presented in a finished form appears as purely demonstrative and consists of proofs only, design presented in a finished form appears as purely demonstrative and consists of proofs only. Proofs that the design solution works *a priori*.

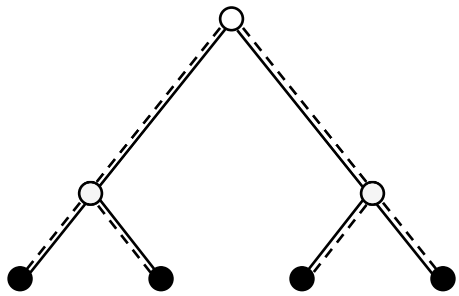

Figure 11 - Hierarchical decomposition interpretation of design prior production

Moreover, when production and thereafter performance tests are carried out, two possibilities exist as depicted in Figure 12. The first possible outcome (represented on the left) is that the production of the artefact does accomplish the task. Therefore, the constructed artefact provides, in parts or as a whole, the **veridical evidence** necessary to demonstrate that the task is accomplished by the proposed system, whether the system is the right one or not, and also that the *a priori* model is correct. Thus, like analysis is only complete if followed by synthesis, design is only complete if followed by its production. The second (on the right) is that the production of the artefact does not accomplish the task. In this case, the construction of the artefact is **potential evidence** that:

(a) The *a priori* model or the problem identified are inaccurate and must be revisited. Here, the iterative nature of design occurs at a late and undesirable stage. In this respect, approaches such as Concurrent Engineering (Prasad, 1996) bring that level of iteration to an earlier stage so issues related to the design problem and its interface with production are identified earlier; or

(b) The production itself was not done according to the design. Note that, to this point, considerations about whether the system is the right one or not are only considered if there is a verification process in place (for instance, checking with the client if the artefact fulfils the expectation). In some cases, this is done through prototyping, but unless the client can experience the artefact in its real context, the verification cannot be completed. Carmakers, for example, achieve the complete validation and verification within the *ramp-up* phase as described by Clark and Wheelwright (1993) and Ulrich and Eppinger (2005).

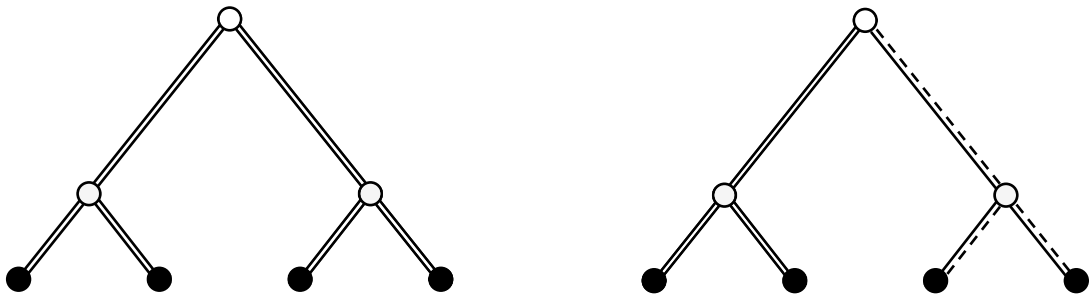

Figure 12 - Hierarchical decomposition interpretation of design post construction

In this respect, the question is to whether the above type of potential evidence improves design. The short answer is YES (but we do not present evidence for that here, we assume that by detailing design the chances that the design will go wrong are reduced – i.e. detailing improves design – and that has been discussed by many already such as Cross, 1989 and Lawson, 2006). Thus, (following the discussion in Section 3.4.3) using analysis is potential evidence for successful design as the probability of success is higher than it would be without analysis. As argued by Achinstein (1994, 2010) higher probability does not implies stronger evidence, however the more tests (of a variety of tests) are carried out more likely is that the design solution will perform as specified.

Now, lets use the 'Vee' model to further investigate the role of evidence in design[52]. In the 'Vee' model, the first phase of design is the identification of user requirements through, amongst other methods, market research. This process envisions a better understanding of user needs from myriad levels (i.e. from the core need to future needs that may emerge as discussed by Levit, 1986). According to Forsberg and Mooz (1998), a baseline measure of performance and the measurement protocol/method are set and verification tests are conducted for each phase, discipline and part of the artefact being developed. These tests provide 'evidence' that the system and subsystems perform accordingly in relation to the elicited requirements as discussed above. Based on this depiction of design, analysis is related to the left leg of the 'V' whereas the final proof takes place in synthesis - i.e. it will take place when the artefact is built, validated and verified – right leg (Figure 13).

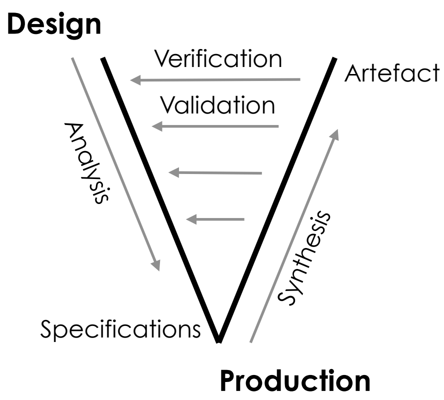

Figure 13 – The 'Vee' model and analysis and synthesis

In addition to the model developed by Forsberg and Mooz (1998), it was observed that an additional validation process is carried out. As highlighted in Section 4.2.10, the design proposals were 'presented' to CRs as a way to seek for validation of the proposed solution. This process took place in a much earlier stage of design than

[52] In relation to selection criteria for choosing a model for the comparison between design and knowledge, the model devised by Morris Asimow would be ideal as it is the model with the highest number of features that are similar to the method of analysis. However, this model does not have a diagram for its representation that could facilitate the discussion. Thus, the adoption of the 'Vee' model is justified as this model is the second in terms of having features of the method of analysis and synthesis and it has a diagram that represents the design process.

that proposed by Forsberg and Mooz as presented in Figure 14. In this respect, the validation process as proposed by Forsberg and Mooz has a technical character and it assumes that user needs can all be identified up-front and that a set of tangible indicators can be developed and measured to either validate or not the developed system. On the other hand, the validation process as observed in the design meetings has a socio-technical characteristic and it is used to validate the design solution against implicit knowledge about the operation of the artefact being developed (i.e. the healthcare facility). As discussed in Section 4.1.3 "in the absence of knowledge or evidence (in its philosophical meaning), deliberation gives room to argumentation based on what is best available (i.e. anecdotal empiricist evidence) or in the case of observed meetings the opinion of expert clients (authorities). This justifies approaches such as early supply chain involvement (O'Neil, 1993) and stakeholder involvement (Cooper et al., 1998).

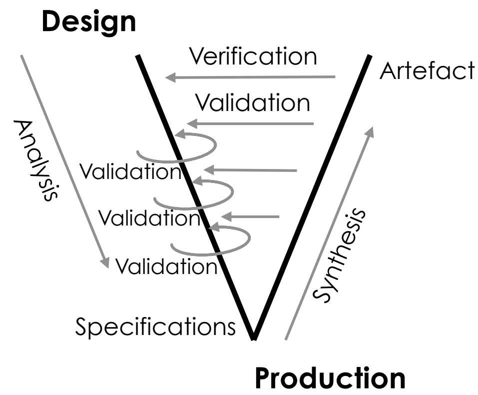

Figure 14 – The 'Vee' model with an additional validation process

Following this rationale, the concept (or problem) is deployed into its many facets through 'detailing'. Here, we interpret deployment as transformative analysis. In this respect, the transformation happens by moving from the *a priori* domain towards the *a posteriori* one. Thus, the deployment in the *a posteriori* domain relates to the auxiliary constructions that are necessary to identify the relationships that were not explicit or identified in the antecedent step. In this respect, the *a posteriori* dimensions of the 'Vee' model include: the elaboration of a validation and verification system; the development of configuration systems; the documentation related to the artefact's architecture; and the development of the fabrication and assembly code. That would justify the development of techniques such as DFX (Design for X) as presented by Pahl and Beitz (1996). These authors present fourteen different dimensions in which design can be detailed such as: design for ergonomics, design for easy assembly, design for aesthetics, design for sustainability and so on. The dimensions within DFX (as in transformative analysis) add information to the original problem revealing hidden relationships. Similarly, the application of approaches such as QFD (Quality Function Deployment - Cohen, 1995) and Set-Based Design (Sobek, 1999) also provides potential evidence for the relationships amongst the nodes. In this respect, this approach satisfies the criteria of stronger evidence as discussed in Section 3.4.3. Thus, as represented in Figure 15, the more transformations, the stronger the evidence we have that the design will accomplish the tasks for which it was designed. The nodes (• • • •) in Figure 15 represent the different 'X' in DFX.

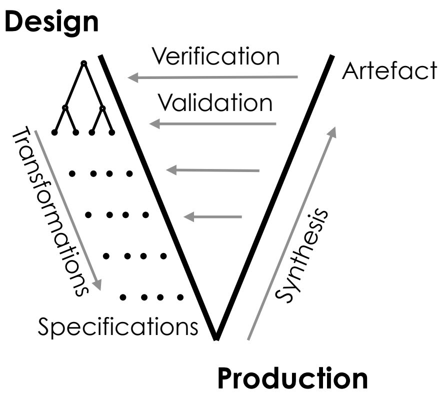

Figure 15 – Transformative feature of analysis and synthesis and the 'Vee' model

Based on the above discussion, it is contended that, within design, evidence can be classified further as being internal and external (Figure 16). This classification is unique in the field of evidence and as such constitutes a major contribution of this thesis. It is relevant because it indicates that there are differences in the roles of internal and external evidence that were not understood before. In this respect, internal evidence (**IE**) refers to the validation of the systemic aspects of the artefact being developed (parts and relationships) and its internal consistency, coherence and integrity (i.e. if the system is right). It also refers to the verification of the interface between artefact and user. For instance, within socio-technical systems, it is only at the end of synthesis that verification can be conducted (i.e. if it is the right system). Thus, in analysis (left leg) IE is potential evidence and therefore it is used as a reason for believing that each part of the artefact being developed accomplishes its intended functions. In this case, evidence confirms or refutes assumptions and generates the proof that gives the necessary confidence that the system performs as designed (independently of being the right system). In relation to synthesis (right leg), IE is veridical so validation and verification assessment processes take place in this stage. In this respect, the evidence is used within design as confirmation that the product is what users expect in terms of content, performance and operationalization (easy-to use) amongst other requirements. Thus, IE relates to providing an answer for the two questions: 'is the system right?' and 'is it the right system?' Interestingly, the answer to the first question emerges prior to the second (in an inverted order) – i.e. there is an inherent and unavoidable risk of developing a solution that performs tasks just as it was designed for, but that does not accomplish the right tasks as required by the client.

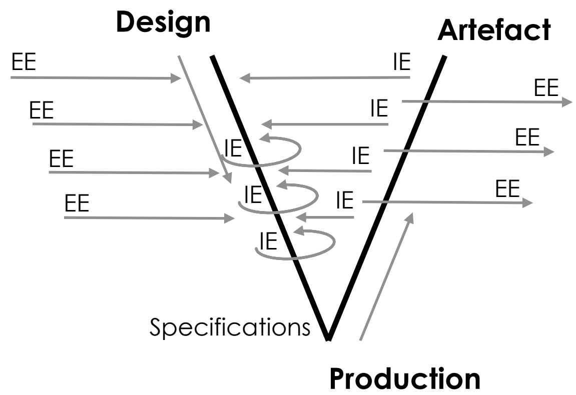

Figure 16 – Evidence in Design: Conceptual framework

Accordingly, external evidence (**EE**) refers to evidence from validated systems (i.e. for which veridical evidence is available) that are used outside its original context. For instance, evidence generated elsewhere that can be used as a source of knowledge about the internal composition and relationships of similar systems in the development of a design proposal. In this respect, veridical evidence generated elsewhere will be potential evidence that a particular composition works. Also, depending on how the evidence was generated (i.e. its source) the evidence that was veridical in its original system is not more than anecdotal into another. Thus, with a basis on anecdotal empiricist evidence one is justified to believe that it will work again for a 'similar' condition. The emphasis in using evidence from a past-validated system is currently seen in approaches such as Evidence-Based Design (EBD) (CHD, 2008). Conversely, the emphasis on evidence generation so to be used in future projects can be seen in traditional design approaches such as POE (Post-Occupancy Evaluation – Preiser and Vischer, 2005) as well as emergent project management and design approaches such as Benefits Realisation (Sapountzis *et al*., 2010).

From the above discussion, it is clear that the use of **internal evidence** is inherent to design. In this respect, the evidence gathered refers to the results of continuous tests that are carried out to verify and validate assumptions used to lead the development of a product or service. In this respect, the meaning of evidence is not related to 'truth' as the rules of a universal law[53], instead it refers to the truth of the specific context being generated through the creation of an artefact or service. In terms of value generation, the use of evidence does increase value. From a product's point of view, it supports to a greater extent the development of a system that is right and less so to the right system. On the other hand, in relation to **external evidence,** the adopted direction for development with a basis on evidence should supposedly avoid the occurrence of unnecessary loops of interaction and correction. This is the assumption that forms the basis of the evidence-based design process. However, the exact role that external evidence plays are less obvious and not properly understood, therefore EBD is further investigated in the next section.

[53] However, the system created may lead to insight about relationships and lawn that are unknown and were discovered by 'accident'.

5 EXTERNAL EVIDENCE IN DESIGN

This section focuses on understanding the use of evidence in the design practice. The object of the investigation is the design of healing environments, in particular healthcare buildings. The unit of investigation is 'evidence' of the relationship between the built environment and health. In this respect, two tasks were conducted to support the discussions: the first relates to the investigation of the process in which external evidence is embedded within a design solution for the particular object investigated; the second relates to the characterisation of the evidence that has been used in this area. In this respect, for the first task, an investigation about the evidence-based design approach is carried out in addition to the prescriptive design methods reviewed in Section 4[54]. In relation to the characterisation of evidence (second task), the data collected through the systematic literature review (see Section 2) is structured so to assist the discussion[55] that follows.

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[54] In relation to the development process short characterisation of key issues related to the design of healthcare facilities is presented.

[55] The development of task 2 required the preparation of data so to support the characterisation of what was found. The data preparation involved the development of an open matrix that serves two

5.1 Evidence-Based Design: Process Overview

The term evidence-based design is an extension of the idea of evidence-based medicine (EBM) to the field of design. According to the CHD (2008), the strength of this approach relies on the systematic way in which data or evidence is collected. Thus, decisions are made with the support of information available from rigorous research. In this respect, the systematic use of scientific evidence to support decision-making is a simple and powerful concept. In medicine, this approach has been used to support the decision made between doctor and patient on the best treatment alternative for patients based on individual clinical expertise with the best available external clinical evidence from systematic research (Sackett *et al*., 1996). This involves identifying, for example, which treatment has the shortest healing time, which ones cause the least side effects and impacts on patients' quality of life and which ones are affordable (Mulrow, 1994).

The evidence-based approach has also been used within areas other than medicine, including for instance, education (e.g. Reed *et al*., 2005), economics (e.g. Pignone *et al*., 2005), management (Tranfield *et al*., 2003) and design (Malkin, 2008). Likewise EBM, the evidence-based approach, when applied to different knowledge areas, aims at better informing decision-makers about different candidate alternatives. Within design, EBD is defined as:

> *"…a process for the conscientious, explicit, and judicious use of current best evidence from research and practice in making critical decisions, together with an informed client, about the design of each individual and unique project (Hamilton and Watkins, 2009) … with the goal of improving outcomes and of continuing to monitor the success or failure for subsequent decision-making." (Malkin, 2008)*

According to Fischl (2006) this approach aims to provide scientific evidence for bridging designers' knowledge gap about humans' social and behavioural attitudes towards the surrounding environment. In this respect, the designer acts as a 'researcher' working as an interpreter investigating and describing human behaviour, wants and needs. This approach implies a change in the traditional practice of

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purposes: (a) to map existing research in the particular field of healthcare environments and its impacts on health and well-being; (b) to highlight areas where research has not been conducted or not deeply explored, thus supporting the elaboration of research agendas. The data prepared can be seen in **Error! Reference source not found.** that is presented in electronic format.

design considering that designers are increasingly required to have a considerable amount of knowledge that is beyond their own field (Hamilton and Watkins, 2009). For Hamilton and Watkins, this happens especially because building projects have become more complex, considering not only the product but also related services associated to it. Thus, by following this route, it is expected that risks related to design solutions could be reduced up front once evidence is available to demonstrate the efficiency and effectiveness of tested solutions (CDH, 2008).

The idea of using evidence to inform decision-makers in design is not novel. In general, design solutions have to comply with socio-technical regulations, norms and principles that are put in place after thorough tests have been carried out to set out the standards with which to comply (e.g. norms for health and safety, ergonomics, density, etc). For instance, in the 1960s the UK National Health System (NHS) started developing design guidance for the construction of healthcare environments. In this respect, to date, there are approximately 70 Health Building Notes (HBNs) and 240 Health Technical Memoranda (HTMs) that were developed with a basis in evidence and good practice. Since that time, these documents have been updated regularly with current scientific findings and good practice. In this respect, if from the one hand the use of mandatory standards support continuous improvement, on the other it may hinder innovation. That is arguably one role of EBD, i.e. to identify evidence that suggests solutions that may provide better results than standardised options.

Currently, in the context of healthcare projects, the use of EBD has been adopted in various ways (Hamilton, 2007). Hamilton describes four different levels regarding the role that practitioners can apply EBD: at Level 1, practitioners make an effort to stay up to date with the existing literature and design specification is based on current available information; at Level 2, practitioners progress further by hypothesising the outcomes of their proposed solutions and measuring them. The results are arguably used to evaluate their design proposals and improve future proposals; at Level 3, in addition to the previous steps, practitioners publish their findings in the public arena; finally, at Level 4, practitioners also publish their findings in quality journals that require review by qualified peers. Hamilton has also discussed the misuse of the evidence-based approach. In this sense, practitioners use disconnected pieces of evidence to support the non-adoption of standards and the bias in their design proposals.

Despite the proclaimed importance related to the use of evidence in design, not much can be said about the process steps for its implementation. Very little can be found in the literature about the theme (e.g. CHD, 2008; McCullough, 2010; Evans, 2010; Codinhoto *et al*., 2010). In this respect, the CHD (2008) developed the Evidence-based Design Accreditation and Certification (EDAC) guidance, which contains directions for the implementation of EBD. The process steps suggested by the CHD are:

- Define evidence-based goals and objectives;
- Find sources for relevant evidence;
- Critically interpret relevant evidence;
- Create and innovate EBD concepts;
- Develop a hypothesis;
- Collect baseline performance measures;
- Monitor implementation of design and construction;
- Measure post-occupancy performance results.

The CHD process steps have a focus on the gathering of scientific research that is related to the design problem. However, very little information is provided about how the evidence found is used in the design process. The EDAC guides suggest that research is used to inform design as described below:

> *"Research is vital during the pre-design and design. A review of literature can help to evaluate existing design options and spark design innovations. This is also the time during which EBD professionals develop a hypothesis and obtain and translate evidence into design. In addition, EBD professionals might use a small-scale research project to test the effectiveness of a product or design innovation and, thus, help them decide to go forward with a larger scale project." (CDH, 2008)*

From the above, two distinct processes can take place: the first relates to gathering evidence (through a systematic literature review) that addresses the same or similar issues found in the formulation of the design problem. The second relates to developing research for the collection of empirical evidence related to the design solution being proposed whilst the design is taking place. According to Hamilton (2012), EBD, as applied at the current time, follows only the latter approach. Moreover, for both processes, the role of evidence in design is not discussed in detail. From other fields, it can be said that the only systematic feature in this approach is the development of systematic literature reviews. Systematic reviews differ from traditional narrative reviews by adopting a replicable, scientific and transparent process which aims to minimize bias through exhaustive and time-consuming literature searches of published and unpublished studies and by providing an audit trail of the reviewer's decisions, procedures and conclusions (Cook *et al*., 1997; Tranfield *et al*., 2003).

The strength of systematic reviews is related to the establishment of qualitative and quantitative criteria that helps the identification of similar cases. Thus, evidence can be built on a cumulative basis (increasing evidence strength). Another important issue related to systematic reviews is the traceability of data. In this regard, Tranfield *et al*. recommend steps to be followed aiming to guarantee replicability and generalisation of the outcomes. Conducting research in management, Tranfield *et al*. (2003) have proposed the three stages of a systematic review, based on the work of the Cochrane collaboration (2001[56] and the National Health Service dissemination (2001)[57]: a) planning the review; b) conducting the review; and c) reporting and dissemination. Implicitly, this approach indicates that the solution found in the systematic review should be adopted as the solution to the design problem if it it agreed with the client. Thus, we assume that the conclusion of the review would be in the format of design recommendations. However, this assumption was derived from the practice in the field of management rather than design.

Furthermore, the ultimate goal of carrying out systematic reviews (at least in medicine) is the development of evidence models that demonstrate cause-effect networks (Mulrow *et al*., 1997). According to these authors, "*reviewers addressing broad questions that involve linkages among multiple bodies of both direct and indirect evidence need to use explicitly defined models*". These authors provide an example of an evidence model (Figure 17) assembled with the support of a framework that considered causality, prognosis, effectiveness of diagnostic and intervention strategies, and specific relationships between surrogate and clinically

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[56] Cochrane Collaboration (2001), The Cochrane Brochure, http://www.cochrane.org/cochrane/cc-broch.htm#BDL.

[57] NHS Centre for Reviews and Dissemination (2001), Undertaking Systematic Reviews of Research on Effectiveness. CRD's Guidance for those Carrying Out or Commissioning Reviews. CRD Report Number 4 (2nd Edition), York.

meaningful outcomes. Thus, as represented in Figure 17, each link represents a sub-question for which a systematic review was conducted (Mulrow *et al.*, 1997). The development of network models as part of the EBD process was not found in the review conducted[58].

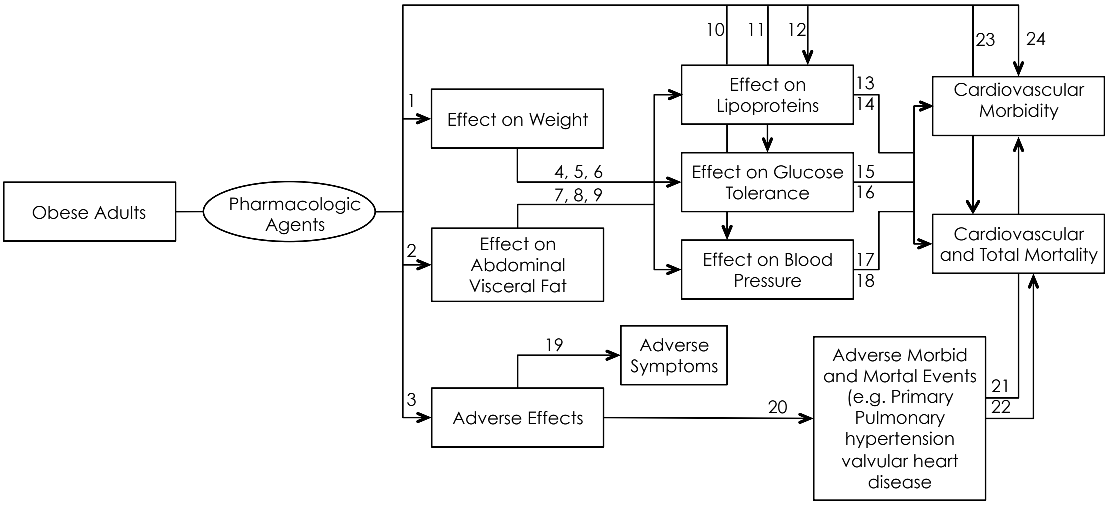

Figure 17 - An evidence model for the pharmacologic treatment of obesity
(Source: Mulrow *et al.*, 1997)

In this respect, Mulrow *et al.* (1997a) argue that evidence models are usually dependent on the use of heterogeneous pieces of evidence. For these authors, two types of evidence are considered in the development of evidence-models: direct and indirect. According to them, direct evidence in medical research links an exposure, diagnostic strategy, or therapeutic intervention to the occurrence of a health outcome. Conversely, indirect evidence arises if two or more bodies of evidence are required to link the exposure, diagnostic strategy, or intervention to the health outcome. In relation to Achinstein's (1978) model of evidence presented in Section 3.4, direct evidence refers to veridical evidence, whereas indirect refers to potential evidence or situational evidence.

In the medical area, Eddy (1990), *as cited in* Mulrow and Cook (1997), considers that the outcomes to be assessed should be clinically relevant to the patient. According to Fleming and DeMets (1996) and Mulrow *et al.* (1997a), relevant outcomes are symptoms, loss of function, and death. They must consider the perspective of the

[58] The only literature found in EBD about the development of evidence models refers to the author's own work and as such was not included in this thesis.

patient because physicians and patients often do not agree on what issues are important (Goodare and Smith, 1995; Smith, 1996 *as cited in* Mulrow and Cook, 1997). Indirect or surrogate outcome measures, such as laboratory or radiological results, should be avoided or interpreted with extreme caution because they rarely predict clinically important outcomes accurately.

In relation to design, the only attempt found that suggests a classification of evidence and a route for incorporating evidence within design is present in the work of Evans (2010). Evans claims that there is a need for proper understanding about how to fill the 'application gap' that links evidence and designing. He suggests revisiting the argument of Hillier *et al*. (1972) that substitutes the Analysis-Synthesis-Evaluation design process in favour of Popper's Conjecture-Analysis (i.e. the synthetic route). He then suggests that evidence, to be useful for designers, must be part of 'conjecturing' so as to be used as propositions to support problem findings rather than being used as rules (solutions). However, Evans highlights that the 'analytical' character of evidence generated by science is significantly analytical and therefore constitutes a barrier for the implementation of his own suggested approach.

Thus, based on the above discussion, we contend that EBD is not yet a mature and fully developed approach and that the most relevant issue that still remains to be addressed is the relationship between evidence and design. In this respect, the following sections present an examination of existing evidence related to the built environment and health outcomes[59]. The information gathered in the following section is later used to assist inferences about how it can be used in design.

5.2 The Built Environment and Health Outcomes: Evidence Characterisation

A myriad of studies have investigated the impact of the built environment into health outcomes. For instance, Devlin and Arneill (2003) found evidence regarding eight different aspects of the built environment (e.g. light, noise, etc.) that affect health

[59] It is also contended here that there is an element of practicality to be considered in the application of EBD that has not been addressed in current models. For that, it is suggested that the use of IT tools and the creation of a database can support the practical aspects of EBD such as the reduction of time to find evidence and the construction of evidence models (this is further discussed in Appendix 7).

outcomes. Also, Ulrich and Zimring (2004; 2008) and Lawson and Piri (2005) compiled extensive amounts of evidence from secondary sources that relates to different aspects of the built environment that have a direct or indirect impact on health and well-being. Built environment and health (also well-being) are complex concepts. Thus, their definitions are provided, so as to delineate boundaries for the phenomenon investigated.

The term 'built environment' can be defined in many different ways. On the one hand, it has a broad view and it considers aspects within the natural environment or at an urban scale; on the other, it is only focused on buildings (e.g. Halpen, 1995; Handy *et al*., 2002; Northridge *et al*., 2003; Mallak *et al*., 2003; Dearry, 2004). In general, the definition of the built environment refers to human-made surroundings (not necessarily restricted to buildings) or conditions that provide the settings for human activity, ranging from large-scale civic surroundings to personal places in which a person, animal, or plant lives or operates. Hence, in this report, the definition of **built environment refers to open and enclosed spaces designed and built through human intervention, where a person, animal or plant lives or operates.**

Similarly, health is a complex concept that is broadly defined as the "*state of complete physical, mental, and social well-being and not merely the absence of disease or infirmity*" (WHO, 1946). This definition implies that health is dependent on well-being. Well-being or psychological well-being is a commonly used term (Pollard and Lee, 2003) that refers to "*the emotional quality of an individual's everyday experience - the frequency and intensity of experiences of joy, fascination, anxiety, sadness, anger, and affection that make one's life pleasant or unpleasant*". It is also defined as the mental condition characterised by pleasant feelings of good health, exhilaration, high self-esteem and confidence" (Kahneman and Deaton, 2010). Here, we narrow this definition to the emotional quality of an individual's everyday experience that is enhanced or worsened by the individual's health condition. Due to the medical nature of this work, additional (health related) terminology is necessary. These are provided in Appendix 3. In the next section, candidate theories that explain how the built environment affects humans are presented.

5.2.1 The Theoretical Principles linking the Built Environment and Well-being

There are many theories explaining how the built environment affects human life and behaviour. In this respect, Sundstrom *et al.* (1996) argue that despite the progress in the development of theories, consensus regarding the explanation for how the environment impacts on humans has not yet been achieved. For Sundstrom *et al.* (1996), amongst the theories that have been guiding research, six appear to be more influential in recent research developments. These are presented in the following as extracted from Sundstrom *et al.* (1996).

- ***Arousal***: *"Psycho-physiological arousal is well established as a process that mediates influences of environmental features such as sound and temperature. The arousal hypothesis predicts optimum performance and satisfaction under conditions of moderate arousal, depending on task complexity and other factors (Thayer, 1989). Biner et al. (1989) found students' preferences for lighting scenarios consistent with predictions of the arousal hypothesis. Extensions of the hypothesis suggest that through arousal, high temperature increases the likelihood of violence, though the nature of the relationship remains in debate (Anderson, 1989; Bell, 1992)."*
- ***Environmental load***: *"The overload hypothesis assumes that humans have a finite capacity for processing stimuli and information and predicts that we cope with sensory or information overload through (among other responses) selective attention and ignoring low-priority inputs. Consistent with the hypothesis, a laboratory experiment by Smith (1991) showed that 78dB (A) noise led to reduced performance by college students in a letter writing task but not in a letter-search task. Loewen and Suedfeld (1992) found that masking sound mitigated the performance deficit produced by office noise but added to arousal. Veitch (1990) extended the arousal hypothesis to individual differences and reported better reading comprehension in noisy conditions by individuals with internal locus of control, and better reading comprehension in quiet conditions by individuals with external locus of control."*
- ***Stress and adaptation***: *"Previous research and theory associated extremes of temperature, sound, and other environmental variables with physiological and psychological stress and with coping and adaptive behaviours that reduce stress or its impact. Environmental stress research examined prolonged exposures (e.g.*

Hedge, 1989) and post-traumatic outcomes (Rubonis and Bickman, 1991) including chronic illness and psychological impairment. Such findings reinforce the need for theoretical distinction of acute and chronic environmental stress (e.g. Baum et al., 1990; Hobfoll, 1991; and Baum and Fleming 1993)."

- ***Privacy-regulation**: "Research on privacy, spatial behaviour, crowding, and territoriality together suggests a human tendency to seek optimum social interaction, partly through use of the physical environment (Altman, 1993). Privacy regulation theory suggests that when a person fails to achieve the subjective, optimum level of social contact for the situation, the resulting stress motivates coping behaviour, which may rely on the physical setting (Brown, 1992). Consistent with the theory, Haggard and Werner (1990) found that students who temporarily occupied a laboratory setting rejected intrusions more often when the chair arrangement delineated their work area than when it did not. Block and Garnett (1989) reported higher satisfaction among college students who worked on complex tasks in private rather than non-private settings."*
- ***Ecological psychology and behaviour setting theory**: "This theory analyses environments in terms of behaviour settings: 'small scale social systems composed of people and physical objects configured in such a way as to carry out a routinised program of activities with specifiable time and place boundaries' (Wicker, 1992). The July 1990 issue of Environment and Behaviour reviews the history of ecological psychology. Analysis of a recent worker survey supported the predictions of behaviour setting theory (e.g. Wicker and August, 1995). Extensions of the theory have focused on specific settings (e.g. Schoggen, 1989) such as gas stations (e.g. Sommer and Wicker, 1991), and on what Wicker (1992) called a 'sense-making' model-based on naturalistic research that addresses occupants' understandings of the context."*
- ***Transactional approach**: "In a substantial extension of privacy regulation theory, Altman (1993) and colleagues (e.g. Brown et al., 1992 and Werner et al., 1992) elaborated their transactional approach, which treats the physical environment as a potential context for social interaction that can support, constrain, symbolize, and confer meaning upon various aspects of social relationships. This holistic, systems-oriented analysis incorporates multiple levels and facets, variation over time, and cyclical processes. It describes social relationships and physical settings in terms of dialectics, or tensions between opposing influences."*

In addition to the above, **Proxemics** is another theory that relates humans and their behaviour in the built environment. Proxemics relates to peoples' use of their perceptual apparatus in different emotional states during different activities, in different relationships, settings, and contexts (Hall, 1968). Examples of studies include Cook (1970) and Raybeck (1991) who investigated privacy and territorial boundaries. Although these studies were not conducted in healthcare environments, they provide insights about human behaviours under stressful conditions.

Furthermore, considering the literature in architecture, the language of the space theory as proposed by Lawson (2001) states that the built environment has signs and specific characteristics that can be 'read' (as interpreted) by its users. Therefore, it is the language of the space and its 'readability' that influences human behaviour. In general, the behaviour is guided by the users' most important needs first and, basically, it varies from conscious to unconscious behaviours, as well as from controlled to uncontrolled ones (Lawson, 2001).

According to Lawson (2001), behaviour (controlled, uncontrolled, conscious and unconscious) leads to the generation of a matrix that combines the different behaviours. For example, the combination of unconscious and uncontrollable behaviours relates to what we call instinct (e.g. the blink of eyes), whereas the combination of conscious and controllable behaviours relates to what is called cognitive activity (i.e. includes intellectual thought and problem-solving). The combination of conscious and uncontrollable is termed conative behaviour and includes feelings and emotions. Finally, the combination of unconscious and controllable is related to what Lawson calls skills. Behaviours in this category include praying or singing a lyric of a song without realising the content (doing it mechanically). Lawson (2001) also recognises that this is a simplistic model and there are other types of behaviour that can be included within this model. In this respect, Lawson quotes Proshansky *et al.* (1976) in relation to the fact that the physical (built) environment also involves a social phenomenon and as such it cannot be isolated. In other words, not just buildings affect the way humans behave, but also humans, in an attempt to develop their social relationships, affect other humans.

Table 21 - Existing theories about the effects of the environment on humans' reaction

Theory	Effect	Cause	Explanation
Arousal (Thayer 1989)	Optimum performance and satisfaction	Moderate arousal	There is a universal environmental balance/equilibrium that impacts on us if disturbed
Environmental load (Cohen 1978)	Humans coping through selective attention	Humans' finite capacity for processing stimuli and information	Humans ignore low-priority inputs because a human's capacity for processing information is limited
Stress and adaptation – environmental stress (Evans 1984)	Physiological and psychological stress and coping and adaptive behaviours that reduce stress or its impact	Extremes of temperature, sound, and other environmental variables	There is a universal environmental balance/equilibrium that impacts on us if disturbed
Privacy regulation (Brown *et al.* 1992)	Coping behaviour stimulated by the stress caused by the lack or excess of social contact	Failure to achieving the subjective, optimum level of social contact.	There is a universal social balance/ equilibrium that impact on us if disturbed
Ecological psychology and behaviour (Barker 1969)	Humans carrying out '*routinised*' program of activities with specifiable time and place boundaries	Specific small scale social systems configuration	Not clear
Transactional approach (Altman 1993)	The stimulation of social interaction	Specific arrangements and characteristics of the physical environment	The physical environment provides the context for social interaction that can support, constrain, symbolize, and confer meaning upon various aspects of social relationships
Proxemics	Distortion in the perception of reality	Sense perception is affected by emotional status, social and environmental configuration	Sensorial apparatus is affected by cognition that is affected by the interpretation of context
Language of the space (Lawson 2001)	Stimuli in humans' behaviour	'Readability' of physical environments' intentions	Built environmental characteristics have specific meanings (which are associated with socio-cultural aspects) and may have an inductive role in humans behaviour

In summary, the phenomenon under investigation, i.e. changes in humans' reactions due to the stimulus caused by characteristics or different configurations of the built environment, can be explained through different ways according to the observed outcome. Table 21 above presents a summary of the presented theories related to this phenomenon, making explicit the observed effect, its possible cause and the dependency (or relation) between both. From the presented theories it can be concluded that:

- The built and social environment cannot be considered as separate environments. This is aligned with the concept of the built environment as adopted in this report;
- The built environment is perceived through the use of our senses, which stimulate our cognition in the first place and a reaction in the second place;
- Cognition can be stimulated when the 'natural' environmental balance is disturbed, through the 'readability' of the features of the built environment or through humans' priorities. Readability is related to individuals' own cultural background; i.e. the parameters that establish balance, readability, and priorities and whether they vary from person to person were not identified in the literature.
- The psychological impacts caused by the built environment may lead to subsequent physical or physiological consequences.

The following section presents variables related to the built environment and health outcomes identified within the literature.

5.2.2 Measures of Health and Well-being

Although the concepts of health and well-being are essential to the development of this research, the previously provided definitions do not state exactly what can be meant by a health outcome. Thus, in this section, we seek to identify the performance indicators of health that are considered to be dependent on or related to the built environment.

In the literature about measures of health, there is a variety of models, typologies and theories of health and well-being (e.g. Bergner, 1985; Patrick and Bergner, 1990; and Johnson and Wolinsky, 1993). These models tend to consider physical, physiological or psychological aspects of health and well-being separately. In this respect, Wilson and Cleary (1995) proposed a conceptual model of health-related quality of life that integrates both biological and psychological aspects of health outcomes. This model has been highly influential in medical research (Ferrans *et al.*, 2005) and as such it is used here as a major reference to the topic. According to Wilson and Cleary (1995), there is a wide spectrum of alternatives for measuring health or the lack of it. They argue that disturbances in health can be perceived at molecular and genetic levels at the one end as well as being broad and subjective measures such as 'feeling well' at the other. According to Wilson and Cleary (1995) there are at least five (relevant and practical) different levels of health outcomes (Figure 18).

- Biological and physiological factors refer to the processes that support life. In this category, it is the performance of cells and organ systems that can be measured through lab tests, physical assessment and medical diagnosis. Alterations in biological function can affect all the subsequent categories of quality of health;
- Symptoms refer to the 'reactions' of the organism as a whole, including the perception of an abnormal physical, emotional, or cognitive state. Symptoms are not necessarily related to changes in the biological function and are unique to the individual and can differ from someone who is experiencing the same health dysfunction process;
- Functional status relates to the ability of performing certain tasks. Four domains of functioning are often measured: physical, social, role, and psychological. Changes in the functional status are not necessarily related to changes in the previous categories of health indicators;
- General health perception is a subjective measure of health that is based on the person's perception and prioritisation of changes in their physiological functions, symptoms and functional status;
- Overall quality of life is related to the person's sense of well-being and as such, it is a highly subjective and individualized measure of health.

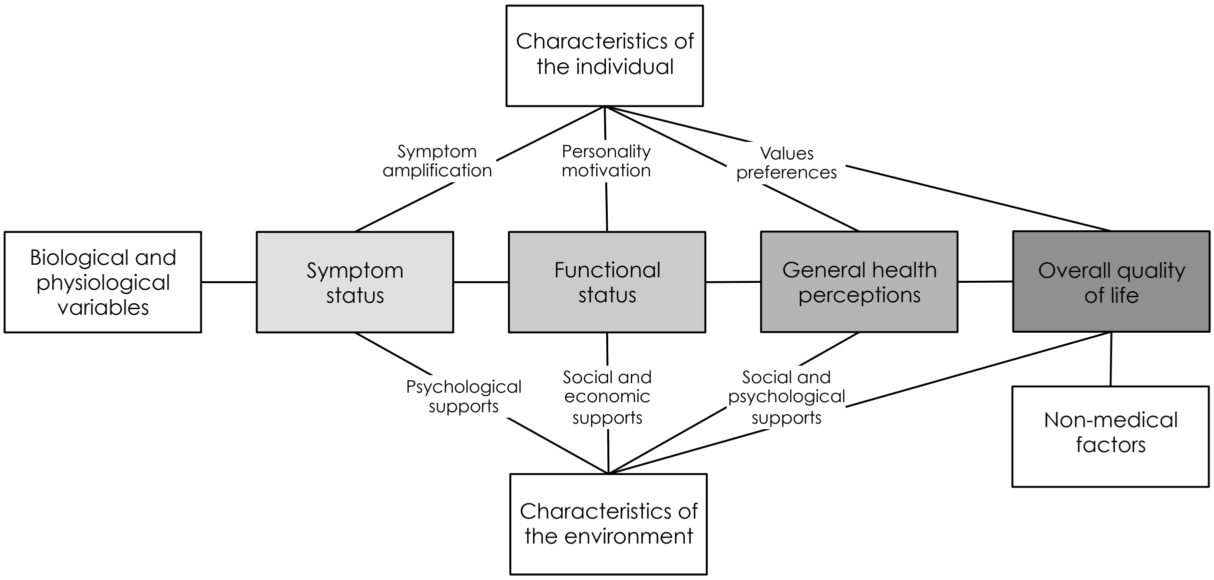

Figure 18 - Relationships among measures of patient outcomes in a health-related quality of life conceptual model (Source: Wilson and Cleary, 1995)

Although Wilson and Cleary (1995) argue that molecular and genetic factors are the most fundamental determinants of health status, their model begins with biological and physiological factors because they are more commonly conceptualised, measured, and applied in routine clinical practice. Furthermore, in relation to the measurement of health disruption, there are a considerable number of methods and tests for doing so, varying from interviews and the application of questionnaires to patients and their families to highly technological investigations and tests conducted in controlled environments (e.g. blood test, scans, biopsies, DNA tests, etc.). These methods are not discussed here. In addition, Wilson and Cleary argues that there are no clear boundaries between their suggested levels and this is because one level may influence the other. Finally, they argue that health outcomes are influenced by the individuals' characteristics as well as by the characteristics of the surrounding environment.

In this respect, Wilson and Clearly (1995) and Ferrans *et al*. (2005) considers that the environment has an indirect (rather than direct) impact on patients. For instance, Ferrans *et al*. (2005) consider that characteristics of the environment can be either social or physical. Social characteristics include, for instance, the marital status and the interaction between couples. It also includes the social milieu where the patient interacts, such as the specific culture of a haemodialysis clinic, waiting rooms, etc. Physical characteristics on the other hand, include the distinctive attributes of settings that may influence health outcomes, such as neighbourhood pollution or exercise facilities. According to Wilson and Cleary, 'biological and physiological variables' is the only category that is not affected by the environment and the characteristics of the patient. These authors do not explain why this occurs.

Now, once the specific health disorder (or disorders) is identified, the clinical team can link the information obtained (potential evidence) with possible diagnosis and decide a treatment route. In principle, any health disorder can be captured through Wilson and Cleary's model. Thus, health disorders that seem related to (or influenced by) the built environment (as identified through the systematic review conducted in this thesis) are presented in Table 22.

Table 22 – Categories and related health outcomes

Category	**Health Disorder**		
	Psychological	**Physical**	**Other**
Biological and Physiological variables	NA	Respiration rate	Infection
Symptoms	Delirium, anxiety, stress, confusion and disorientation, cognitive dysfunction, arousal, mood disorder	Heart rate, blood pressure, body integrity (broken bones)	
Functional Status	Depression, insecurity, fear, panic, attentional capacity, sleeplessness,	Injuries caused by falls, physical health improvement	Social interaction improvement;
General Health Perception	Health care independency	Pain	
Overall Quality of Life	Well-being, satisfaction		
Non-medical			Length of stay, healing time, staff errors, substance use decrease, setting infection level, work effectiveness, staff time per patient, privacy

In relation to the health outcomes identified, a large proportion is related to psychological disorders as opposed to physical ones. In this respect, the results of the review indicate that outcomes are sought in relation to the presence or reduction of symptoms and improvement of the functional status of the studied groups. In addition, emphasis is placed upon non-medical outputs, such as the overall performance of the care provider in relation to the whole population of patients visiting a particular care institution. In relation to this aspect, results can also be positive or negative. Finally, both positive and negative outcomes (for medial and non-medical categories) can also be measured to different degrees, e.g. relevant or irrelevant to health enhancement or decline.

5.2.3 Characteristics of Individuals

Research linking the built environment and health outcomes usually involves participants with varied characteristics and needs (Mulrow *et al.* 1997a). Thus, an important issue that must be considered when analysing the impact of the built environment on patient's health is related to whether or not patients under different conditions perceive and react differently to the environment. In this respect, it is assumed here that patients with different diseases have different needs in relation to the environment they are in. For some, the need might be a stimulating environment, whereas for others the priority would be to have access to a quiet and private place in which to rest. Also, it has to be considered that the need might change for a person over time during the healing process. For example, patients with mental illnesses seem to loose familiarity of the surroundings as the disease progress (e.g. Laditka *et al.*, 2005). Also, artificial light can cause damage to the vision of premature babies but not that of adults (e.g. Glass *et al.*, 1985).

The number of variables that characterise patients is considerably large. According to Wilson and Clearly (1995) this is because the characterisation of individuals is also dependent on the health condition of the individual. In this respect, Ferrans *et al*. (2005) argues that there are four categories of characteristics: (a) demographic; (b) developmental; (c) psychological; and (d) biological factors that influence health outcomes, as described below.

- <u>Demographic characteristics</u> are not modifiable and include sex, age, marital status and ethnicity of the individual (Ferrans *et al*., 2005).

- Developmental stages are usually defined for every 3 years of an individual and each stage has its own characteristics in relation to the degree of anatomic, physiologic, mental, and emotional maturation (pre-born, infant, pre-adult, adult, older person are examples of developmental stages). Developmental factors are not static or modifiable and have influence upon the decision for health interventions (Ferrans *et al*., 2005).
- Psychological factors are dynamic and modifiable. They include cognitive processes that alter perceptions, such as motivation and beliefs. According to Cox (1982, 2003), *as cited in* Ferrans *et al*. (2005), cognitive appraisal, affective response, and motivation are determinants of the psychological status. In this respect, cognitive appraisal includes factors such as knowledge, beliefs, and attitudes toward an illness, treatment, or behaviour. Affective response is the emotion produced including anxiety, fear, sadness, or joy. According to Cox (1982, 2003), *as cited in* Ferrans *et al*. (2005), motivation can be intrinsic or extrinsic. Intrinsic motivation is triggered by inherent enjoyment or satisfaction whereas extrinsic motivation is triggered by external rewards (Ferrans *et al*., 2005).
- Biological factors are the genetically linked characteristics that may manifest as disease, thus impacting on biological functions. Examples of biological factors include body mass index, skin colour, and family history related to genetically linked disease and disease risk (Ferrans *et al*., 2005).

From the systematic review carried out, three other categories were added to the taxonomy provided by Ferrans *et al*., (2005) that are related to patients' contextual information: (a) condition of the individual in relation to the intervention to promote health (e.g. pre-and post-operation, during treatment, etc.); (b) type of treatment as related to physical intervention (e.g. surgery), the use of drugs (e.g. chemotherapy, corticoids, etc.) and psychological or psychotherapeutic procedure; and (c) disease or injury as discussed in the previous sub-section.

In principle, any person can be characterised through this model. However, it is important to highlight that this taxonomy of individuals' characteristics is not exhaustive. For instance, cultural, social and economical characteristics are not included in the model because the research was limited in investigating these categories as relevant in relation to the built environment and health outcomes. Thus, considering the above taxonomy, groups of individuals that seem affected positively or negatively by the built environment (as identified through the systematic review) are presented in Table 23.

Table 23 – Categories and characteristics of individuals

Category		Characteristic
Demographic	**Gender**	Male and female
	Age	Any, dependent on the individual
	Ethnicity	White (British, Irish, European, other); Indian; Pakistani; mixed; Black (Caribbean, African, others) Bangladeshi, Chinese, Asian (non-Chinese), other
Developmental		Pre-born; infant; pre-adolescent; adolescent; emerging adulthood; adult; older person
Psychological		No variable was identified
Biological		No variable was identified
Condition		Pre-operative; post-operative; pregnant; post-stroke (cardio-vascular accident); post-heart attack; post-stop breathing; catatonic, post-traumatic
Treatment		Dependent on disease: based on drugs; based on operation; based on psychological or psycho-therapeutic treatment.
Disease or injury		Infectious diseases (e.g. respiratory infections, HIV/AIDS, tuberculosis, meningitis, etc.); injuries (e.g. burns, fractures, wound, etc.); physical diseases (e.g. cancer, heart diseases, Parkinson's, kidney dysfunctions, etc); and psychological diseases (e.g. Alzheimer's, dementia, depression, chemical dependency, etc.).

The interpretation of the data obtained from the systematic review is that male and female groups are equally impacted. As expected, fragile groups such as pre-born or older people seem to be more affected than other groups. It seems that there is an escalation of stress (or related symptoms such as blood pressure, anxiety) for patient in certain contextual situations (e.g. pre-operation, pre-diagnosis and emergencies) that is exacerbated by features of the built environment. Conversely, patients in situations such as post-clinical intervention seem to heal faster in settings with certain characteristics (e.g. exposure to natural light and view). In relation to the data obtained, psychological and biological characteristics have not been reported in the sources identified through the systematic review. Finally, also in relation to the sources identified, it can be said that there is no consensus in relation to a framework for reporting the characteristics of individuals. In this respect, in general the description of patients' characteristics is poor and restricted to demographic characteristics.

5.2.4 Characterisation of the Built Environment in Healthcare

In this section, the organisation of data is presented according to a framework developed during data collection. In this respect, the search for pre-established frameworks that characterise the built environment was unsuccessful in relation to finding a suitable format for data organisation. For instance, the literature about healthcare facilities design (e.g. Kliment, 2000; Miller and Swensson, 2002; Malkin, 2008; Grunden and Hagood, 2012; Purves, 2012 and Clarke, 2012) is, in general, focused on the functional decomposition of the building; for example, by considering main unit areas within hospitals, such as Intensive Care Units (ICUs), Maternity, Accident and Emergency (A&E) amongst others. Conversely, scientific evidence, when presented in the format of systematic reviews such as Devlin and Arneill (2003) and Ulrich *et al*. (2004, 2008), emphases specific building components (e.g. light, colour, noise, wayfinding, etc.) where the narrative about the functional area where phenomena occur is not explicit. Thus, in aiming for the better structuring of data, several attempts were made to develop a framework for the characterisation of the built environment in healthcare (these are presented in Appendix 4). The approach for the development of a framework was based on the search of emergent patterns from the data collected as presented in the following.

- <u>Multidisciplinary attention</u>: building characteristics of healthcare environments have been investigated within different knowledge areas such as design, architecture, art, engineering, psychology, environmental psychology, medicine and nursing, amongst others. In architecture, for instance, considerable attention has been given to design solutions that improve patients' experience (e.g. CABE, 2006; Malkin, 2008). In engineering, research has been focused on the investigation of systems and the improvement of systems' performance (e.g. ventilation, illumination and air conditioning) and how the improvement of these systems affects healthcare delivery (e.g. Chow and Yang, 2003).
- <u>Effects and side effects</u>: the design solution is analysed in relation to the different outcomes that a single characteristic can produce. This problem is well described

in Nuffield Provincial Hospitals Trust (1960) in relation to the design of a window. According to the Nuffield Provincial Hospitals Trust sunlight is a characteristic that may have both a good and bad impact on health. On the one hand, it is effective in reducing the levels of *haemolytic streptococci* bacteria, but if the design does not consider the amount of glare generated, it may cause discomfort to the patient, therefore leading to falls. In this respect, this example was the closest attempt of an evidence model found in the review.

- Decompositional approach: the identified data relates to multi-levels of analysis. In other words, the built environment can be investigated from the whole building (e.g. primary, secondary and tertiary care facilities) to an individual or specific set of features and characteristics (e.g. a chair, a colour and texture on a wall). Consequently, the same element or characteristic can be observed within different types of buildings and be associated with different outcomes, making the integration and generalisation of results more difficult.
- Multi-dimensional attention: there are different dimensions through which a building can be observed. For example, a physical dimension (e.g. temperature, ventilation, dimensions), an aesthetic/composition dimension (e.g. symmetry and balance) a functional dimension of the space (e.g. privacy and maintainability) and a psychological dimension (e.g. crowdedness, secureness, homeliness, etc.). In this respect, these dimensions can be measured in different ways and therefore amplifying the possibilities of establishing relationships between the built environment and health outcomes.

In considering these patterns in the literature, it was found that the presence of one dimension does not necessarily exclude another, therefore generating data complexity. Thus, considering the complexity of the field, the framework for characterisation of the built environment was developed as a map that accommodates the elements found within the research that was carried out. In this respect, the main categories considered in the map are: specialist type building, care unit, setting, component, furniture and equipment, sub-systems, functions and characteristics. In this respect, a building type will accommodate many care units that will have within them many settings. Settings are composed by components, furniture and equipment, sub-systems and will perform certain functions. In this respect, characteristics are the minimum elements found within the categories within a setting and the setting itself (e.g. the colour of a chair or the colour of a room). The depiction of this framework is presented in Figure 19 and the categories are described in the following.

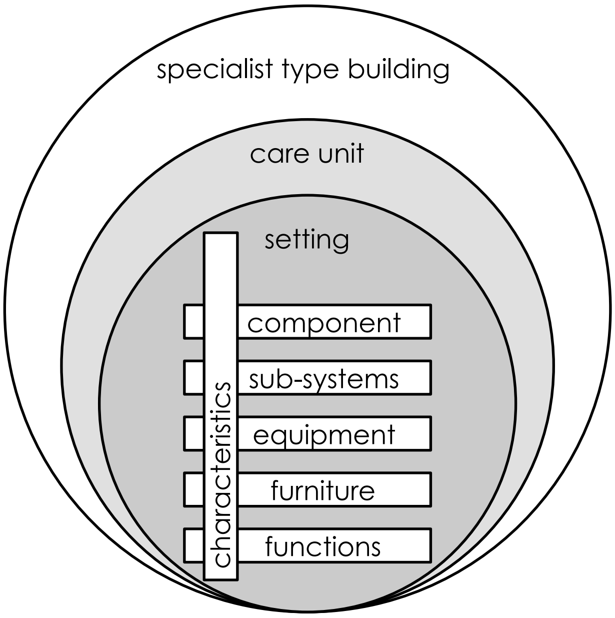

Figure 19 – Framework for the built environment in healthcare facilities

- Specialist type building: this category includes the different types of healthcare buildings such as primary, secondary and tertiary care facilities (including their variants and combinations), mental care facilities, hospices, etc. In some cases, the type of hospital facility accommodates more than one type of care unit. In those cases, the type of facility was defined with a basis on the type of unit where the experiment was carried out;
- Care unit: referring to a specialist area within a hospital that is focused on the specialist treatment of disease. Examples of care units include: intensive care, coronary care, dental care, neonatal care, accident and emergency, cancer care, orthopaedic care unit, etc.;
- Setting: refers to the specific area within a care unit that was investigated, such as: wards, single occupancy bedroom, operation theatre, corridor, waiting area, hospital entrance, kitchen, bathroom, garden, haemodialysis room, etc. It is important to highlight that in some cases, it was found that the research was carried out within many settings. Thus, for these cases, a multi-environment category was included;

- Component: the components of a setting should define its envelope. As such it includes: horizontal enclosure – floor and ceiling; vertical enclosure – walls, partitions, windows, and doors.
- Furniture and equipment: includes everything within the setting that is not a component. Examples include sink, bed, sofa, alcohol-rub, television, over-bed table, door handle, curtains, blinds, bedside rail, shower, chair and computers.
- Sub-systems: in general are distributed at the facilities management level of care units or the hospital, but its existence provides control over ambience characteristics within a setting. Examples include: ventilation, heating, acoustics, information and communication, plumbing, electrical, etc.;
- Functions: qualifies settings in relation to what they should perform. Safety, privacy, accessibility, functionality, maintainability, comfort and stability are examples of functions of a setting.
- Characteristics: relates to the primary features of the setting, its components, furniture and equipment, sub-systems and functions that can be perceived through the human senses, including their variations. Examples include: temperature, humidity, ventilation, luminosity, acoustics, colour, dimensions, texture and material. The deployment of these into their variants is presented in Table 24.

Results of the systematic review show that the range of studies varies considerably from a holistic viewpoint to a reductionist one. Examples of the holistic approach are presented in Qatari (1999) and Leather et al. (2000). In both studies, specific areas within hospitals were investigated in relation to clients' satisfaction and improved well-being. Examples of the reductionist approach can be found in Wilson, (1966); Nourse and Welch (1971); Jacobs and Hustmyer Jr. (1974) and Jacobs and Suess (1975) in relation to the use of colour and its psychological impacts on people within a specific setting and circumstance. Another example can be found in Chow and Yang (2003) who investigated the performance of ventilation systems in relation to temperature control in a non-standard operating room. Chow and Yang (2003) concluded that the appropriate ventilation and temperature (in terms of effectiveness in 'washing' bacteria during an operation) might cause discomfort for staff whilst using the space.

Table 24 – Characteristics and their variants in healthcare facilities

Variants	Lighting: natural light, artificial light, different types of artificial light Colour: yellow, orange, red, black, white, blue, green, grey Pattern: stripes, dots, chequerboard, plain Textures: smooth, rough, silky Ventilation: natural ventilation, artificial ventilation Temperature: cold, hot Dimension: size, height, width, depth Material: carpet, copper, steel, aluminium, plastic Composition: symmetry, balance, rhythm, movement, hierarchy

In addition, it became clear that certain features of the environment are influenced by more than one characteristic. Luminosity within a setting, for instance, can be influenced by the amount of light from natural and/or artificial sources and the colour of the surroundings. In this respect, its perception will also vary in relation to the person perceiving it – i.e. humans naturally loose sight capacity as they age, thus an older person does not perceive the environment in the same way that a younger person does.

Moreover, the number of levels of analysis, variables and variants that can be used to characterise the built environment is considerably large. This aspect of the field generates complexity to its investigation, as the number of possible combinations is considerably large to be empirically tested. There are other aspects that add to the complexity of the field such as the number of possible patient configurations and the number of outcomes that can be measured.

Finally, as described by Cooper *et al*. (2008) there are three generic categories that agglutinate the features of the built environment that impact on health and well being: the fabric of the environment, the ambience of the environment, and the psychological impact of buildings upon humans. In this respect, the fabric of the environment includes the design and construction of buildings (e.g. floors, walls, doors, ceilings, windows) and the spaces between buildings (e.g. gardens, paving).

Consideration should be given to the use of colour (e.g. red, blue, yellow); texture (e.g. rough, smooth, silky); pattern (e.g. checked, stripes, flecks); material (e.g. wood, metal, rubber) and structure (e.g. hard, soft, firm). The ambience of the environment pertains to the surrounding character and atmosphere of the environment. This includes noise (background, white-noise, silent, loud, constant); lighting (harsh, stark, mellow, bright, dim); temperature (cold, hot, mild); colour (warm, cool, cheerful, natural, subdued); air quality and ventilation (clear, polluted, dirty, fresh); humidity (damp, dry) and views of nature (natural sunlight). The psychological impacts of the environment are the perceptions of the physical environment and its impact upon individuals such as density (e.g. crowding, desolate); sense of safety or fear; way-finding (e.g. easy, hard, confusing); accessibility (e.g. difficult, direct, easy, off putting) and identity (e.g. homely, clinical, institutional, traditional or modern).

5.2.5 Evidence: The Impact of the Built Environment on Health Outcomes

In this section, a series of studies investigating characteristics of the built environment that impact on patients' health outcomes is presented. The list of studies linking the built environment and health outcomes is presented discussing the following characteristics: lighting, ventilation, temperature, arts and acoustics individually. The effects of other environmental variables are also summarised.

Lighting

The literature highlighted that light (either natural or artificial) can be associated directly and indirectly with physical, physiological and psychological health outcomes. In this respect, excessive exposure or the lack of exposure to light can have negative impacts on health. Examples of diseases that are related to light exposure include retinopathy, seasonal affective disorder and melanoma. Conversely, if provided appropriately, light is considered to have stimulating properties that affects metabolism and mind. Examples of studies investigating light and its impact on health and well-being are presented below:

- Natural and artificial light was associated with the reduction of the levels of contamination by haemolytic streptococci bacteria (Nuffield Provincial Hospitals Trust, 1960);

- The increased duration of exposure to fluorescent light was associated with the rise of the risk of development of melanoma in adults (Beral *et al.* 1982);
- High levels of ambient illumination contribute to the incidence of oxygen-induced retinopathy of premature infants (Glass *et al.* 1982). Controversially, a study conducted by Ackerman *et al.* (1989) concluded that there was no difference in the incidence and severity of retinopathy of premature infants. Ackerman *et al.* (1989) also identified that shielding infants in isolation from incidental lighting has no effect on the development of retinopathy of premature infants;
- The exposure to cycled light was associated with infants' superior rates of weight gain, faster development of the capability of being fed orally and enhanced motor coordination when compared with non-cycled light (Miller *et al.* 1995);
- The exposure to bright fluorescent light was associated with beneficial effects on seasonal depression. The same effects were not verified on non-seasonal depression (Kripke *et al.*, 1982; Kripke *et al.*, 1983; Yerevanian *et al., 1986;* Kripke *et al.*, 1998);
- Light in intensive care units was associated with variability of patients' sleeping patterns (Richards and Bairnsfather, 1988);
- Low frequency (red) light waves were associated with less sleep-wake frequency and more sleep thereby contributing to night sleeping. High frequency (blue) light waves were associated with greater sleep-wake frequency and more waking, thus contributing to day waking or being useful for undesirably sleepy neonates (Girardin, 1992).
- The exposure to ultra-violet radiation in daylight was associated with the stimulation of the metabolism and consequently production of Vitamin D (Veitch and McColl, 1993).

Ventilation

Both natural and artificial routes can be used to produce ventilation. The literature shows that research related to artificial ventilation and its impact on health outcomes are mainly associated with the dissemination of infectious disease. Research about natural ventilation is mainly related to window types and sizes. However it can be associated with different levels of pressure between adjacent rooms (e.g. bedrooms and corridors). The identified issues are presented below:

- Reduction of nosocomial infections through the adoption of negative pressure in settings occupied by infected patients (Anderson *et al.,* 1985);
- Contamination by acremonium kiliense conducted through the humidifier water used in the ventilation system (Fridkin *et al.,* 1996);
- Contamination by staphylococcus aureus (MRSA) through the ventilation system in combination with natural ventilation (Cotteril *et al.,* 1996);
- Recommendations for the use of heat and moisture exchangers in patients with acute respiratory failure (Pelosi *et al.,* 1996);
- Tuberculin conversion among healthcare workers was strongly associated with inadequate ventilation in general patient rooms (Menzies *et al.,* 2000);
- Increased risk of airborne bacteria contamination from the surgical team on the patient, and vice versa through the ventilation system (Chow and Yang, 2003).

Temperature

Little was found about the impact of temperature on patients' health. The literature demonstrates that there are many parameters that are used to specify the temperature performance of indoor environments. These parameters rely on both subjective and objective indicators (Frasson *et al.,* 2007) and may vary as they are provided by different organisations such as ANSI/ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers) and ISO (International Standards Organisation). Examples of research related to indoor temperature are presented below.

- Bell and Green (1982) investigated the impact of temperature on physiological stress;
- Results of the impact of thermal stress is presented in Hickman *et al.* (2003);
- Charles (2003) presents a compilation of studies looking at comfort generated by the use of localized air distribution systems;
- Temperature related comfort was studied by Chow and Yang (2003) and Hwang *et al.* (2006);
- Nagano and Mochida (2004) investigated the control conditions of ceiling radiant cooling systems. The study concluded that some measures and parameters that have been used to design should be reviewed;

- Lu and Zhu (2006) investigated the heat stress and heat tolerance of 148 males. The study proposed physiological limit values at exposure limits;
- The dissemination of waterborne infections due to warm temperature conditions is presented in Joseph (2006b).

Acoustics

The investigation of acoustics characteristics is mainly related to noise and its effects on health. It was found that music and music therapy (e.g. Cabrera *et al.,* 2000, Devlin and Arneill, 2003; Ikonomidou *et al.,* 2004 and CABE, 2004) can enhance health. In the literature, noise is associated mainly with sleeplessness and stress. Also, that the route causes of noise varies and is associated with the operation of machines, equipment and tools, staff conversation and transportation (Christensen, 2004). Research findings related to noise and health are presented below.

- Noise disturbance produced by the operation of the facility can negatively affect patients' recovery (Bayo *et al.*, 1995);
- Noise produced by the operation of the facility was associated with sleep disturbance (Richards and Bairnsfather, 1988; Haddock, 1994; Topf *et al.,* 1996; Ersser *et al.,* 1999);
- Noise produced by the operation of the facility was associated with stress (Topf, 2000);
- Noise levels above the international recommendations were found in operating theatres. The measured noise levels exceed the thresholds to produce noise-induced cardiovascular and endocrine effects (Liu and Tan, 2000);
- Psycho-physiological effects (such as decreased wound healing, sleep deprivation and cardiovascular stimulation) due to excessive noise exposure was investigated by Christensen (2004);
- Noise produced by the operation of the facility was associated with patients' bad experience of healthcare service (Douglas and Douglas, 2005).

Art

Art and mental health have been investigated from a myriad of perspectives. These include the use of music with particular attention paid to different types of instruments; the use of live, video or recorded performances; drawings and paintings, and; traditional and contemporary art (Staricoff 2004). The existing literature also distinguishes between art therapy (i.e., the effect of actively getting involved in the development of art work) and the passive exposure to art in specific environments within healthcare settings (Daykin and Byrne 2006). These authors argue that few controlled and randomised studies of the therapeutic effects of art in mental health have been carried out. Literature reviews specifically looking at art and mental health include ones by Staricoff *et al.* (2003), Staricoff (2004) and Daykin and Byrne (2006). Other literature reviews, such as Devlin and Arneill (2003) and Ulrich *et al.* (2004) also consider the impacts of art on health; however, these reviews are focused on the impact of the physical environment (rather than the built environment) on health. Art and health related investigations are presented in the following.

- A study conducted by Ulrich (1991) revealed that inappropriate visual art styles are related to the disturbance of mental health conditions;
- Mornhinweg (1992) found significant reduction of stress levels by using patients' pre-selected music in the background;
- McGarry (1998) and Korlin *et al.* (2000) argue that creative arts programmes induce significant improvements in the communication of psychiatric patients;
- Gerdner (2000) showed that classical music impacts positively in the reduction of levels of agitation of patients with Alzheimer's disease;
- According to Philipp (2002), the arts can help mitigate mental health conditions, such as depression, anxiety and low self-esteem. For Philipp art also supports the improvement of social integration and isolation. There is a diverse range of art activities that are incorporated into the study of art and mental health care;
- Research results presented in literature reviews, such as Staricoff (2004) and Daykin and Byrne (2006), suggest that the arts can have a therapeutic effect on people suffering with mental disorders. However, Staricoff (2004) draws attention to the fact that the introduction of creative arts, such as dance, drama, music, visual arts and creative writing in mental health can also bring with them potential risk factors. These are associated with the psychological effects of being engaged in these activities, which could become too demanding for the patient (Staricoff, 2004).

Colour

There are different assumptions about how colour affects humans (Dalke *et al.*, 2006). For instance, there is anecdotal evidence speculating that red, orange and yellow in shiny and polished surfaces stimulate appetite and anxiety (this would explain why these colours are very often used by fast-food chains). Grey, purple and red have been associated with depression and are excluded from the palette of colours of designers designing hospices and psychiatric hospitals. Examples of studies about colour and health are presented below.

- Respiration: the study about the effects of red, yellow, green and blue concluded that there is no significant effect of these colours on respiration rates (Jacob and Hustmyer, 1974);
- Heart rate: the study about the effects of red, yellow, green and blue concluded that there is no significant effect of these colours on heart rates (Jacob and Hustmyer, 1974);
- Anxiety: the study about the effects of red, yellow, green and blue (in non-healthcare environment) concluded that red and yellow can be associated with high levels of anxiety levels and that blue and green can be associated with low levels of anxiety (Jacob and Suess, 1975);
- Etnier and Hardy (1997) studied colour influence on performance of mentally and physically demanding tasks;
- Kaya and Crosby (2004) investigated individuals' colour associations with different building types;
- The effects of colour in hospital design are discussed in Dalke *et al.* (2006);
- The effects of colour on stress and arousal levels in healthcare environments (Dijkstra *et al.*, 2008).

Layout

Setting layout is another aspect affecting the way humans behave (Zimring *et al.*, 2005), specifically the way patients and staff react to the environment (e.g. Leather *et al.*, 2003a). There are several aspects associated with the layout of the facility or the setting under investigation (NHS Estates, 1999). Privacy seems to be one of the most investigated outcomes, which has been mainly associated with occupancy. There are a variety of studies stating that single occupancy bedrooms increases privacy and, therefore, it is better for patients and staff because it reduces noise levels and consequently improves sleep rates and reduces stress, and reduce the risk on infections. Studies looking at these issues are presented bellow.

- Evans and McCoy (1998) and Altimier, (2004) associate occupancy and privacy with the development of the social environment, which is relevant to patients recovery;
- Passini *et al.*, (2000) explore layout and wayfinding in a nursing home for advanced dementia of the Alzheimer's type;
- Grosenick and Hatmaker (2000) associate privacy as one important building characteristic to be considered in the treatment of substance use treatment;
- Baskaya *et al.*, (2004) discuss the aspects of layout related to wayfinding;
- Improved healthcare experience associated with privacy and occupancy is presented by Douglas and Douglas, (2004, 2005);
- Chaudhury *et al.* (2005) present a review of the advantages and disadvantages of adopting single and multiple occupancy bedrooms.

Gardens and other green spaces

Finally, positive health outcomes are perceived as related to the exposure or having access to gardens and other green spaces. Some of the outcomes include the reduction of stress and levels of anxiety, increased social interaction, and an improved healthcare experience. Researchers looking at this issue include Ulrich, (1981, 1984, 1992, 2004, 2008); Marcus and Barnes (1999), Kaplan (2001), Whitehouse *et al.* (2001); Milligan *et al.* (2004), and Marcus (2005).

5.2.6 Summary and Final Considerations

The objectives of this section were to investigate the underpinning process of EBD and to better understand and characterise evidence that indicates a relationship between the built environment and health. In relation to the former, a literature review was carried out to investigate EBD. In regard to the latter, a systematic review was conducted. In addition to the systematic review, a literature review was carried out to investigate existing theories that explain the relationship between the built environment and health. The interpretation of the results had a focus on the different types of measures of health and well-being, on the characterisation of patients and of the built environment. Key issues that have been identified are presented in the following:

In relation to EBD, very little exists in the literature that explains how evidence supports decision-making. In this respect, whilst the gathering of evidence via systematic review is well explained, the use of the evidence gathered in relation to the design process is not. In addition, Mulrow *et al.* (1997a) recommends the elaboration of evidence-based models for complex cause-effect relationships in medical research. The same approach was not found in the literature related to EBD. Finally, the focus of EBD seems to have shifted from the use of evidence to support decision-making at early stages of design to the generation of evidence whilst designing.

Referring to theories explaining the relationship between the built environment and health, no consensus exists amongst candidate theories. The commonality between the investigated theories is in the fact that humans are in contact with the environment through their senses. Sensorial experience triggers physical and cognitive reactions. In relation to health and well-being, cognitive processes started via external stimuli can also trigger physical reactions. Despite alternative explanations existing, the mechanisms that explain this process are currently unknown.

Regarding measures of health, the model devised by Wilson and Cleary (1995) predicts five main categories: biological and physical, symptoms status, functional status, general health perceptions and overall quality of life. A sixth category, non-medical reasons, is indicated but not discussed in depth by Wilson and Cleary (1995). The review carried out in this research indicates that this category is formed by general hospital managerial measures. As argued by Wilson and Cleary (1995), none of the categories are independent.

In respect to patients' characterisation, there are four main categories (as proposed by Ferrans *et al*., 2005). These include demographic, developmental stage, psychological and biological factors. In addition to these, three contextual categories were identified as also being relevant: condition, treatment and disease or injury. With concern to the evidence found, in general, the description of individual or group characteristics are relatively poor.

In relation to the built environment, a framework was proposed that considers the type of healthcare facility, the specialist unit and the setting within them. For each setting a series of components, functions and subsystems complement the setting. Each of them, including the setting, will have a series of characteristics. In this respect, a fourth category was identified in addition to the three categories suggested by Cooper *et al*. (2008). This refers to the consideration of the sociological impact of the environment upon health and well-being. The sociological impact of the environment is the social significance of buildings and their environments in relation to symbolic values and meanings, for example grouping (e.g. young/old, political/religious, staff/patient, male/female, unisex space/single sex space, public, private and communal spaces for socialising, care, work, leisure, reflection) amongst others.

Moreover, in relation to the data gathered, it is contended that in general the impact of the built environment on health outcomes seems indirect rather than direct. In other words, the role of the built environment is to provide stable environmental and physical conditions so as to avoid disturbance amongst patients (i.e. the environment must have appropriate levels of noise, temperature, humidity, light, etc. and promote adequate levels of social interaction as well as spaces where to rest). In relation to this aspect, building operational aspects and the delivery of appropriate maintenance of the built environment have an important role.

Furthermore, more clarity is also needed in the literature in terms of the relevance of research findings (i.e. measured health outcomes) to the improvement of the patient or patient groups being investigated. In this respect, although positive and negative impacts are reported, the relevance of the improvement and decay are, in general, not explicit. Thus, the support to decision-making inherent to the evidence-based approach cannot be obtained.

Finally, perceived difficulties related to integrating research results and lack of clarity in this research field include: a) the multidisciplinary characteristic of the subject and the lack of a shared theoretical view explaining the phenomenon; b) the use of different terminologies amongst different areas of knowledge to refer to the same concept; c) the use of similar terminology amongst different areas of knowledge to refer to different concepts.

5.3 External Evidence from Project Investigation

It is important to highlight that the project where the design process was observed did not followed an EBD approach in the sense described above. Still, it was considered that its organisation revealed aspects that are relevant to this research. These aspects are discussed in the following.

In relation to the organisation of the project and the dissemination and discussion of design information, meetings were held between design team representatives and client's stakeholders group. These meetings were organised as 'consultancy' sessions with specialist groups including **investors** (i.e. the project management team), **client user groups** (i.e. clinical staff such as nurses and doctors and non-clinical staff such as from estates and facilities management; end-user groups such as patient groups; communities groups such as local residents and neighbour); **consultant groups** (e.g. regulatory bodies, planning, legal and costing) and **design and construction specialist team**.

In principle, the way the development of design was organised reveals that a considerable emphasis on the validation and verification of the design solution as the design evolved. However, the validation and verification process when related to involving the above-mentioned specialists groups was not based on internal evidence as depicted in the 'Vee' model. Instead, the types of external evidence present in testimony (inductive reasoning) was used for validation and verification and with no exclusions, only reasoning through enthymeme was identified.

From the classification suggested by Rieke and Sillars (1984) anecdotal, statiscal, causal and expert evidence were observed to support argumentation within the design meetings. In this respect, examples of anecdotal evidence can be seen the use of "Oxford hospital design as a model" as discussed in meeting 1, and in "open plan – somewhere – satisfaction levels are low – they hate it" in meeting 5. In both cases analogy is the approach used. Examples of statistical evidence can be seen in all meetings, for instance 'typical morning is 70 to 80 patients' in meeting one and '9m2 for 1 person and 12m2 for 2' in meeting 2. An examples of causal evidence can be seen in meeting 2 - 'segregate PET (Positron Emission Topography) patients from others as radiation is much stronger' and in meeting 11 – 'quiet room is necessary to talk to patients and family about confidential issues'. Finally, expert evidence is seen in all meetings, for instance, 'one patient does not visit once because there are multiple process' as identified in meeting 1. In all cases, expertise is linked to experience (familiarity) of the specialist person or group with the operation of the facility and the delivery of the healthcare service. In no occasion, scientific evidence from an external source was mentioned or used within the observed meetings.

5.4 Discussion – External Evidence in Design

Following the discussion presented in Section 4.3, here a discussion about external evidence within the design process and its role within a knowledge formation system is presented. To support the discussion the conceptual framework for evidence within design (Figure 20) is revisited.

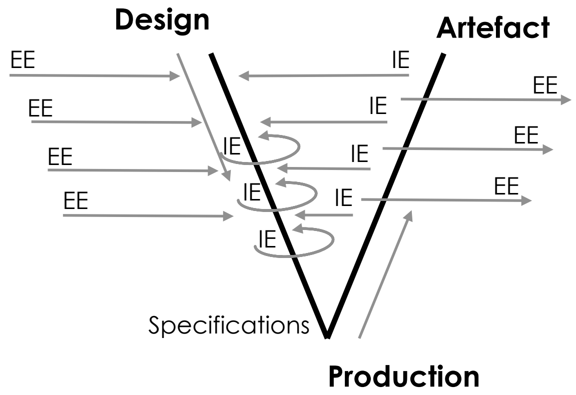

Figure 20 - Evidence in Design: Conceptual framework

As presented in Section 4.3 evidence was classified as being internal and external. Internal evidence was defined as referring to knowledge of the design solution being developed whereas external evidence was defined as knowledge related to the design being developed but not being knowledge of the design solution as such. In this respect, Section 5 was focused on further exploring the role of external evidence in design by reviewing the literature about the EBD approach as applied to healthcare facilities design, by investigating the relationship between the built environment and health outcomes as an input to EBD and by inferring from data and observations the use of external evidence within a healthcare project. The interpretation of results are presented in the following.

5.4.1 EBD as External Evidence

Generally speaking, the concept of an evidence-based design process relies on the principle of induction. In this respect, the principle of induction is not stated, presented or made clear within existing guidance to EBD. The same issue is present in research about the impact of the built environment to health outcomes. Evidence-based design has been consistently based on the use of scientific empirical evidence.

As argued by Popper (1968) empirical sciences can be characterised by the use of inductive methods and therefore truth is established by the use of the logic of induction. In this respect, a few principles apply to this logic:

- The verification of general laws through the exhibition of causal relations merging from data (as discussed by Johnson and Duberley 2004);
- The establishment of the principle of induction as an explanation of the logic expressing the cause-effect relationship (as discussed by Russell, 1948; and Popper 1968);
- Alternatively, as stated by Popper (1968), rather than trying to prove a theory through empirical observation the researcher should also considerer the possibility of falsifying it.

In this respect, the guidance available for the adoption of an EBD approach, as well as the research about the built environment and the impacts on health outcomes seems not to address such issues. In relation to the former, that demonstrates that the principle that links the external evidence to the design been proposed is not present in current descriptions of the approach. In relation to the latter, that only demonstrates that existing research was not developed for being used in an EBD process.

In relation to the research about the built environment and health outcomes, the list of scientific studies presented in this report were organised according to the characteristics (e.g. lightning, temperature, humidity) identified in Section 5.2.4. It was considered that all settings within a healthcare environment are composed of these characteristics. In this sense, it is understood that each setting (e.g. operation theatres, intensive care unit and pre-born unit) operates following specific, controlled and normative physical performance parameters that are dependent of the function that the setting is designed for. Therefore, generalisation of research findings within and across settings is limited. The same principle applies in relation to different patients' configuration (e.g. age, gender, condition), it was considered that each possible combination of characteristics constitutes a case for evidence. Therefore, each patient might have a different need and general patterns of behaviour may not apply. Therefore, generalisation of predicted outcomes within and across patient groups is limited. Finally, research in the field fail to demonstrate how positive or negative health outcomes were a result of a specific (or group of) characteristic(s) of the built environment isolated from the effectiveness or failure of the treatment and/or intervention that patients were submitted to. Therefore, generalisation is not possible.

In reference to the design of healthcare facilities, it has been discussed that the design problem is, in general, multifaceted. Whilst it seems logical, coherent and appropriate to design an environment that supports healing, there are certain conflicting situations where trade-offs may benefit as less healing environment in favour or better operational solution. For example, the trade-off between higher ventilation leading to lower temperature and better capability of washing bacteria and reduced ventilation and washing capability but adequate temperature for doctors to perform an operation (Chow and Yang, 2003). In this regard, it is common sense rather than evidence that supports decision-making.

In this respect, Evans (2010) argues that evidence from research is considerably analytical. Indeed, it emerges from the data collected that research studies related to the impact of the built environment on health are focused on the impact that a specific characteristic of the environment in isolation has on a specific measure of health as observed in a specific cohort or patients (the cohort investigated). As discussed in section 5.2 the number of variables and consequently the number of combinations of environment, health outcome and patient profile is considerably high to be empirically tested. Thus, evidence found in these studies can only be potential evidence of one phenomenon and as such does not address the multifaceted characteristic of the design problem.

5.4.2 Experience as External Evidence

Koskela et al. (n.d.) argue that designers have to choose a path to follow when searching for a design solution. This process of assuming a direction is usually based on evidence of some sort indicating the right direction to follow.

The first is the experience of the designer is solving the problem and that is well discussed in the literature (e.g. Polya, 2004 and Cross, 2004). The second refers to the experience of the client. As highlighted in Section 4.2.11 it was observed in the design meetings that the experience of the client is used to validate the design solution being developed at earlier stages of design. Here, experience is placed under testimony as a source of knowledge and despite the issues related to its reliability this type of knowledge seems crucial to deal with contextual design problems. As such, testimony can be classified as potential evidence. In addition, the fact that this knowledge is not generated only in the designers mind corroborates that design intelligence is distributed amongst digital tools/systems, people, and organizations in a social context as discussed by Kocaturk and Codinhoto (2009)[60].

5.4.3 External Evidence and JTB

Finally, in regard to justification, truth and belief, the types of external evidence (whether anecdotal, potential or veridical) seem to play different roles within design (Figure 21). These findings contradicts that veridical evidence is at all instances more relevant than potential and anecdotal evidence. This constitutes another major contribution of this thesis, as such interpretation has not been proposed before. In the following a discussion is presented that explains these findings.

- In relation to justification, anecdotal evidence within design seems considerably more relevant than potential or veridical evidence. The observation of design meetings revealed that the socio-technical aspects of the design problem are validated via the approval (validation) of its users. That means that veridical or potential evidence generated elsewhere can be disregarded if contextual issues contradicts their use for justification. For instance a design proposition that

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[60] Distributed Intelligence is defined as the cross-disciplinary network of design intelligence that is distributed across various design media, people, modules of knowledge and the various representations of the design artefact (Kocaturk and Codinhoto, 2009).

complies with design rules that makes the solution unaffordable. The compromise will be on compliancy rules, since or the non-execution of the project. Another example is the case of trade-offs where common sense rather then evidence is used for decision. Also important is the analytical characteristic of evidence. In this respect, healthcare environments are designed for different types of patients; therefore any decision cannot be made with a basis on one particular truth. In this context, potential or veridical evidence have limited relevance, as they do not address the specific multi-dimension contextual situation in which the design problem is embedded.

- In relation to truth, there is a relationship between evidence strength and truth (as discussed in Section 3). As concerns to the existence of different levels of evidence strength, the research findings shows that anecdotal evidence acquired through testimony has lowest level of strength and that veridical evidence used in evidence-based medicine (for instance) has the highest. Evidence in medicine was considered the highest due to the fact that at least two pieces of clinical trial (within relatively highly controlled environment) with similar characteristics demonstrating the same results are necessary to be considered as evidence. In relation to the built environment, the same rigour seems impossible to achieve due to the number of variables and relationships as presented in Section 5.2.4. Therefore, the studies included in this research were classified as having a general standard of evidence i.e. which considers only one unique case. Anecdotal evidence has the lowest level of strength, as its acquisition does not rely on systematic and reliable methods.
- As concerns to belief, veridical evidence seems to subside the relevance of anecdotal evidence and potential evidence. In the case where veridical evidence is not available, anecdotal evidence seems to establish confidence in belief. In this respect, it seems that anecdotal evidence from experience generates higher confidence than potential evidence. Also, it seems there is a relationship between relevance and confidence. In other words, anecdotal evidence can provide higher levels of confidence than veridical evidence. In the observations, for instance, clients with many years of experience would question the accuracy of certain design rules with a basis on their own perception constructed through years working in the healthcare environment. However, this idea was not tested in this thesis.

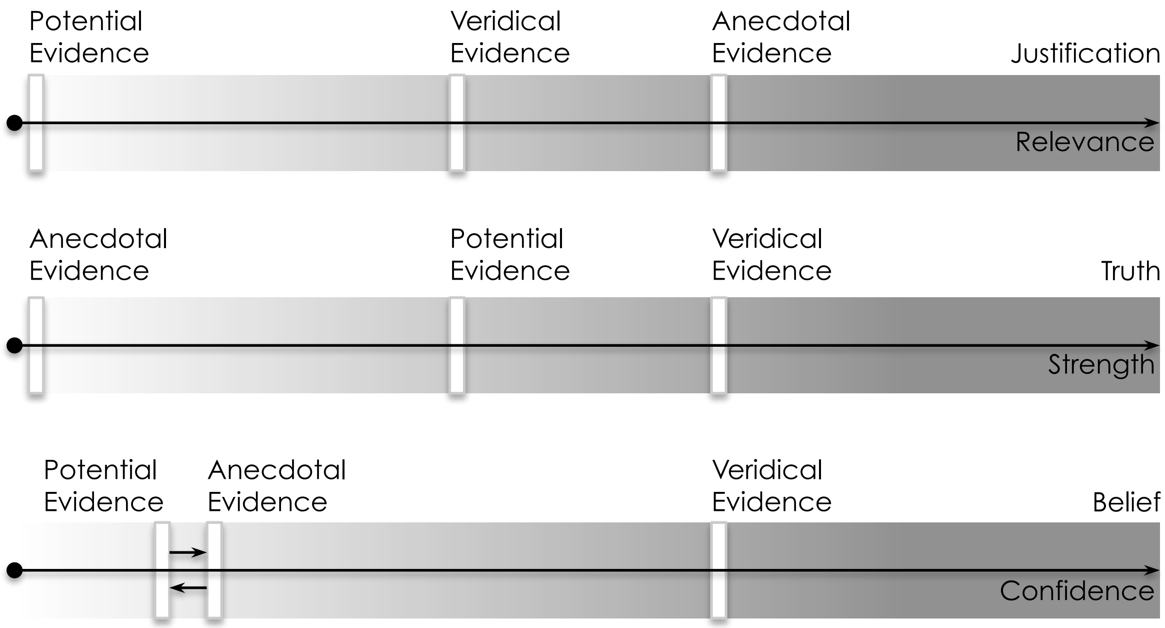

Figure 21 – Evidence, justification, truth and belief

6 SUMMARY AND CONCLUSIONS

The research problem that led to the development of this research relates to investigating alternative ways to improve design and overcome the current challenges that designers face such as increased complexity of artefacts, more demanding clients and above all less room for mistakes. The alternative investigated in this research related to the incorporation of scientific evidence as an input to design. In this respect, despite the fact that knowledge about what evidence is and the roles it plays in a knowledge formation system is available, the application of this knowledge to support the interpretation of the role of evidence within the design field has not been attempted.

In this respect, the present study was designed to address this issue and aimed at better understand how evidence supports design. The achievement of the aim was based on: (a) revisiting the philosophical debate about the definitions of evidence and knowledge formation to propose a conceptual framework that can be used to classify evidence within the design domain; (b) investigating the proposed use of evidence within prescriptive design methods of design; (c) understanding how evidence has been used in design practice (specifically in the design of healthcare facilities) and to propose a taxonomy for different categories of evidence that support building design and their advantages and disadvantages; and (d) exploring the existence of opportunities to improve design practice with a basis on a better understanding of evidence. The focus of the research was the design process of healthcare facilities and the unit of analysis was the role of evidence within design.

The research method proposed for this study was framed within the method of analysis and synthesis. In this respect, the analytical route was adopted and the research work was devised in three phases. Phase 1 referred to the philosophical investigation about evidence and knowledge. Phase 2 referred to the investigation of the cognitive design processes followed by its interpretation with the conceptual framework generated in Phase 1. To this end, only prescriptive design models were selected for interpretation. At the end of this section, a discussion is conducted that explains design as a knowledge generation system. Finally, in Phase 3, empirical evidence was collected and re-interpreted in relation to its role within design and classified as part of a knowledge system. A mixed approach was used for data collection that included a systematic literature review, the compilation of information from a healthcare building design project through observation of design meetings for the development of a healthcare facility and the use of design information related to the project. The contributions to knowledge generated from the research and the research process are presented in the following.

In relation to research methodology, the method of analysis and synthesis was used for the first time in design related research. In this respect, the method had to be revisited from sources outside the design domain and abstracted so to be transferrable into design research. As prescribed in the method, the research process starts with the gathering of available information about the studied problem. The focus of information gathering is placed upon identifying what the investigated system accomplishes, its parts and the relationships amongst parts. This compilation of information should lead to the establishment of a hypothesis through intuition. In this thesis this process led to consider design as a knowledge generation system, i.e. if design is seeing as a system its function is to generate knowledge. Reflectively and retrospectively, the intuitive mechanisms used to generate the hypothesis is not clear to the author indicating that experience of the process does not lead to the understanding of it. The steps following from the hypothesis definition are the identification of the necessary parts and the relationships amongst parts. In this respect, starting from what the system accomplishes indeed avoids the risks inherent to the synthetic route such as the inappropriate use of analogy to explain how the system achieves its end as indicated by Riemann (1866, as cited in Ritchey, 1991).

Another contribution to methodological aspects is related to the use of systematic literature review. The initial idea and process for conducting a systematic review was drawn from its application in EBM. In this respect, whilst in EBM the focus of the review is convergent (i.e. it emphasizes specific patient profile, disease and treatments routes) in EBD, or at least in the way it has been applied in this thesis, it has a divergent focus. Thus, from the experience generated from the application of SLR, it can be argued that there are issues that are not mentioned in the literature about SLR that makes this approach inadequate for divergent research about the built environment and health outcomes.

The first issue relates to the lack of clarity regarding cause and effect relationships between the built environment and health outcomes. In medical research experiments can be controlled to a larger extent in comparison to research about the built environment and health. In this respect, it is considered that the lack of a unifying cause and effect principle generates uncertainty regarding the exact element or characteristic of the built environment that triggers a health effect. In addition, the number of variables and combinations that can influence health outcomes is extremely large making impossible the replication of tests.

The second issue is related to variety of health outcomes that can be measured. As concerns to the measurement of health outcomes a considerably large number of measures and techniques for measurement exist. In this respect, access to different ways for measuring the same health outcomes was considered a favourable aspect as it supports the argument for stronger evidence. However, the range of measures is very large and extremely complex and its combination with the different ways for measurement and the different contextual situations that can trigger the health effect makes the field too vast to be researched through SLR.

Finally, the last issue related to the application of SLT to the field of built environment and health outcomes relates to the depth (or lack of it) of the descriptions provided in scientific literature that investigates this phenomenon. In this respect, many (if not all) descriptions of investigations related to the built environment and health outcomes fail to provide an accurate description of the variable that formed the investigated scenario. As already discussed, the difficulty is related to the large number of variables present in each study and that problem is exacerbated by the fact that written descriptions (in many circumstances) can be a limited vehicle for the description of the built environment.

In relation to the characterisation and role of evidence (objective 1), the contribution of this thesis is related to the clarification that that evidence is a type of knowledge that is used to sustain belief, to support justification and to establish truth. The concepts of justification, truth and belief are interdependent and form the tripartite model of knowledge. This concept is not faultless, as it does not provide a solution for Gettier's problem of knowledge and it does not escape the sceptic trilemma of Agrippa. This issue is well known and classifies as fallibilist all knowledge that is generated outside rationalist schools of though. Thus, knowledge has a volatile, latent and dynamic characteristic that impedes us from having certainty of anything. Considering that evidence is (a type) knowledge, thus, all that applies to knowledge also applies to evidence, hence bringing together these two areas that have been treated separately.

In regards to the types of evidence (whether scientific or anecdotal), the literature demonstrate consensus in relation to its classification as potential, veridical and anecdotal evidence. Consensus also exists in relation to the criteria for stronger evidence that excludes higher probability as a favourable criterion. In this respect, the main role of evidence is to sustain justification and belief, even though its fallibilist quality imposes uncertainty in relation to reaching universal truths. Thus, with regards to evidence in design, the interpretation of the design process as a knowledge generation mechanism indicated that the three types of evidence (potential, veridical and anecdotal) are used in design and an additional classification of internal and external evidence was proposed Figure 22.

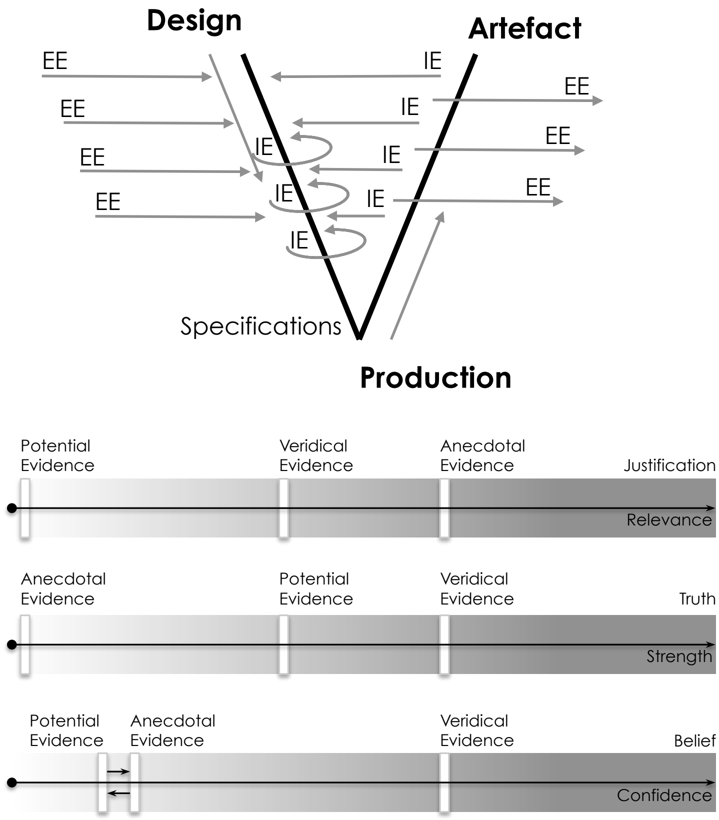

Figure 22 – Internal and external evidence in design

Here, we highlight the two major contributions of this work. The first refers to identification of two types of evidence (internal and external) that are used within systematic method of design (objective 2). The second refers to a better understanding of external evidence within the design of healthcare facilities (objective 3). In relation to internal evidence, potential, veridical and anecdotal evidence are constantly sought so to support the development of the design proposal. This fact explains and justifies the existence of myriad design methods and tools. The potential and veridical evidence generated internally within the design process provides assurance that the artefact being developed does accomplish its designated tasks. On the other hand, anecdotal evidence generated through validation in earlier stages of design increases the assurance that the artefact being developed is the right one. In this respect, the order of importance in relation to justification, truth and believe follows the traditional proposition, i.e. veridical evidence is more important than potential and anecdotal evidence. The relationship between veridical, potential and anecdotal evidence with justification, truth and belief seems to be explained by the relevance, strength and confidence levels in the evidence provided. This proposition requires further investigation.

In relation to external evidence in design, potential and anecdotal types of evidence were identified as having different roles in contrast with the ones identified in internal evidence. In relation to anecdotal evidence, it was observed that testimony is extremely important in the development of design. Testimony in relation to designers' experience of solving design problems is well documented, however, in relation to clients' experience not so much. The validation process at earlier stages of design is perceived as extremely beneficial not just in relation to the identification of the problem but also in relation to finding the solution to the problem. Here, in certain circumstances the client becomes the designer and the designer becomes the vehicle for generating the demonstrative presentation, thus explaining distributed intelligence in design. In regards to potential evidence, as suggested in the EBD approach, design can never be based on external evidence but merely informed by it. This happens because the contextual condition inherent and unique to each design problem can never be replicated due to the amount of variables involved in designing a space.

In relation the study about the built environment and its impact on health outcomes, four secondary contributions were made. The first is related to the development of an open framework/taxonomy for the classification of built environment features and characteristics and an overall map for the organisation of scientific data (objective 3). In this respect, the framework originally proposed by Wilson and Clearly (1995) was expanded in regards to the aspects of the built environment that have an impact on health (Figure 19). It considers the different dimensions in which a healthcare building can organised from the macro level (e.g. type of hospital) to the micro level (e.g. the specific characteristic of elements and components such as colour, dimension, texture, etc.). This framework makes explicit the analytic characteristic of evidence in this field. It is important to highlight that such framework did not exist in a format to accommodate data related to the field of investigation and also important is the fact that the map generated can be used to indicate the similar areas where research has been carried out as well as the gaps in knowledge.

The second contribution comes from the expansion of understanding regarding non-medical measures of health outcomes. This category of health outcome is present in current literature despite the lack of explanation for what it accounts. Here, we discussed this category as embedding managerial measures of hospital performance (e.g. healing time, mortality rates, number of readmissions). In regards to health outcomes, positive, negative and neutral results can be found. This is a very important issue to be considered because any intervention based on evidence should also look for side effects. The same can be said in relation to other issues that may impact in decision. In this respect, improved health is a desirable outcome, however there are certain situations (such as the trade-off between better washing of bacteria and adequate room temperature for the physician to operate) where common sense and context influence the decision.

The third contribution relates the identification of a fifth category for the classification of patients. This relates to contextual data related to (a) condition of the individual in relation to the intervention to promote health, (b) type of treatment as related to physical intervention, the use of drugs and psychological or psychotherapeutic procedure, and (c) the diagnosed disease or injury that led the patient to seek support from a healthcare facility. In this respect, data analysed shows that the condition of the patient at the point of data collection (generation of evidence) does influence the results. In other words, a patient in a pre-operation condition will react differently from one in a post-operation condition. That indicates that the needs for these different groups are dissimilar and must be considered as an input to the design process.

Finally, an additional contribution refers to the consideration of the sociological impact of the environment upon health and well-being. The sociological impact of the environment relates to the social significance of buildings and their environments in relation to symbolic values and meanings attributed by its users. This dimension was not captured within the framework proposed in Figure 19 as it refers to a different organisation of space that is not linked to physical structuring of healthcare buildings.

Also of great importance, is the contribution made to the understanding about the design process, the first problem identified was the lack of consensus amongst prescriptive models developed in the last 70 years. To deal with this issue, a hypothesis was raised that the method of analysis and synthesis used by ancient Greek geometers is the proto-theory of design. Detailed investigation confirmed that indeed, the features of the method of analysis and synthesis are present in relevant prescriptive methods of design. Therefore the problem is not related to the lack of consensus but rather associated with the way the ideas have been transmitted. In this respect, considerable progress has been achieved by clarifying the features of the method of analysis and synthesis as a proto-theory of design. Also in clarifying, how contemporary candidate theories relate to the ancient method.

6.1 Significance and Relevance to Research and Practice

The findings of this research enhance our understanding of design as a knowledge formation system that is sustained by the use of evidence, in relation to the design process as related to the method of analysis and synthesis, in relation to the practice of evidence-based design and to the specific field of healthcare facilities and its impacts on health and well-being. The perceived relevance of the presented findings for research and practice relates to objective 4 and are discussed in the following.

In relation to our understanding of design as a knowledge formation system that is sustained by the use of evidence, it is considered that the use of this approach (i.e. interpreting the design process as a knowledge formation system) opens opportunities for future studies related to the interpretation and the development of tools that assist design by generating stronger evidence, as well as provides insights related to distributed intelligence in design. The research carried out here indicates that the underpinning idea behind design tools is the generation of internal evidence. This fact, indicates that there is scope for the development of systematic methods for areas of design unassisted by such tools.

As concerns to the method of analysis and synthesis as the proto-theory of design, it is considered that the issue of consensual agreement and the clarification related to prescriptive methods of design has moved a step forward. The immediate application of this knowledge can be sought through the revision of methods used for teaching problem solving in design. In this respect, at present design students learn design by designing (and planners by planning) and the guidance related to the problem-solving mechanism used by them while design is left adrift. The use of systematic approaches for design has been tested by Lawson (2006). These tests revealed positive results for those using systematic methods in comparison with those designing randomly. The method of analysis is considered here as a more robust method, thus it is expected that a more robust method should provide better results. This hypothesis needs to be tested.

In relation to the Evidence-Based Design approach, practice should be informed about the limitations of this approach. Perhaps, practice has already accounted for this fact and that would explain the shift of focus from using external evidence in design to generating internal evidence that is present in contemporary literature. The term evidence-based design as an analogy to evidence-based medicine should be banned and replaced by the term evidence-informed design. This change should reflect the limited role that external scientific evidence has upon the design process of healthcare facilities.

Finally, in relation to research related to the built environment and health outcomes, more robust methods should be used to compile evidence from a field that involves so many variables. Here, a suggestion is made based on the use of IT to support data stratification and the generation of evidence models suitable for design practice. In this respect, Appendix 7 presents a validate suggestion for how this issue can be tackled.

6.2 Limitations of the Research

A number of important limitations need to be considered.

The first limitation is related to the features of the method of analysis as synthesis as the proto-theory of design. The literature about the method of analysis and synthesis is scarce and sometimes conflicting. Thus, the extent that all features of the method are presented and are clearly explained is dependent on the positioning of the author in relation to the candidate interpretations of the method.

The second limitation refers to the number of descriptive models used to demonstrate that the features of the method of analysis and synthesis are present in current models of the design process. In this respect, a considerably high number of models exist from many fields of design. The restriction of this investigation to 9 prescriptive models was related to time constraints for the development of this thesis. In this respect, further investigations are necessary.

A final limitation of this research relates to the number of observations in design meetings that were restricted to a specific phase of design development. In this respect, observation within other phases of design must be carried out.

6.3 Recommendations for Further Research

It is recommended that further research be undertaken in the following areas:

- The research on the relevance of theories indicates that theories are useful to support teaching. In this respect, the introduction of the method of analysis as a proto-theory of design needs to be tested amongst students learning design. In this respect, the method itself needs to be better understood or developed into a methodological approach for teaching and the results compared in a experimental type of research.
- The literature review about the method of analysis and synthesis indicates that there is confusing regarding the use of inductive and deductive reasoning. In this respect, the term deductive seems to be related to analysis whereas inductive is related to synthesis. Thus, an investigation comparing the characteristics of inductive and deductive processes in comparison with analysis and synthesis is required.
- The role of evidence in decision-making process: This study has provided a better understanding of the meaning of evidence and its roles in designing. The research was based on the interpretation of the researcher upon participating in design meetings. Whilst this research approach provides insights, research using more robust methods is required to validate results.
- Distributed intelligence: users' experience as relevant evidence in design. This study also indicates that contextualised anecdotal evidence can overcome out-of-context veridical evidence during design. That indicates that veridical evidence can be convergent and have an element of bias towards technical aspects as opposed to socio-technical systems. Also that anecdotal evidence can be divergent and encompass multi-dimensional perceptions necessary to

explain the socio-technical aspects that are not considered within veridical evidence. These issues need further clarification.

- The use of external evidence in the design of artefacts that are different from healthcare facilities. It was indicated earlier that a limitation of this research did not cover other fields of design. Thus, other fields must be explored so to that results presented here can be generalised to other fields;

7 REFERENCES

Achinstein, P. (1978). Concepts of evidence. Mind, 87(1), 22-45.

Achinstein, P. (1994). Stronger evidence. Philosophy of Science, 61(3), 329-350.

Achinstein, P. (2010). Evidence, Explanation, and Realism: Essays in Philosophy of Science. Oxford University Press, USA.

Ackerman, B., Sherwonit, E., & Williams, J. (1989). Reduced incidental light exposure: effect on the development of retinopathy of prematurity in low birth weight infants. Pediatrics, 83(6), 958-962.

Alexander, C. (1964). Notes on the Synthesis of Form (Vol. 5). Harvard University Press.

Altimier, L. B. (2004). Healing environments: for patients and providers. Newborn and Infant Nursing Reviews, 4(2), 89-92.

Altman, I. (1993). Dialectics, physical environments, and personal relationships. Communications Monographs, 60(1), 26-34.

Altshuller, G. S. (1988) Creativity as an Exact Science: The Theory of Inventive Problem Solving. Gordon and Breach, New York.

Anderson, C. A. (1989). Temperature and aggression: ubiquitous effects of heat on occurrence of human violence. Psychological bulletin, 106(1), 74.

Anderson, J. D., Bonner, M., Scheifele, D. W., & Schneider, B. C. (1985). Lack of nosocomial spread of Varicella in a pediatric hospital with negative pressure ventilated patient rooms. Infect Control, 6(3), 120-1.

Ann Noble Architects (2003). Reduction of Hospital Acquired Infections by Design. N. E. Research, NHS Estates: 40.

Archer, L. B. (1984). Systematic method for designers. In: Cross, N (ed) Developments in Design Methodology. Chichester, Wiley.

Aristotle (2000) Nicomachean ethics. In: Ross, W.D. (transl.) Nicomachean ethics. Book I. Raleigh NC: Boulder, Colo: Alex Catalogue, NetLibrary

Asimow, M. (1962) Introduction to Design: Fundamentals of Engineering Design. Prentice-Hall.

Austin, S., Baldwin, A., & Newton, A. (1994). Manipulating the flow of design information to improve the programming of building design. Construction management and economics, 12(5), 445-455.

Austin, S., Baldwin, A., Li, B., & Waskett, P. (1999). Analytical design planning technique: a model of the detailed building design process. Design studies, 20(3), 279-296.

Austin, S., Baldwin, A., Li, B., & Waskett, P. (2000). Analytical design planning technique (ADePT): a dependency structure matrix tool to schedule the building design process. Construction Management & Economics, 18(2), 173-182.

Austin, S., Steele, J., Macmillan, S., Kirby, P., & Spence, R. (2001). Mapping the conceptual design activity of interdisciplinary teams. Design Studies, 22(3), 211-232.

Bacharach, S. B. (1989). Organizational theories: Some criteria for evaluation. Academy of Management Review, 14(4): 496-515.

Baehr, J. S. (2006). A priori and a posteriori. Internet Encyclopedia of Philosophy. Available at: http://www.iep.utm.edu/apriori/. Last accessed: 20th July 2012.

Ballard, G. (2000) Managing work flow on design projects. In: Proceedings of the International Conference on Design Management in the Architectural and Engineering Office, CIB W096, Atlanta, USA.

Ballard, H. G. (2000). The last planner system of production control (Doctoral dissertation, the University of Birmingham).

Baptese, E. and Brochier, C. (2004). On the conceptual difficulties in rooting the tree of life. Trends in Microbilioly, 12 (1), 9-13.

Barker, R. G. (1969). Ecological Psychology: Concepts and Methods of Studying the Environment of Human Behavior. Stanford University Press.

Baskaya, A., Wilson, C., & Özcan, Y. Z. (2004). Wayfinding in an Unfamiliar Environment Different Spatial Settings of Two Polyclinics. Environment and Behavior, 36(6), 839-867.

Batljan, I. and M. Lagergren (2004). "npatient/outpatient health care costs and remaining years of life—effect of decreasing mortality on future acute health care demand. Social Science & Medicine, 59(12), 2459-2466.

Baum, A. and I. Fleming (1993). Implications of psychological research on stress and technological accidents. American Psychologist 48(6) 665–67.

Baum, A., O'Keeffe, M. K., & Davidson, L. M. (2006). Acute Stressors and Chronic Response: The Case of Traumatic Stress1. Journal of Applied Social Psychology, 20(20), 1643-1654.

Bayazit, N. (2004). Investigating design: A review of forty years of design research. Design Issues, 20(1), 16-29.

Bayo, M. V., García, A. M., & García, A. (1995). Noise levels in an urban hospital and workers' subjective responses. Archives of Environmental Health: An International Journal, 50(3), 247-251.

Beaney, M. (2003a). Analysis. In: E. N. Zalta (ed), The Stanford Encyclopedia of Philosophy. Available at: http://plato.stanford.edu/archives/sum2003/entries/analysis/.

Beaney, M. (2003b) Ancient conceptions of analysis: A supplement to analysis. In: E. N. Zalta (ed), The Stanford Encyclopaedia of Philosophy. Available at: http://plato.stanford.edu/archives/sum2003/entries/analysis/.

Beaney, M. (2007). The analytic turn in early twentieth-century philosophy. The Analytic Turn. Routledge, 302p.

Beaney, M. (2009) Definitions and descriptions of analysis (supplement to analysis). In: E. N. Zalta (ed), The Stanford Encyclopaedia of Philosophy. Available at: http://plato.stanford.edu/entries/analysis/s1.html#Pappus

Beauchemin, K. M., & Hays, P. (1996). Sunny hospital rooms expedite recovery from severe and refractory depressions. Journal of affective disorders, 40(1), 49-51.

Bell, P. A. (1992). In defense of the negative affect escape model of heat and aggression. Psychological Bulletin 111, 342–46.

Bell, P. A., & Green, T. C. (1982). Thermal stress: Physiological, comfort, performance, and social effects of hot and cold environments. Environmental stress, 75-104.

Bencko, V. and M. Schejbalova (2006). From Ignaz Semmelweis to the Present: Crucial Problems of Hospital Hygiene. Indoor Built Environment, 15(1), 3-7.

Beral, V., Shaw, H., Evans, S., & Milton, G. (1982). Malignant melanoma and exposure to fluorescent lighting at work. The Lancet, 320(8293), 290-293.

Bergner, M. (1985). Measurement of health status. Medical care, 23(5), 696-704.

Bertelsen, S.; Koskela, L.; Henrich, G.; Rooke, J. (2006). Critical flow - towards a construction flow theory. In Proceedings of the14th Annual Conference of the International Group for Lean Construction, Santiago, Chile (pp. 31-40).

Biner, P. M., Butler, D. L., Fischer, A. R., & Westergren, A. J. (1989). An Arousal Optimization Model of Lighting Level Preferences an Interaction of Social Situation and Task Demands. Environment and Behavior, 21(1), 3-16.

Blackburn, S. (1999). Think: a compelling introduction to philosophy. Oxford University Press.

Block, L. K., & Stokes, G. S. (1989). Performance and satisfaction in private versus nonprivate work settings. Environment and Behavior, 21(3), 277-297.

Boaz, A., Ashby, D., & Young, K. (2002). Systematic reviews: what have they got to offer evidence based policy and practice. ESRC UK Centre for evidence based policy and practice: working paper, 2.

Boyce, P., Hunter, C., & Howlett, O. (2003). The benefits of daylight through windows. Troy, New York: Rensselaer Polytechnic Institute.

Bravata, D. M., McDonald, K. M., Shojania, K. G., Sundaram, V., & Owens, D. K. (2005). Challenges in systematic reviews: synthesis of topics related to the delivery, organization, and financing of health care. Annals of internal medicine, 142(12 Pt 2), 1056.

Brook, A. (2008). Kant's view of the mind and consciousness of self. In: Zalta, E. N. (ed). The Stanford Encyclopaedia of Philosophy. Available at: http://plato.stanford.edu/entries/kant-mind/

Brown, B. B. (1992). The ecology of privacy and mood in a shared living group. Journal of Environmental Psychology, 12(1), 5–20.

Brown, B. B., Altman, I., & Werner, C.W. (1992). Close relationships in the physical and social world: dialectic and transactional analyses. In Deetz, S. (Ed.) Communication yearbook, 15 (pp. 509–22), Newbury Park, CA, Sage.

Bruce, M. and Cooper, R. (2000) Creative product design: a practical guide to requirements capture management. Wiley and Sons.

Bruseberg, A., & McDonagh-Philp, D. (2000, September). User-centred design research methods: the designer's perspective. In Integrating design education beyond 2000 conference (pp. 179-184).

CABE - PricewaterhouseCoopers, L. L. P. (2004). The role of hospital design in the recruitment, retention and performance of NHS nurses in England.

CABE (2006). Designed with care: design and neighbourhood healthcare buildings. Retrieved 10 Jan, 2006, from http://www.cabe.org.uk/AssetLibrary/4349.pdf.

Cabrera, I. N., & Lee, M. H. (2000). Reducing noise pollution in the hospital setting by establishing a department of sound: a survey of recent research on the effects of noise and music in health care. Preventive medicine, 30(4), 339-345.

Carnap, R. (1936). Testability and meaning. Philosophy of Science, 3(4), 419-471.

Carnap, R. (1937). Testability and meaning - continued. Philosophy of Science, 4(1), 1-40.

Carnap, R. (1945). On inductive logic. Philosophy of Science, 12(2), 72-97.

Carnap, R. (1946). Remarks on induction and truth. Philosophy and Phenomenological Research, 6(4), 590-602. Available at: www.jstor.org/stable/2103107.

Carnap, R. (1948). Rudolf Carnap's analysis of "truth": reply. Philosophy and Phenomenological Research, 9(2), 300-304. Available at: www.jstor.org/stable/2103397.

Chakravartty, Anjan (2011) Scientific Realism. In Zalta, E.N. (Ed.) The Stanford Encyclopedia of Philosophy. Available at: http://plato.stanford.edu/archives/sum2011/entries/scientific-realism/.

Chan, P., Carmichael, S., Tzortzopoulos, P., & Cooper, R. (2004). Beyond process protocol: a review of the generic design and construction process protocol to explore future work. In Proceedings of the Salford Centre for Research and Innovation (SCRI) International Symposium. Salford, UK.

Charles, K. E. (2003). A review of occupant responses to localized air distribution systems. In Proceedings: Healthy Buildings (pp. 304-310).

Chaudhury, H., Mahmood, A., & Valente, M. (2005). Advantages and disadvantages of single versus multiple-occupancy rooms in acute care environments: a review and analysis of the literature. Environment and Behavior, 37(6), 760-786.

Chou, R., & Helfand, M. (2005). Challenges in systematic reviews that assess treatment harms. Annals of internal medicine, 142(12 Pt 2), 1090. -1099.

Chow, T. T., & Yang, X. Y. (2003). Performance of ventilation system in a non-standard operating room. Building and environment, 38(12), 1401-1411.

Christensen, M. (2004). Noise levels in a general surgical ward: a descriptive study. Journal of Clinical Nursing, 14(2), 156-164.

Clark, K. B., & Wheelwright, S. C. (1993). Managing new product and process development: text and cases. Simon and Schuster.

Clarkson, P. J., Buckle, P., Coleman, R., Stubbs, D., Ward, J., Jarrett, J., Lane, R., & Bound, J. (2004). Design for patient safety: a review of the effectiveness of design in the UK health service. Journal of Engineering Design 15(2),123-140.

Cochrane Collaboration. (2001). The Cochrane Brochure. Available at: http://www.cochrane.org/cochrane/cc-broch.htm#BDL.

Codinhoto, R. (2003). Diretrizes para o planejamento integrado dos processos de projeto e produção na construção civil. Master dissertation, Universidade Federal do Rio Grande do Sul.

Codinhoto, R. & Formoso, C. T. (2005) Contributions for the integration of design and production management in construction. In: Proceeding of the International Conference on Design Management in the Architectural and Engineering Office, Copenhagen, Denmark, CIB W096.

Codinhoto, R., Koskela, L. J., Kagioglou, M. (2006) Product development life cycle: the potential use of the “V” Model within construction [Online]. Available from http://www.obom.org/PAGES/EGLCabstractCodinhoto.html

Codinhoto, R., Koskela, L. J., Tzortzopoulos, P., & Kagioglou, M. (2006). How analysis and synthesis have been understood in design. In Proceedings of the 14th Annual Conference of the International Group for Lean Construction (pp. 121-134).

Cohen, L. (1995). Quality function deployment: how to make QFD work for you. Reading, Massachusetts, Addison-Wesley Publishing Company.

Cohen, S. (1978). Environmental load and the allocation of attention. In Baum, A. & Valins, S. (Eds). Advances in environmental psychology. Hillsdale, Lawrence Erlbaum.

Cook, D. J., Greengold, N. L., Ellrodt, A. G., & Weingarten, S. R. (1997a). The relation between systematic reviews and practice guidelines. Systematic reviews: synthesis of best evidence for health care decisions. Philadelphia, PA: American College of Physicians, 55-65.

Cook, D. J., Mulrow, C. D., & Haynes, R. B. (1997b). Synthesis of best evidence for clinical decisions. Systematic reviews: Synthesis of best evidence for health care decisions, 5-12.

Cook, M. (1970) Experiments on orientation and proxemics. Human Relations, 23(1), 61-76

Cooper, H. M. (1998). Synthesizing Research: A guide for Literature Reviews (Vol. 2). Sage Publications.

Cooper, R. (2005). Why do we get 'het up' about theory and practice? Presentation made for workshop on Theory and Research in Built and Human Environment, The University of Salford.

Cooper, R., Bruce, M., Wootton, A., Hands, D., & Daly, L. (2003). Managing design in the extended enterprise. Building Research & Information, 31(5), 367-378.

Cooper, R., Ghassan, A., Lee, A., & Wu, S. (2004). Process Management in Design and Construction. Blackwells.

Cooper, R., Kagioglou, M., Aouad, G., Hinks, J., Sexton, M., & Sheath, D. (1998, March). The development of a generic design and construction process. In European Conference, Product Data Technology (PDT) Days 1998, Building Research Establishment, Watford, UK.

Cooper, R., Wootton, A. B., & Bruce, M. (1998). Requirements capture: theory and practice. Technovation, 18(8), 497-585.

Cooper, R., Wootton, A., & Bruce, M. (1999). Requirements capture as process of technology-market integration. International Journal of Technology Management, 17(6), 582-596.

Cotterill, S., Evans, R., & Fraise, A.P. (1996). An unusual source for the outbreak of methicillin-resistant staphylococcus aureus on an intensive therapy unit. Journal of Hospital Infection, 32(3), 207- 216.

CRAG (1996). Introduction to Systematic Reviews. Critical Reviews Advisory Group. Sheffield, University of Sheffield.

Craig, E. (2000). Metaphysics. Concise Routledge Encyclopaedia of Philosophy. London, Routledge: 567-570.

Crawford, S. and Wiers, V. C. S. (2001) From anecdotes to Theory: A review of existing knowledge on human factors of planning and scheduling. In B. L. MacCarthy and J. R. Wilson (Eds.). Human performance in planning and scheduling.. London, Taylor & Francis: 15-43.

Cross, N. (1989) Engineering Design Methods, John Wiley & Sons Ltd.

Cross, N. (1997) Descriptive models of creative design: application to an example, Design Studies, 18(4), 427-440.

Cross, N. (2000). Engineering design methods: strategies for product design (Vol. 58). Chichester, UK: Wiley

Cross, N. (2004). Expertise in design: an overview. Design Studies 25(5), 427-441.

Cross, N. (2006) Designerly ways of knowing. London: Springer, 2006.

Cross, N., Naughton, J., & Walker, D. (1981). Design method and scientific method. Design studies, 2(4), 195-201.

Dalke, H., Little, J., Niemann, E., Camgoz, N., Steadman, G., Hill, S., & Stott, L. (2006). Colour and lighting in hospital design. Optics & Laser Technology, 38(4), 343-365.

Darke, J. (1979). The primary generator and the design process. Design studies, 1(1), 36-44.

Davies, H. T. O. & Crombie, I. K. (1998). Getting to grips with systematic reviews and meta-analysis. Hospital Medicine, 59(12), 955-958.

Day, C. (2002). Spirit and Place. Oxford, Architectural Press.

Daykin, N. & E. Byrne (2006). The impact of visual arts and design on the health and wellbeing of patients and staff in mental health care: A systematic review of the literature. Bristol, Centre for Public Health Research in the University of the West of England.

Dearry, A. (2004). Impacts of our built environment on public health. Environmental Health Perspectives, 112(11), A600.

Deming W.E. (1982) Out of the Crisis. Cambridge, University Press.

Descartes, R. (1637) Descartes: Discourse on Method and Meditations, Penguin Books.

Devlin, A. S. & A. B. Arneill (2003). Health care environments and patient outcomes: a review of the literature. Environment and Behavior, 35(5), 665-694.

Dijkstra, K., Pieterse, M.E., & Pruyn, A.Th.H (2006). Physical environmental stimuli that turn healthcare facilities into healing environments through psychologically mediated effects: systematic review. Journal of Advanced Nursing, 56(2), 166-181.

DiMaggio, P. J. (1995). Comments on "What theory is not." Administrative Science Quarterly, 40(3), 391-397.

DOH (2004a). The NHS improvement plan: putting people at the heart of public services. Available at: from http://www.dh.gov.uk/PublicationsAndStatistics/Publications/PublicationsPolicyAndGuidance/PublicationsPAmpGBrowsableDocument/fs/en?CONTENT_ID=4097241&MULTIPAGE_ID=4910828&chk=XLVYCw.

DOH (2004b). Towards cleaner hospitals and lower rates of infection: a summary of action, Department of Health: 22.

DOH (2005). Guidance for Pandemic Influenza: Infection Control in Hospitals and Primary Care Settings, Department of Health: 68.

DOH. (2007). IDEA, Inspiring Design Excellence and Achievements. Retrieved 12th March, 2007, Available at: http://design.dh.gov.uk/ideas/.

Dorst, K. (2003). The problem of design problems. Design Thinking Research Symposium, University of Technology, Sydney (Australia).

Dorst, K. (2006). Design Problems and Design Paradoxes. Design Issues, 22(3), 4-17.

Douglas, C. H. & Douglas, M. R. (2004). Patient-friendly hospital environments: exploring the patients' perspective. Health Expectations, 7(1), 61–73.

Douglas, C. H. & Douglas, M. R. (2005). Patient-centred improvements in health-care built environments: perspectives and design indicators. Health Expectations, 8(3), 264–276.

Doyle, A.C. (1930). A Study in Scarlet, The Complete Sherlock Holmes, Doubleday & Co., pp. 83.

Dubin, R. (1969). Theory Building. New York, The Free Press.

Eddy, D. M. (1990). Anatomy of a decision. JAMA: the journal of the American Medical Association, 263(3), 441-443.

Eisenhardt, K. M. (1989). Building Theories From Case Study Research. Academy of Management Review, 14(4), 532-550.

Ersser, S., Wiles, A., Taylor, H., Wade, S., Walsh, R., & Bentley, T. (2001). The sleep of older people in hospital and nursing homes. Journal of Clinical Nursing, 8(4), 360-368.

Estates, N. H. S. (1996). Health Building Note 35–Accommodation for People with Mental Illness. Part 1–The Acute Unit.

Estates, N. H. S. (2005). Wayfinding: effective wayfinding and signing systems; guidance for healthcare facilities. Stationery Office.

Etnier, J.L. and Hardy, C.J. (1997) The effects of environment color. Journal of Sport Behavior, 20 (3), 299-312.

Evans, B. (2010). Evidence-based design. In: Lombaerde, P. (Ed.), Bringing the World into Culture: Comparative Methodologies in Architecture, Art, Design and Science, 227.

Evans, G. W. (1984). Environmental stress, Cambridge University Press.

Evans, G. W., & McCoy, J. M. (1998). When buildings don't work: the role of architecture in human health. Journal of Environmental Psychology, 18(1), 85-94.

Feng, D. and Zeng, Y. (2009) Validation of environment-based design (EBD) through protocol analysis experiment. In Proceedings: International Conference of Engineering Design, ICED'09, 24-27 August 2009, Stanford University, Stanford, CA, USA, pp.423-234.

Ferrans, C. E., Zerwic, J. J., Wilbur, J. E., & Larson, J. L. (2005). Conceptual model of health-related quality of life. Journal of Nursing Scholarship, 37(4), 336-342.

Fischl, G. (2006). Psychosocially supportive design in the indoor environment. Division of Engineering Psychology, Department of Human Work Sciences, Luleå University of Technology.

Flanigan, W. H. (1984). The conduct of inquiry in social science history. Social Science History, 8(4), 323-339.

Fleming, T. R. & D. L. DeMets (1996). Surrogate end points in clinical trials: are we being misled? Annals of Internal Medicine, 125, 605-613.

Force, T. (2005). Challenges in systematic reviews of economic analyses. Ann Intern Med, 142, 1073-1079.

Forsberg, K; Mooz, H; & Cotterman, H. (1996). Visualizing Project Management, John Wiley &Sons, US.

Forsberg, K. & Mooz, H. (1998). Systems engineering for faster, cheaper, better. Center for Systems Management, 1-11.

Forsberg, K. and Mooz, H. (1991). The relationship of system engineering to the project cycle. In: Proceedings: National Council On Systems Engineering (NCOSE) and American Society for Engineering Management (ASEM), Chattanooga, TN. 21–23 October.

Fransson, N., Vastfjall, D., & Skoog, J. (2007) In search of the confortable indoor environment: a comparison of the utility of objective and subjective indicators of indoor comfort. Building and Environment, 42(5), 1886-1890.

Fridkin, S. K., Kremer, F. B., Bland, L. A., Padhye, A., McNeil, M. M., & Jarvis, W. R. (1996). Acremonium kiliense endophthalmitis that occurred after cataract extraction in an ambulatory surgical center and was traced to an environmental reservoir. Clinical infectious diseases, 22(2), 222-227.

Friedman, K. (2003). Theory construction in design research: criteria: approaches, and methods. Design Studies, 24(6), 507-522.

Gabbay, D.M. & Woods, J. (2005). A Practical Logic of Cognitive Systems, Volume 2: The Reach of Abduction: Insight and Trial. Elsevier/North-Holland, Amsterdam.

Gaukroger, S. (1989). Cartesian logic: an essay on Descarte's conception of inference, Clarendon Press.

Gedenryd, H. (1998). How designers work: making sense of authentic cognitive activities. Lund University.

General Health Protection and DOH (2006). Infection control: Guidance for care homes, Department of Health: 80.

Gero, J. S. (2002). Computational models of creative designing based on situated cognition. In Proceeding of the 4th Conference on Creativity and Cognition. Loughborough, UK.

Gettier, E. (1963). Is Justified True Belief Knowledge? Analysis, 23, 121-123.

Girardin, W., B. (1992). Light wave frequency and sleep- wake frequency in well, full-term neonates. Holistic Nursing Practice, 6,(4), 57- 66.

Glass, P., Avery, G. B., Subramanian, K. N., Keys, M. P., Sostek, A. M., & Friendly, D. M. (1985). Effects of bright light in hospital nursery on the incidence of retinopathy of maturity. The New England Journal of Medicine, 313(7), 401- 404.

Goldman, A. (1967). A Causal theory of knowing. Journal of Philosophy, 64 (12), 357-372.

Goldman, A. (1976). Discrimination and perceptual knowledge. Journal of Philosophy, 73(20), 771-779.

Goldman, A. (2001). Social epistemology. The Stanford Encyclopaedia of Philosophy.

Goodare, H., & Smith, R. (1995). The rights of patients in research. British Medical Journal, 310, 1277-8.

Gralton, E., Pearson, S., Sutherland, A., Donovan, M., & Lewis, G. (2001). The environment psychiatric patients create for themselves: the varying perceptions of professional staff. Psychiatric Bulletin, 25, 134-137.

Grosenick, J. K., & Hatmaker, C. M. (2000). Perceptions of the importance of physical setting in substance abuse treatment. Journal of Substance Abuse Treatment 18(1), 29-39.

Haddock, J. (1994). Clinical sleep: Reducing the effects of noise in hospital. Nursing Standard, 8(43), 25-28.

Haggard, L. M. & Werner, C. M. (1990). Situational support, privacy regulation, and stress. Basic and Applied Social Psychology, 11(3), 313–37.

Hall, A. D. (1962). A methodology for systems engineering, Princeton.

Hall, E.T. (1968). Proxemics. Current Anthropology, 9(2/3).

Halpern, D. (1995). Mental health and the built environment: More than bricks and mortar? Taylor & Francis.

Hamilton, K. (2007). The four levels of evidence-based practice. Healthcare Design Magazine: Designing, building and renovating healthcare buildings. http://www.healthcaredesignmagazine.com/Past_Issues.htm?ID=2922. Last access: 05/03/2007.

Handy, S. L., Boarnet, M. G., Ewing, R., & Killingsworth, R. E. (2002). How the built environment affects physical activity. American journal of preventive medicine, 23(2), 64-73.

Harper, D. (2012). Theory. Online Etymology Dictionary. Available at: http://www.etymonline.com/index.php?term=theory. Last accessed: 25 September 2012.

Harriss, C. (1998). Why research without theory is not research: a reply to Seymour, Crook and Rook. Construction Management and Economics, 16(1), 113-116.

Hartling, L., McAlister, F. A., Rowe, B. H., Ezekowitz, J., Friesen, C., & Klassen, T. P. (2005). Challenges in systematic reviews of therapeutic devices and procedures. Annals of internal medicine, 142(12 Pt 2), 1100.

Hatchuel, A. & Weil, B. (2002) C-K theory: Notions and application of a unified design theory. Herbert Simon International Conference on Design Sciences. Lyon, Fr.

Hatchuel, A. & Weil, B. (2003). A new approach of innovative design: an introduction to C-K theory. International conference on Engineering Design, ICED 03, Stockholm.

Hatchuel, A., & Weil, B. (2008). CK design theory: an advanced formulation. Research in Engineering Design, 19(4), 181-192.

Heath, T. L. (1981). A history of Greek mathematics. New York, Dover Publications.

Hedge, A. (1989). Environmental conditions and health in offices. International Reviews of Ergonomics, 3, 87–110.

Hendrickson, C., & Au, T. (1989). Project management for construction: Fundamental concepts for owners, engineers, architects, and builders. Chris Hendrickson.

Heylighen, A.; Cavallin, H. and Bianchi, M. (2009) Design in mind. Design Issues, 5(1), 94-106.

Hickam, D. H., Severance, S., Feldstein, A., Ray, L., Gorman, P., Schuldheis, S., ... & Helfand, M. (2003). The Effect of Health Care Working Conditions on Patient Safety: Summary.

Hillier, B., Musgrove, J., & O'Sullivan, P. (1972). Knowledge and design. Environmental design: research and practice, 2.

Hintikka, J., & Remes, U. (1974). The method of analysis: its geometrical origin and its general significance (Vol. 25). Springer.

Hobfoll, S. E. (1991). Traumatic stress: A theory based on rapid loss of resources. Anxiety Research, 4(3), 187-197.

Holton, Gerald James. The Scientific Imagination: With a New Introduction. Cambridge, Ma.: Harvard UP, 1998. Print.

Hornikx, J. (2005). A review of experimental research on the relative persuasiveness of anecdotal, statistical, causal, and expert evidence. Studies in Communication Sciences, 5(1), 205-216.

Hubka, V., & Eder, W. E. (1988). Theory of technical systems: a total concept theory for engineering design. Berlin and New York, Springer-Verlag, 1988, 291 p., 1.

Hubka, V., & Eder, W. E. (1996). Design science: introduction to needs, scope and organization of engineering design knowledge.

Huovila, P., Koskela, L., & Lautanala, M. (1997). Fast or concurrent: the art of getting construction improved. Lean construction, 143-159.

Hwang, R. L., Lin, T. P., Cheng, M. J., & Chien, J. H. (2007). Patient thermal comfort requirement for hospital environments in Taiwan. Building and environment, 42(8), 2980-2987.

Hwang, R. L., Lin, T. P., Cheng, M. J., & Chien, J. H. (2007). Patient thermal comfort requirement for hospital environments in Taiwan. Building and environment, 42(8), 2980-2987.

IDEF0 (1993) Integration definition for function modelling (IDEF)). Draft Federal Information Processing Standards Publication 183. Available at: http://www.idef.com/pdf/idef0.pdf. Last accessed: April, 2008

Ikonomidou, E., Rehnström, A., & Naesh, O. (2004). Effect of music on vital signs and postoperative pain. Aorn, 80(2), 269-278.

Jacobs, K. W. & Hustmyer Jr., F. E. (1974). Effects of four psychological primary colors on GSR (galvanic skin response) heart rate and respiration rate. Perceptual and Motor Skills, 38, 763-766.

Jacobs, K. W. & Suess J.F. (1975). Effects of Four Psychological Primary Colors on Anxiety State. Perceptual and Motor Skills, 41(1), 207-210.

James, C. N., & Robert, B. W. (1971). Emotional attributes of color: A comparison of violet and green. Perceptual and motor skills, 32(2), 403-406.

Jeffrey, R. C., & Burgess, J. P. (1981). Formal logic: Its scope and limits (Vol. 1967). New York: McGraw-Hill.

Johnson, P. & Duberley, J. (2004). Understanding Management Research. London, SAGE Publications Ltd.

Johnson, R. J., & Wolinsky, F. D. (1993). The structure of health status among older adults: disease, disability, functional limitation, and perceived health. Journal of Health and Social Behavior, 105-121.

Jones, J. C. (1970). Design methods. Wiley.

Jones, J. C. (1984). A method of systematic design. In Cross, N (Ed.), Developments in design methodology. Chichester, New York, Wiley.

Joseph, A. (2006). The impact of light on outcomes in healthcare settings. Center for Health Design.

Joseph, A. (2006). The impact of the environment on infections in healthcare facilities. Center for Health Design.

Kagioglou, M; Cooper, R; Aouad, G; Hinks, J; Sexton, M; & Sheath, D; (1998). Final Report: Generic Design and Construction Process Protocol. University of Salford, UK.

Kahkonen, K. (1993) Modelling activity dependencies for building construction project scheduling. PhD Thesis, Department of Construction Management & Engineering, University of Reading, UK.

Kahneman, D., & Deaton, A. (2010). High income improves evaluation of life but not emotional well-being. Proceedings of the National Academy of Sciences, 107(38), 16489-16493.

Kamara, J. M., Anumba, C. J., & Evbuomwan, N. F. O. (1997). Considerations for the effective implementation of concurrent engineering in construction. In Concurrent Engineering in Construction: Proceedings of the First International Conference, Institution of Structural Engineers, London (pp. 33-44).

Kamara, J. M., Anumba, C. J., & Evbuomwan, N. F. O. (2001). Establishing and processing client requirements—a key aspect of concurrent engineering in construction. Engineering Construction and Architectural Management, 7(1), 15-28.

Kaplan, R. (2001). The Nature of the View from Home Psychological Benefits. Environment and Behavior, 33(4), 507-542.

Kaya, N., & Crosby, M. (2006). Color associations with different building types: an experimental study on American college students. Color Research & Application, 31(1), 67-71.

Kendall, S. (2005). Open building: an architectural management paradigm for hospital architecture. CIB W096 Architectural Management, Lyngby, Denmark, TU Denmark.

Klein, P. (2005). Skepticism.

Kocaturk, T., & Codinhoto, R. (2009) Dynamic Coordination of Distributed Intelligence in Design. Computation: The New Realm of Architectural Design. Istanbul Technical University, Istanbul pp 61-68

Koskela, L. (2000). An exploration towards a production theory and its application to construction. VTT Technical Research Centre of Finland.

Koskela, L. (2005). On theories in SCRI research. Presentation made for workshop on Theory and Research in Built and Human Environment, The University of Salford.

Koskela, L. J., & Kagioglou, M. (2005). On the metaphysics of production. In Proceedings of 13th International Group for Lean Construction Conference. (pp. 37-45).

Koskela, L. J., & Kagioglou, M. (2007). The proto-theory of design: the method of analysis of the ancient geometers. Strojarstvo: Journal for Theory and Application in Mechanical Engineering, 49(1), 45-52.

Koskela, L., & Kagioglou, M. (2006) The proto-theory of design: the method of analysis of the ancient geometers, International Design Conference - Design 2006, Dubrovnik - Croatia, May 15 - 18, 2006.

Koskela, L., Codinhoto, R., Tzortzopolous, P., & Kagioglou, M. (n.d.) The method of analysis of the ancient geometers as the proto-theory of design. Research in Engineering Design. Unpublished.

Kothari, C. R. (2004). *Research methodology: methods and techniques*. New Age International.

Kotler, P. (1999). Administração de Marketing: análise, planejamento, implementação e controle. São Paulo: Atlas, 1998. Interdisciplinar Científica Aplicada, Blumenau, 1(2), 01-15.

Kotler, P. (1999). Kotler on marketing: How to create, win, and dominate markets. Simon and Schuster.

Kotler, P., & Keller, K. L. (2006). Marketing management 12e. New Jersey.

Kripke, D. F. (1998). Light treatment for nonseasonal depression: speed, efficacy, and combined treatment. Journal of affective disorders, 49(2), 109-117.

Kripke, D. F., Mullaney, D. J., Klauber, M. R., Craig Risch, S., & Christian Gillin, J. (1992). Controlled trial of bright light for nonseasonal major depressive disorders. Biological Psychiatry, 31(2), 119-134.

Kripke, D. F., Risch, S. C., & Janowsky, D. (1983). Bright white light alleviates depression. Psychiatry research, 10(2), 105-112.

Laditka, J. N., Laditka, S. B., & Cornman, C. B. (2005). Evaluating hospital care for individuals with Alzheimer's disease using inpatient quality indicators. American Journal of Alzheimer's Disease and Other Dementias, 20(1), 27-36.

Lantelme, E. M. V., Formoso, C. T., & Powell, J. A. (2005). Desenvolvimento de competências dos gerentes da construção: construção de uma teoria. Ambiente Construído, 5(1), 69-86.

Lawson, B. (2001). Language of space. Oxford, Elsevier.

Lawson, B. (2004). Schemata, gambits and precedent: some factors in design expertise. Design Studies, 25(5), 443-457.

Lawson, B. (2006). How designers think: the design process demystified. Architectural press.

Lawson, B., & Phiri, M. (2004). Providing single rooms for patients: a study of the benefits to patients and staff within the NHS in England. Sheffield, The University of Sheffield, School of Architecture, 60.

Lawson, B., Phiri, M., & Wells-Thorpe, J. (2003). The architectural healthcare environment and its effects on patient health outcomes: a report on an NHS estates funded project. N. Estates. London, NHS Estates and University of Sheffield, 22.

Lawton, M. P. (2001). The physical environment of the person with Alzheimer's disease. Aging & Mental Health, 5(S1), 56-64.

Leather, P., Beale, D., & Sullivan, L. (2003a). Outcomes of Environmental Appraisal of Different Hospital Waiting Areas. Environment and Behavior 35(6): 842-869.

Leather, P., Beale, D., & Sullivan, L. (2003b). Noise, psychosocial stress and their interaction in the workplace. Journal of Environmental Psychology, 23(2), 213-222.

Leather, P., et al. (2000). A comparative study of the impact of environmental design upon hospital patients and staff. Nottingham, Institute of Work, Health & Organisations - University of Nottingham: 62.

Lee, A., Marshall-Ponting, A. J., Aouad, G., Wu, S., Koh, I., Fu, C., Cooper, R., Betts, M., Kagioglou, M., Fischer, M. (2003) Developing a vision of nD-enabled construction, Construct IT Report, ISBN: 1-900491-92-3.

Lee, H. D. P. (1935). Geometrical method and Aristotle's account of first principles. The Classical Quarterly, 29(02), 113-124.

Lehrer, K., & Paxson, T. (1969). Knowledge: undefeated justified true belief. The Journal of Philosophy, 66(8), 225-237.

Levitt, T. (1986). The marketing imagination, The Free Press.

Levitt, T. (1990). A imaginação de marketing. Atlas.

Liu, E. H., & Tan, S. M. (2000). Patients' perception of sound levels in the surgical suite. Journal of clinical anesthesia, 12(4), 298-302.

Loewen, L. J., & Suedfeld, P. (1992). Cognitive and arousal effects of masking office noise. Environment and Behavior, 24(3), 381-395.

Love, T. (2000). Philosophy of design: a meta-theoretical structure for design theory. Design Studies, 21(3), 293-313.

Love, T. (2002). Constructing a coherent cross-disciplinary body of theory about designing and designs: some philosophical issues. Design Studies, 23(3), 345-361.

Lu, S., & Zhu, N. (2007). Experimental research on physiological index at the heat tolerance limits in China. Building and Environment, 42(12), 4016-4021.

Maempaa, P. (1997). From backward reduction to configurational analysis. In Otte and Panza (Eds.). Analysis and Synthesis in Mathematics. Kluwer Academic Publishers, London, 440p.

Malkin, J. (2003). The business case for creating a healing environment. Center for Health Design Business Briefing: Hospital Engineering & Facilities Management.

Mallak, L. A., Lyth, D. M., Olson, S. D., Ulshafer, S. M., & Sardone, F. J. (2003). Culture, the built environment and healthcare organizational performance. Managing Service Quality, 13(1), 27-38.

Marcus, C. C. (2000). Gardens and health. Design and health: the therapeutic benefits of design, 461-71.

Marcus, C. C., & Barnes, M. (Eds.). (1999). Healing gardens: Therapeutic benefits and design recommendations. Wiley.

Markie, P. (2013). Rationalism vs. empiricism. *The Stanford Encyclopedia of Philosophy* (Summer 2013 Edition), Edward N. Zalta (ed.), forthcoming URL = <http://plato.stanford.edu/archives/sum2013/entries/rationalism-empiricism/>.

Markus, T. A. (1969). The role of building performance measurement and appraisal in design method. Design methods in Architecture, 109-17.

Maver, T. W. (1970). Appraisal in the building design process. Emerging methods in environmental design and planning, 195-202.

McCullough, C. (2010) Evidence-based Design. In: McCullough, C. (ed) Evidence-based design for healthcare facilities. R. Wilmeth, USA, 252p.

Meade, M. O., & Richardson, W. S. (1998). Selecting and appraising studies for a systematic review. Systematic reviews: synthesis of best evidence for health care decisions. Philadelphia: American College of Physicians, 81-90.

Menzies, D., Fanning, A., Yuan, L., & FitzGerald, J. M. (2000). Hospital ventilation and risk for tuberculous infection in canadian health care workers. Canadian

Collaborative Group in Nosocomial Transmission of TB. Annals of Internal Medicine, 133(10), 779.

Meredith, J. (1998). Building operations management theory through case and field research. Journal of operations management, 16(4), 441-454.

Miles, R. S. (1998, August). Alliance lean design/construct on a small high tech project. In The 6th Annual Conference of the International Group for Lean Construction. Guaruja, Sao Paulo, Brazil (pp. 13-15).

Miller, A. (2010). Realism.

Miller, C. L., White, R., Whitman, T. L., O'Callaghan, M. F., & Maxwell, S. E. (1995). The effects of cycled versus noncycled lighting on growth and development in preterm infants. Infant behavior and development, 18(1), 87-95.

Milligan, C., Gatrell, A., & Bingley, A. (2004). 'Cultivating health': therapeutic landscapes and older people in northern England. Social Science & Medicine, 58(9), 1781-1793.

Morris, R. (2005). The cognitive psychology of planning. Psychology Press.

Morton, A. (2008) A guide through the theory of knowledge, 3rd ed., Blackwell Publishing, 192p.

Mulrow, C. D. (1994). Rationale for systematic reviews. BMJ: British Medical Journal, 309(6954), 597.

Mulrow, C. D. & D. J. Cook (1997). Formulating questions and locating primary studies for inclusion in systematic reviews. Annals of Internal Medicine, Academia and Clinic, Systemtic Review Series 127(5): 380-387.

Mulrow, C. D., Cook, D. J., & Davidoff, F. (1997). Systematic reviews: critical links in the great chain of evidence. Annals of internal medicine, 126(5), 389.

Mulrow, C., Langhorne, P., & Grimshaw, J. (1997a). Integrating heterogeneous pieces of evidence in systematic reviews. Systematic reviews: synthesis of best evidence for health care decisions. Philadelphia: American College of Physicians, 103-112.

Nagano, K., & Mochida, T. (2004). Experiments on thermal environmental design of ceiling radiant cooling for supine human subjects. Building and environment, 39(3), 267-275.

Newell, A., & Simon, H. A. (1972). Human problem solving (Vol. 14). Englewood Cliffs, NJ: Prentice-Hall.

Newton, I. (2003). Opticks new edn.

NHS Estates (2001). Undertaking Systematic Reviews of Research on Effectiveness: CRD's Guidance for those Carrying Out or Commissioning Reviews. York, National Health Service: Centre for Reviews and Dissemination.

NHS Estates (2005). ASPECT: staff and patient environment calibration toolkit: 21.

NHS Estates (2007). NHS Design Champions. Available at: http://195.92.246.148/nhsestates/chad/chad_assets/downloads/design_champions_leaflet.pdf. Last access: 05/03/2007.

NHS Estates. (2005). Safer Environment Database - efm-evidence. Lawson, B (Ed.).

NHSEstates (2005). AEDET Evolution: Design evaluation toolkit: 25.

Niiniluoto, I., (1990) Edgar Allan Poe ja geometrinen analyysi [Edgar Allan Poe and geometric analysis], in: "Maailma, minä ja kulttuuri", I. Niiniluoto, Otava, Helsinki,. Oxford, Oxford University Press.

Northridge, M. E., Sclar, E. D., & Biswas, P. (2003). Sorting out the connections between the built environment and health: a conceptual framework for navigating pathways and planning healthy cities. Journal of Urban Health, 80(4), 556-568.

Nuffield Provincial Hospitals Trust (1960). Studies in the functions and design of hospitals, Oxford University Press.

O'Brien, D. (2006). An introduction to the theory of knowledge. Polity.

O'Neal, C. (1993). Concurrent engineering with early supplier involvement: a crossfunctional challenge. Journal of Supply Chain Management, 29(2), 2-9.

Oxman, A. D. (1994). Checklists for review articles. British Medical Journal, 309(6955), 648.

Oxman, A. D. (1994). Checklists for review articles. British Medical Journal, 309(6955), 648.

Oxman, A. D., Sackett, D. L., Guyatt, G. H., & Evidence-Based Medicine Working Group. (1993). Users' guides to the medical literature. JAMA, 270(17), 2093-2097.

Pahl, G., & Beitz, W. (1995). Engineering Design: a systematic approach. 1988. London: Design Council.

Panza, M. (1997). Classical sources for the concepts of analysis and synthesis. Boston Studies in the Philosophy of Science, 365-414.

Papert, S. (2000). What's the big idea? Toward a pedagogy of idea power. IBM Systems Journal, 39(3.4), 720-729.

Passini, R., Pigot, H., Rainville, C., & Tétreault, M. H. (2000). Wayfinding in a nursing home for advanced dementia of the Alzheimer's type. Environment and Behavior, 32(5), 684-710.

Patrick, D.L. & Bergner, M. (1990) Measurement of Health Status in the 1990s. Annual Review of Public Health. 11, 165-183.

Pelosi, P., Solca, M., Ravagnan, I., Tubiolo, D., Ferrario, L., & L., Gattinoni (1996). Effects of heat and moisture exchangers on minute ventilation, ventilatory drive, and work of breathing during pressure-support ventilation in acute respiratory failure. Critical Care Med, 24, (7), 1184- 1188

Plato (380BC) Meno, Translated by Benjamin Jowett, available in: http://classics.mit.edu/Plato/meno.html

Pollard, E. L., & Lee, P. D. (2003). Child well-being: A systematic review of the literature. Social Indicators Research, 61(1), 59-78.

Polya, G. (1954). Mathematics and plausible reasoning: Induction and analogy in mathematics. Princeton, New Jersey, Princeton University Press.

Polya, G. (2004). How to solve it: a new aspect of mathematical method, Princeton University Press.

Popper, K. R. (1968) The logic of scientific discovery London Hutchinson.

Popper, K. R. (1972). The logic of scientific discovery, London Hutchinson.

Prasad, B. (1996). Concurrent engineering fundamentals: integrated product and process organisation. New Jersey, Prentice Hall.

Proshansky, H. M., Ittelson, W. H., & Rivlin, L. G. (1976). Environmental psychology: People and their physical settings. London, New York : Holt, Rinehart and Winston.

Pugh, S. (1991) Total Design, Addison-Wesley, Wokingham.

Qatari, G. A., & Haran, D. (1999). Determinants of users' satisfaction with primary health care settings and services in Saudi Arabia. International Journal for Quality in Health Care, 11(6), 523-531.

Raybeck, D. (1991). Proxemics and privacy: Managing the problems of life in confined environments. In A. A. Harrison, Y. A. Clearwater, & C. P. McKay (Eds.), From Antarctica to outer space: Life in confined environments (pp. 317-330). New York: Springer-Verlag.

Reed, D., Price, E. G., Windish, D. M., Wright, S. M., Gozu, A., Hsu, E. B., ... & Bass, E. B. (2005). Challenges in systematic reviews of educational intervention studies. Annals of internal medicine, 142(12 Pt 2), 1080.

Reinertsen, D. G. (1997). Managing the design factory: a product development toolkit. New York, The Free Press.

Richards, K., C., & Bairnsfather, L.. (1988). Sleep in the ICU: A description of night sleep patterns in the critical care unit. Heart & Lung, 17, (1), 35- 42.

Rieke, R. & Sillars, M.O. (1984). Argumentation and the decision making process. New York: Harper Collins.

Ritchey, T. (1991). Analysis and Synthesis: On Scientific Method - Based on a Study by Bernhard Riemann. Systems Research 8(4), 21-41.

Roochnik, D. (2004). Retrieving the Ancients. Blackwell Publishing.

Roozenburg, N. F. M.; & Eekels, J. (1995) Product Design: fundamentals and Methods, Chichester, John Wiley & Sons Ltd.

Rosa, M., & Orey, D. C. (2005). De Pappus a Polya: da heurística grega à resolução de problemas. Plures Humanidades, Revista do Programa de Pós-Graduação em Educação–Mestrado Centro Universitário Moura Lacerda, Ribeirão Preto, ano, 10, 12-27.

Rother, M. & Shook, J. (1999) Learning to See: Value Stream Mapping to Add Value and Eliminate Muda Version 1.3, Lean Enterprise Institute.

Rubonis, A. V. & L. Bickman (1991). Psychological impairment in the wake of disaster. Psychological Bulletin(109): 384–99.

Russell, B. (1948). Human Knowledge, its scope and limits, Allen and Unwin.

Saliba, M. T. & Fischer, C. M. (2000). Managing Customer Value. Quality Progress 33(6): 63-69.

Sapountzis, S., Yates, K., Kagioglou, M., & Aouad, G. (2009). Realising benefits in primary healthcare infrastructures. Facilities, 27(3/4), 74-87.

Schoggen, P. (1989). Behavior Settings. Stanford, CA, Stanford University Press.

Sehulster, L. M., et al. (2004). Guidelines for environmental infection control in health-care facilities. Recommendations from CDC and the Healthcare Infection Control Practices Advisory Committee (HICPAC). American Society for Healthcare Engineering / American Hospital Association. Chicago IL: 249.

Serrano Lasa, I.S., Laburu, C.O., & Vila, R.C. (2008). An evaluation of the value stream mapping tool. Business Process Management Journal;14 (1).

Shewhart, W.A. (1931) Economic Control of Quality of Manufactured Product. Van Nostrand, New York. 501 p.

Shingo, S. (1988) Non-stock production. Productivity Press, Portland.

Simon, H. A. (1969). The sciences of the artificial, Cambridge, Massachusetts and London, MIT Press.

Simon, H. A. (1978). Rationality as Process and Product of Thought. Journal of the American Economic Association, 68, 1-16.

Simon, H. A. (1988). The Science of Design: Creating the Artificial. Design Issues, Vol. 4, No. 1/2, Designing the Immaterial Society (1988), 67-82

Smith, A. P. (1991). Noise and aspects of attention. British Journal of Psychology 82: 313–24.

Smith, D. W. (2005). Phenomenology. The Stanford Encyclopaedia of Philosophy, Edward N. Zalta.

Smith, R. (1996), What clinical information do doctors need? British Medical Journal, 313:1062-8.

Smith, R. (2004). Aristotle's Logic, The Stanford Encyclopaedia of Philosophy, E. N. Zalta (ed.), URL = http://plato.stanford.edu/archives/fall2004/entries/aristotle-logic/.

Sobek II. D. K; Ward, A. C; & Liker, J.K; (1999) Toyota´s Principles of Set-Based Concurrent Engineering. Loan Management Review, Cambridge, v. 40, p. 67-83.

Sommer, R. & A. W. Wicker (1991). Gas station psychology: the case for specialization in ecological psychology. Environment and Behavior, 23,131–49.

Steup, Mattias. (2005). Epistemology. Stanford Encyclopedia of Philosophy. http://plato.stanford.edu/entried/epistemology/ (accessed September 30, 2011).

Stone, N. (2003). Environmental view and color for a simulated telemarketing task. Journal of Environmental Psychology, 23: 63-78.

Suh, N. P. (1990). The Principles of Design, New York

Suh, N. P. (1998). Axiomatic design theory for systems. Research in Engineering Design, 10(4), 189-209.

Suh, N. P. (2001). Axiomatic design: Advances and applications. Oxford, Oxford University Press

Sundstrom, E., Bell, P. A., Busby, P. L., & Asmus, C. (1996). Environmental Psychology 1989-1994. Annual review of psychology, 47(1), 485-512.

Sutton, R. I. & B. M. Staw (1995). What theory is not. Administrative Science Quaterly 40: 371-384.

Thayer, R. E. (1989). The BioPsychology of Mood and Arousal. New York, Oxford University Press.

The Concise Oxford English Dictionary (2006), environment n. Eleventh edition revised . Ed. Catherine Soanes and Angus Stevenson. Oxford University Press, 2006. Oxford Reference Online. Oxford University Press. Salford University. 4 February 2007 http://www.oxfordreference.com/views/ENTRY.html?subview=Main&entry=t23.e18499

The Concise Oxford English Dictionary, (2007), well-being n. Eleventh edition revised . Ed. Catherine Soanes and Angus Stevenson. Oxford University Press, 2006. Oxford Reference Online. Oxford University Press. Salford University. 10 January 2007 http://www.oxfordreference.com/views/ENTRY.html?subview=Main&entry=t23.e64384

Thomson, D. S., Austin, S. A., Root, D. S., Thorpe, A., & Hammond, J. W. (2006). A problem-solving approach to value-adding decision making in construction design. Engineering, Construction and Architectural Management, 13(1), 43-61.

Timmermans, B. (1999). The Originality of Descartes's Conception of Analysis as Discovery. Journal of the History of Ideas 60(3): 433-447.

Topf, M. (2000). Hospital noise pollution: an environmental stress model to guide research and clinical interventions. Journal of Advanced Nursing, 31(3), 520-528.

Topf, M., Bookman, M., & Arand, D. (1996). Effects of criticial care unit noise on the subjective quality of sleep. Journal of Advanced Nursing, 24, 545-551.

Tranfield, D., Denyer, D., & Smart, P. (2003). Towards a methodology for developing evidence-informed management knowledge by means of systematic review. British journal of management, 14(3), 207-222.

Trescastro, M. G. (2005) Diretrizes para a segmentação e seqüenciamento das atividades no processo de projeto em ambientes simultâneos na construção civil. Porto Alegre, Universidade Federal do Rio Grande do Sul,. 163 f. Dissertação (Mestrado em Engenharia Civil)

Tversky, A. & Kahneman, D. (1974). Judgment under uncertainty: Heuristics and biases. Science 185(4157): 1124-1131.

Tzortzopoulos, P; Cooper, R; Chan, P; & Kagioglou, M. (2006). Clients' activities at the design front-end. Design Studies, in press.

Tzortzopoulos, P., Betts, M. & Cooper, R. (2002). Product development process implementation: Exploratory case studies in construction and manufacturing. In Annual Conference of the International Group for Lean Construction. Gramado, Brazil, pp. 1-13. Available at: www.iglc.net.

Tzortzopoulos, P., Chan, P., Cooper, R., & Kagioglou, M. (2005). Fuzzy front-end in the NHS MaST LIFT primary healthcare projects. Salford, UK, The University of Salford, SCRI (Salford Centre for Research and Innovation in the Human and Built Environment).

Tzortzopoulos, P.; Formoso, C.T.; Betts, M. (2001). Planning the product development process in construction: an exploratory case study. IGLC Conference 9th. Singapore, Singapore.

Ullrich, C. (2008). Descriptive and prescriptive learning theories. Pedagogically founded courseware generation for web-based learning (pp. 37-42). Berlin: Springer. doi:10.1007/978-3-540-88215-2_3

Ulrich, K.T.; & Eppinger, S.D. (2005). Product Design and Development. International Edition, Boston: McGraw-Hill.

Ulrich, R. Quan, X. Zimring, C. Joseph, A. and Choudhary, R. (2004). The role of the physical environment in the hospital of the 21st century: a once-in-a-lifetime opportunity, Center for health design for the designing the 21st century hospital project: 69.

Ulrich, R. S. (2000). Evidence based environmental design for improving medical outcomes. An Event Held by McGill University Health Centre, Montreal, Swiss.

Ulrich, R.; Zimring, C; Zhu, X; DuBose, J; Seo, H; Choi, Y; Quan, X.. Joseph, A. (2008) A review of the research literature on evidence-based healthcare design. Health Environments Research & Design Journal, 1 (3), p.61-125.

Ulrich, R.S. (1981). Natural versus Urban Scenes: Some Psychophysiological Effects. Environment and Behavior, 13, pp. 523-556.

Ulrich, R.S. (1984). View Through a Window May Influence Recovery from Surgery. Science, 224, pp. 420-421.

Ulrich, R.S. (1992). Effects of Interior Design on Wellness: Theory and Recent Scientific Research. Journal of Healthcare Design, 3, pp. 97-109.

Unger, P. (1968). An analysis of factual knowledge, the Journal of Philosophy, 65(6), 157-170.

Veitch, J. A. (1990). Office noise and illumination effects on reading comprehension. Journal of Environmental Psychology, 10, 209–217.

Veitch, J. A., & McColl, S. L. (1993). Full spectrum fluorescent lighting effects on people: A critical review (No. 659). Ottawa, Canada: Institute for Research in Construction.

Vickers, J. (2006) The Problem of Induction, The Stanford Encyclopedia of Philosophy (Winter 2012 Edition), Edward N. Zalta (ed.), URL = <http://plato.stanford.edu/archives/win2012/entries/induction-problem/>.

Vogt, K. (2010). Ancient Skepticism. The Stanford Encyclopedi of Philosophy. Edited by Edward N. Zalta. http://plato.stanford.edu/archives/win2011/entries/skepticism-ancient/ (accessed 02 10, 2012).

Wacker, J. G. (1998). A definition of theory: research guidelines for different theory building research methods in operations management. Journal of Operations Management 16, 361-385.

Walker, M. (2002). On the Fourfold Root of Philosophical Skepticism. SORITES, 81.

Wallace, K., & Burgess, S. (1995). Methods and tools for decision making in engineering design. Design Studies, 16(4), 429-446.

Weick, K. E. (1995). What theory is not, theorizing is. Administrative Science Quaterly 40: 385-390.

Werner, C. M., Altman, I., & Brown, B. B. (1992). A transactional approach to interpersonal relations: physical environment, social context and temporal qualities. Journal of Social and Personal Relationships, 9(2), 297-323.

Whetten, D. A. (1989). What constitutes a theoretical contribution? Academy of Management Review 14(4): 490-495.

Whitehouse, S., Varni, J. W., Seid, M., Marcus, C. C., Ensberg, M. J., Jacob, J. R., & Mehlenbeck, R. S.. (2001). Evaluating a children's hospital garden environment: utilization and consumer satisfaction. Journal of Environmental Psychology, 21, 301-314.

WHO – World Health Organisation (1946) Preamble to the Constitution of the World Health Organization as adopted by the International Health Conference, New York, 19-22 June 1946, and entered into force on 7 April 1948.

Wicker, A. W. (1992). Making sense of environments. Person-Environment Psychology: Models and Perspectives. W. B. Walsh, K. H. Craik and R. H. Price, Hillsdale: 157–92.

Wicker, A. W. & R. A. August (1995). How far should we generalize? The case of a workload model. Psychological Science 6, 39–44.

Wideman, R. M. (1990). Total Project Management of Complex Projects, Improving Performance with Modern Techniques. Presentations in five cities in India for The Consultancy Development Centre, New Delhi, India.

Wikipedia Contributors (2007a) Work breakdown structure. Wikipedia, The Free Encyclopedia. Last revision: 17/04/07. Last accessed: 18/04/07. Available at: http://en.wikipedia.org/w/index.php?title=Work_breakdown_structure&oldid=123517290.

Wikipedia Contributors. (2007b), Clinical baseline. Retrieved 7 February 11:43 UTC, 2007, from http://en.wikipedia.org/w/index.php?title=Clinical_baseline&oldid=93459215.

Williamson, T. (1997) Knowledge as Evidence, Mind, 106(424), p.717-741

Wilson, G. D. (1966). Arousal properties of red versus green. Perceptual and Motor Skills, 23, 942-949.

Wilson, I.B., & Cleary, P.D. (1995) Linking clinical variables with health-related quality of life. A conceptual model of patient outcomes Journal of American Medical Association; 273, 59-65

Womack J & Jones D. (1996) Lean Thinking, Simon and Schuster. New York.

Woodward, J. (2003). Scientific Explanation. The Stanford Encyclopaedia of Philosophy. E. N. Zalta (Ed.).

Yerevanian, B. I., Anderson, J. L., Grota, L. J., & Bray, M. (1986). Effects of bright incandescent light on seasonal and nonseasonal major depressive disorder. Psychiatry Research, 18(4), 355-364.

Zeisel, J., Silverstein, Nina M., Hyde, Joan, Levkoff, Sue, Lawton, M.P., Holmes, William (2003). Environmental Correlates to Behavioral Health Outcomes in Alzheimer's Special Care Units. The Gerontologist 43(5): 697-711.

Zimring, C., Joseph, A., Nicoll, G.L. and Tsepas, S. (2005) Influences of building design and site design on physical activity: research and intervention opportunities. American Journal of Preventive Medicine, 28 (2S2), p.186-193.

8 APPENDICES

8.1 Appendix 1 - Systematic Literature Review Process: A Discussion

This section presents an overview of systematic literature reviews (or systematic review) in the process of developing an evidence-base. The aim of this section is to clarify the main aspects of systematic literature reviews and to highlight the differences between using systematic reviews in medicine and design research. The main source of information is the Annals of Internal Medicine (Academia and Clinic – Systematic reviews series) and the ESRC series on Systematic Reviews.

Systematic literature review is an approach that has been used in different areas of knowledge (e.g. medicine, education and design) with the aim of dealing with the difficulties of integrating the results of different pieces of research. In medical research, the method was developed to help physicians to treat rare illnesses where very little information about possible treatment routes was available. In this sense, something was considered as evidence if at least two pieces of similar empirical research (e.g. treatment trials) demonstrated equal or similar outcomes. Difficulties associated with the identification of very similar studies triggered the development of a systematic approach.

The difference between systematic reviews and traditional narrative literature reviews relies on the adoption of a replicable, scientific and transparent reviewing process. The rigour related to systematic reviews aims to minimise bias through exhaustive literature searches of published (e.g. journal papers and books) and unpublished information (e.g. from e-mails and conversations with experts) and by providing an audit trail of the reviewer's decisions, procedures and conclusions (Cook *et al*. 1997b; Tranfield *et al*. 2003).

The use of systematic literature reviews has been associated with the creation of an evidence-base. An evidence-base should be consistent; therefore, the use of a systematic approach is important in establishing whether scientific findings are reliable and can be generalised across populations, within different settings, and under different treatment (Mulrow 1994).

Mulrow (1994), for instance, presents several reasons why to adopt systematic literature reviews, which include:

- To reduce large quantities of information into smaller batches;
- To integrate critical pieces of available information;
- To conduct the review in a systematic and replicable base;
- To increase the possibility of establishing generalisation;
- To assess the consistency of the studied relationships;
- To explain data inconsistencies and conflicts in data;
- To increase the statistical strength of the review through the use of quantitative methods (e.g. sensitive-analysis and meta-analysis);
- To increase precision in estimates of risk or effect size;
- To increase accuracy and improve reflection of reality.

CRAG (1996) summarise the benefits of using systematic literature reviews in two main points. The first relates to the limitations of traditional reviews and the second relates to the added strength obtained by synthesising the results of smaller studies.

It is evident that the use of a systematic approach to review the literature increases the possibility of generating good results. However, to conduct a systematic review is not an easy task. In the literature (e.g. Mulrow *et al*. 1997b, Mulrow and Cook, 1997, and Boaz, 2002) there are important issues that arise when developing systematic literature reviews, including: the definition of the research question, the selection of the cases and the integration of heterogeneous research.

First, according to Mulrow *et al*. (1997b) and Mulrow and Cook (1997), the definition of the research question is one of the most important and crucial issues. According to these authors, the first point is to establish the relevance of the subject to be investigated. The assessment of relevance can be done by submitting the first "draft" idea of the research question to a panel of experts. The feedback might be important to give focus and direction to the investigation. Subsequently, the research question should be sharply defined and include all variables to be investigated. Mulrow *et al*. (1997a) recommends the development of integrative frameworks to map out cause and effect relationships to understand the whole issues involved in the research to be done.

Once the research question is defined, the second part of conducting a systematic literature review is the definition of the criteria for case(s) selection. Meade and Richardson (1997) establish six main features which should be considered in including and appraising cases:

- The definition of the research question;
- The selection of the variables to be considered, for instance, the patient and his/her characteristics such as treatment (intervention) and outcome;
- The type(s) of study design (e.g. case studies, experiments, interviews);
- Type and form of publication (e.g. peer reviewed journal (ideally), abstracts), avoiding duplications and including papers published in different languages;
- Appraisal of the variables, for instance, the kind of patient, i.e. low, medium or high risk; the periodicity of the treatment, i.e. frequency, degree and duration; and the outcome, i.e. definitions, degree and surveillance;
- The quality of the research method, considering for instance, sample sizes, methods used to measure outcomes, appropriate description of the patient and his/her diagnosis. The methodology is most important because, according to (Meade and Richardson 1997), the methodological features of different investigations have been shown to influence the results of studies about therapy;

Meade and Richardson (1997) recommend the use of a protocol which can be considered as a check list to remember the inclusion and exclusion criteria and also to keep track of the decisions made during the research process. In medical research, for instance, the consideration of these features is very important because any difference may be an important source of variation among study results. There are also important issues related to the integration of the research results. According to Mulrow *et al*. (1997a), regardless of whether reviewers are synthesizing direct or indirect evidence , many factors can modify etiologic and prognostic associations, diagnostic accuracy, and therapeutic effectiveness. This is because study participants are often drawn from various settings and have a wide spectrum of baseline risk , disease severity, and socio-demographic and cultural characteristics.

Mulrow *et al*. (1997a) also emphasises that exposures, diagnostic strategies, interventions, and comparison groups have varying formulations and intensities. Also, different outcome measures are used in different studies, and similar outcomes are measured or reported differently. Various study designs are used, and heterogeneity of methodological features occurs within a given design. Although such heterogeneity may stimulate confidence by allowing assessment of general consistency and applicability, it may also increase uncertainty (Mulrow *et al*. 1997a).

The heterogeneity that can be found among studies is an important issue. For instance, the omission of population or setting details may generate a false idea of similarity amongst the selected cases. However, some heterogeneity is permitted in systematic reviews and there are methods to deal with heterogeneous pieces of research. These include the development of frameworks establishing cause and effect relationships or, in the case of rare single bodies of evidence, the use of narrow inclusion criteria (Mulrow *et al*. 1997a). Thus, statistics are used for validation and generalisation. In medical research, meta-analysis is a method that has been largely used to integrate research results.

Meta-analysis is a statistical method used to combine results from different studies into a single summary estimate. In medical research, the use of meta-analysis can increase power and precision of estimates of treatment effects and exposure risks (Mulrow, 1994; CRAG, 1996). However, Pignone *et al*. (2005) states that in some types of research the use of meta-analysis may not be possible, leading researchers to adopt other methods to analyse research results.

Independent of the field or area of research the challenges of conducting systematic literature reviews are related to five main issues including: formulating the right question, identifying studies related to the investigated topic, selecting the studies that are related to the investigation, assessing the studies and synthesising the results (Bravata *et al*. 2005; Chou and Helfand 2005; Hartling *et al*. 2005; Pignone *et al*. 2005; and Reed *et al*. 2005).

In summary, systematic literature reviews have been used for research with a well-defined, narrow question. All variables affecting cause and effect (i.e. outcomes) must be made explicit. There are issues related to the integration of heterogeneous pieces of research, which have been tackled through the use of statistical methods such as meta-analysis. This approach has been mainly used in medical research; however it has been also used in research on the effects of the built environment into health outcomes (e.g. Hickam *et al*., 2003 and Dijkstra *et al*., 2006). The systematic literature review should follow a well established procedure in terms of keeping track of the decisions made throughout the research process. An example of steps of systematic literature reviews is presented in the following section.

Steps of Systematic Reviews

The following section describes generic steps to be followed in a systematic literature review (Cochrane Collaboration 2001; NHS 2001; Tranfield *et al*. 2003) which include: a) planning the review, b) conducting the review and c) reporting and disseminating. These stages are further described below.

- Planning the Review

According to the Cochrane Collaboration (2001), the NHS (2001), and Tranfield *et al*. (2003) planning the review involves three main steps: a) the identification of the need for a review; b) the preparation of a proposal for a review; and c) the development of a review protocol.

Prior to beginning the review, a review panel should be formed including experts in the areas of theory and methodology, as well as practitioners. In addition, in some fields as management, it is necessary to conduct scoping studies to assess the relevance and size of the literature and delimit the subject area or topic. This also includes a brief overview of the theoretical, practical and methodological debates surrounding the field.

Further recommendations are based on the definition of the review question and organisation of a review protocol. The review question is important to systematic reviews as other aspects of the process flow from it. The protocol will be the document that contains the information concerning the specific questions addressed by the study, the sample that is the focus of the study, the search strategy for identification of relevant studies, and the criteria for inclusion and exclusion of studies in the review (Davies and Crombie, 1998). An example of a protocol is presented in Table 25 below.

Table 25 - Protocol for data extraction (adapted from Boaz *et al.* 2002)

Data Extraction Tool
Details of Publication
Author(s):
Title:
Source (**e.g. journal, conference etc.)**
Year/volume/pages/country of origin:
Institutional affiliation:
Research Details
Research question:
Aims:
Objectives:
Study design (**e.g. case study, action research, literature review**):
When was the fieldwork conducted?
Participation in the study:
Target population:
Exclusion criteria:
Recruitment procedures:
Characteristics of participants (**e.g. age, sex, social class, ethnicity, geographical location, health status, income status, other information**):
Research tools
Which research tools were used?
Where were they piloted?
Was a specific attitude scale used? Which?
Theory
Was any theory referred to in the research?
Give details:
Ethics
Was ethics committee approval obtained?
Analysis
Statistical techniques used:
Qualitative analysis techniques used:
Computer analysis tools used:
Reviewers decision
Is the study methodologically sound (see decision tools)?
Is it relevant to the review topic?

Is it to be included?

- Conducting the Review

According to Cochrane Collaboration (2001), NHS (2001), and Tranfield *et al*. (2003) the next stage is when the literature review is done (i.e. the papers, books and other sources of information are collected and selected and information is extracted from them). This stage involves the following steps: a) the identification of the research; b) the selection of studies; c) the study quality assessment; d) data extraction and monitoring progress; and e) data synthesis.

Firstly, a systematic search should begin with the identification of keywords and search terms acquired from the scoping study, the literature and discussions within the review team. The search strategy should be reported in sufficient detail to ensure that the search could be replicated. Searches should include published journals, bibliographic databases, unpublished studies, conference proceedings, industry trials and even personal requests to known investigators. The output of the search will be a list of papers that m*et al*l the inclusion and exclusion criteria.

Today, literature resources are available in databases, the researcher can perform complex searches using Booleans operators such as "and", "or" and "not" and possible truncations in some words (e.g. behavi*r retrieving behaviour and behavior or percept* retrieving perceptual, perception, perceptional and perceptive).

Secondly, the researcher should conduct a review of all potentially relevant citations identified in the search. Relevant sources should be retrieved for a more detailed evaluation of the full text and from these some can be included in the systematic review. Any inclusion and exclusion should be reported in the research protocol including the reasons for exclusions (Cochrane Collaboration 2001; NHS 2001; Tranfield *et al*. 2003).

Third, a quality assessment should be carried out. The quality assessment refers to the appraisal of a study for internal validity and the degree to which its design, conduct and analysis have minimized biases and errors (Cochrane Collaboration 2001; NHS 2001; Tranfield *et al*. 2003). Individual studies in systematic review are judged against a set of predetermined criteria and checklists to assist the process (Oxman, 1994). Dealing with qualitative research, the researcher should consider a range of criteria that might be used to appraise and evaluate studies such as the presentation of the theoretical background (Cochrane Collaboration 2001; NHS 2001; Tranfield *et al*. 2003).

Fourth, the researcher should start the data extraction and monitoring progress. To reduce human error and bias, systematic literature reviews must employ data-extraction forms. These forms often contain general information (title, author, publication details), study features and specific information (population characteristics, context of the study and an evaluation of the study's methodological quality) and notes on emerging themes coupled with details of synthesis. Links to other concepts, identification of emerging themes, and key results and additional notes also need to be included on the data-extraction form (Cochrane Collaboration 2001; NHS 2001; Tranfield *et al*. 2003).

Finally, the research synthesis is the collective term for a family of methods for summarizing, integrating and, where possible, cumulating the findings of different studies on research topic (Mulrow 1994; Tranfield *et al*. 2003). Research synthesis can vary between narrative reviews and meta-analysis. In medical research, meta-analysis has been used to aggregate the research results (Mulrow 1994). In management research interpretive and inductive approaches have been used to synthesise results. Tranfield *et al*., 2003 argue that interpretive and inductive methods, realist synthesis and meta-synthesis and derived methods have been developed to fill the gap between narrative reviews and meta-analysis.

- Reporting and Dissemination

This stage involves not just reporting the findings, but also the establishment of recommendations based on the findings and the use of the evidence-base into practice.

A good systematic review should make easier for the practitioner to understand the research by synthesizing extensive primary research papers from which it was derived. The researcher should be able to provide a broad ranging descriptive account of the field with specific exemplars and an audit trail, justifying his/her conclusions (Cochrane Collaboration, 2001; NHS, 2001; and Tranfield *et al*. 2003).

Researchers also need to report the findings of a 'thematic analysis' whether or not the results were derived through an aggregative or interpretive approach, outlining that which is know and established already from data-extraction forms of the core contributions (Cochrane Collaboration 2001; NHS 2001; Tranfield *et al*. 2003).

It can be also recommended that an extensive report including a description of the research process should be produced. This is because the development of an evidence-base stands on the accumulation of knowledge. Therefore, a detailed report of a systematic review should save time and give direction to researchers interested in extending the research. Other issues related to the conduct systematic literature reviews are described in further references included in Table 26.

Table 26 - Sources of further information on Systematic Literature Reviews

Campbell Collaboration http://www.campbellcollaboration.org/ Building on the experience of the Cochrane Collaboration, Campbell will carry out reviews of interventions in the fields of education, criminal justice and social work. The website currently includes guidance on protocol construction, specimen protocols and other information.
Cochrane Collaboration http://www.cochrane.org The Cochrane Collaboration prepares, maintains and disseminates the results of systematic reviews of research on the effects of health care. The Cochrane Library is a quarterly updated electronic database of reviews. The Cochrane manual and the reviewer's handbook are available on-line.
Evidence for Policy and Practice Information and Co-ordinating Centre http://eppi.ioe.ac.uk The Centre was originally commissioned by the DfEE to provide a resource for those wishing to undertake systematic reviews in the field of education. It will also develop and maintain a database of reviews and other educational research. Useful publications on systematic review methodologies are accessible via this site.
ESRC UK Centre for Evidence Based Policy and Practice http://www.evidencenetwork.org The Centre's Evidence Network website is designed to act as a starting point for accessing key literature and information resources on evidence based policy and practice.
Health Development Agency Evidence Base http://www.hdaonline.org.uk/evidence/eb2000 Evidence Base pulls together health promotion and health improvement evidence from a wide variety of sources. The evidence is searchable via the site which also includes quality criteria for appraising evidence.
Health Education Board for Scotland

http://www.hebs.org.uk

The HEBS Health Promotion Library Scotland is a free national information resource for health promotion and behavioural sciences. The site offers on line access to a range of databases. There is also a specialist site (http://www.hebs.com/research/) that aims to disseminate HEBS research to practitioners, policy makers and researchers.

Health Technology Board for Scotland

http://www.htbs.org.uk

The HTBS works to improve Scotland's health by providing evidence based advice to NHS Scotland on the clinical and cost-effectiveness of new and existing health technologies. Reports are available on-line.

Health Technology Assessment

http://www.hta.nhsweb.nhs.uk

This is a national programme of Department of Health funded research designed to produce user-friendly, high quality research information on the costs, effectiveness and broader impact of health technologies. Research reports are accessible on-line.

Interactive primer on systematic reviews

http://www.comp.leeds.ac.uk/comir/people/eberry/sysrev/sysrev.htm

This interactive site explains what a systematic review is and explores how and why they are carried out. The site includes a quiz to test your knowledge of systematic reviews.

National Institute for Clinical Excellence

http://www.nice.org.uk

NICE commissions reviews and provides guidance on current 'best practice' for patients, health professionals and the public. Publications are accessible through the website.

NHS Centre for Reviews and Dissemination

http://www.york.ac.uk/inst/crd

CRD carries out systematic reviews on selected topics in the health care field and maintains a database of reviews (DARE). A number of useful documents, including *Undertaking systematic reviews of research on effectiveness: CRD report no 4,* are accessible on-line.

Netting the Evidence http://www.shef.ac.uk/~scharr/ir/netting/ Netting the Evidence is intended to facilitate evidence-based healthcare by providing support and access to helpful organisations. It also provides access to useful learning resources, such as an evidence based virtual library, software and journals.
Social Care Institute for Excellence http://www.scie.org.uk SCIE is a newly established organisation. It will commission reviews of research and practice, and of the views, experience and expertise of users and carers. These reviews will be available on the website.

Systematic Literature Reviews on the effects of the built environment into health outcomes

Systematic literature reviews related to the impact of the built environment on health outcomes have been grouped into two main categories: built environment and patient's health outcomes and built environment and the improvement of healthcare staff work effectiveness. The built environment and infection control can be considered as a third category that has not been addressed in this report.

Studies related to how the built environment influence patient's health outcomes are focused mainly on identifying the factors, elements or components of the built environment that have an impact on patients' health. The research methods generally consider the results from exposure of the patient to a specific condition in the built environment e.g. noise, colour or light (Beauchemin and Hays, 1996b; Devlin and Arneill, 2003; Lawson, 2003; Zeisel, 2003; Altimier, 2004; Joseph, 2006; Dijkstra *et al.*, 2006). Physical, physiological and psychological effects are then observed. However, it should be noted that there are many other factors that may affect health outcomes e.g. time in hospital, healing time, and use of drugs (Evans, 1984; Block and Garnett, 1989; Haggard and Werner, 1990; Werner *et al.*, 1992; Grosenick, 2000; Day, 2002; Baskaya *et al.*, 2004; Batljan and Lagergren, 2004; Clarkson 2004; and Daykin and Byrne 2006). Therefore, causal relationships cannot be established.

Research on the built environment and the improvement of staff work effectiveness focuses on the characteristics of built environment that affect staff performance. The underlying premise is that the built environment should be supportive not just to patients, but also to staff. It is believed, for instance, that reducing levels of staff stress contributes to improved health services and increased work effectiveness. One study in this field relates improved building layout to reduction of staff walking distances. This may contribute to improved health outcomes by increasing the proportion of time staff dedicate to patients (Gralton, 2001; Ulrich, 2000; Leather *et al.*, 2003a; and Ulrich *et al.* 2004).

Studies related to the built environment and infection control focus on reducing infection levels through design solutions. An example of the research in this category is the investigation of the relation among sunlight, windows dimensions and the reduction of contamination levels (Ann Noble Architects, 2003; DOH, 2004b; Sehulster *et al.,* 2004; DOH, 2005; Bencko and Schejbalova, 2006; General Health Protection and DOH, 2006).

Although these three categories provide a general overview of the research field, there is more. For instance, a parallel can be drawn between healthcare environments and offices. Characteristics of offices and how they impact on work effectiveness is a subject that has been investigated (e.g. Block and Garnett, 1989; Veitch, 1990; Leather *et al.*, 2003b; Stone, 2003). The effect of the built environment on health has also been investigated by theorists, mainly from the field of psychology.

In respect to data collection and preparation for this study, a first framework was developed with the objective of mapping cause and effects relationships (Figure 23). The framework considered built environment features and characteristics as causal elements and physiological and physical outcomes were considered as effects. The framework also considered physical outcomes caused by psychological effects stimulated by the built environment.

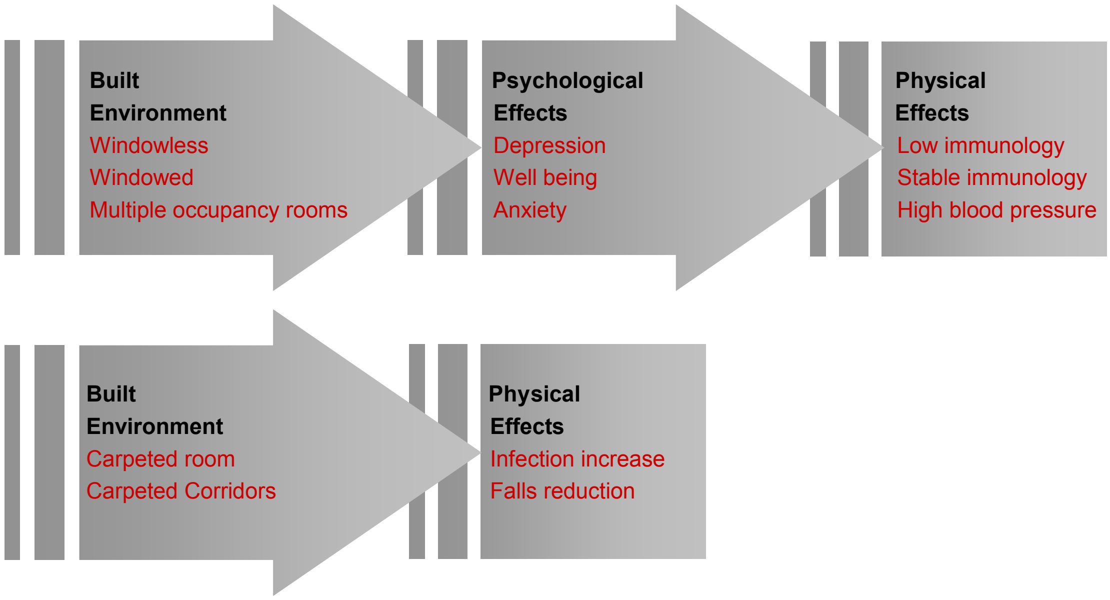

Figure 23 - Framework of cause and effects relationships

After a few attempts at using the framework, it was considered inappropriate. The main reasons were:

- Cause and effect relationships were not clear. For instance, research has been conducted looking at indirect evidence. Examples of indirect evidence are: the built environment causing stress on staff and consequently affecting the delivery of healthcare and impacting on patients' satisfaction (e.g. Ulrich *et al.*, 2004). Another example is noise, which is caused by the use of the built environment and causing sleeplessness of patients (e.g. Ersser *et al.,* 1999).
- The definition of 'built environment' and 'health outcomes' varies in the literature. The impact of features related to the built environment (such as noise, wayfinding and temperature) on health outcomes have been investigated (Altman, 1993). However, the connections between these features with the physical characteristics of the built environment have not been addressed – making it difficult and sometimes impossible to identify the root cause;
- Different research methods have been used to measure similar outcomes. For example, Lawton (2001) conducting research about environments for people with Alzheimer highlights that data can be gathered from surveys, questionnaires and direct observations. According to Lawton (2001) the debate about research method remains opened because there are too many design variations to be empirically tested and also because "*...the interface of person and environment in real*

situations may be simply too complex to capture in a linear experimentally controlled test."

As a consequence, a second framework was developed (Figure 24). The objective of this framework was to group the studies according to their knowledge area rather than the built environment characteristics. The framework considered four different areas of knowledge (ergonomics, fabric and ambient investigated, aesthetic and services) and three categories of patients' outcomes (psychological, physical and physiological outcomes).

The second theoretical framework was also considered inappropriate for data collection because many relevant aspects presented in the selected abstracts and papers were not considered (e.g. patients' condition, which includes: age, gender and acquired illness or injury). Patients' condition was considered as a third group of variables to be integrated in the framework because it has been shown that the outcomes from a specific built environment characteristic may vary according to patients' configuration. For instance, artificial light may cause damage in preterm babies' vision, but not in adults (Miller *et al.* 1995; Joseph, 2006).

Two other frameworks with different emphasis emerged during the research process. For instance, frameworks considering problem-solving paradigm, problem-orientation and cause-sub-cause and effect relationships were developed and considered inappropriate. These frameworks are presented in Codinhoto *et al*., (2008).

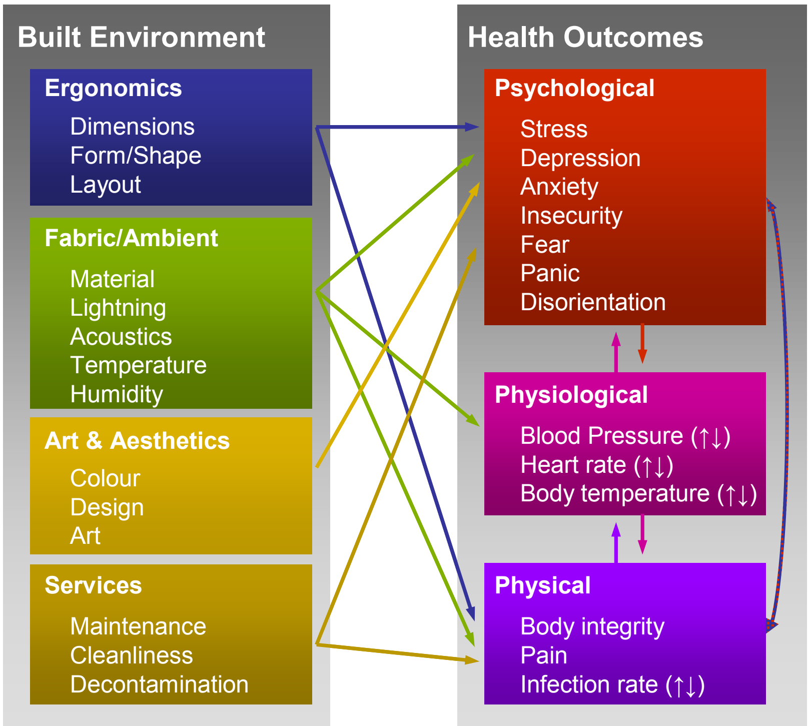

Figure 24. Knowledge areas and health outcomes framework

8.2 Appendix 2 - List of academic journals publishing articles about BE&HO

Table 27 – Academic Journals Publishing Articles about BE&HO

No.	Name of the Journal	NOPQ
1	ACCID. ANAL. & PREC.	1
2	ACHEMS (ABSTRACTS)	1
3	ACTA PAEDIATR SCAND	3
4	ADDICTION	1
5	ADDICTIVE BEHAVIORS	1
6	ADVANCES IN ENVIRONMENTAL PSYCHOLOGY	1
7	AEROSPACE MEDICINE	2
8	AGE AND AGEING	2
9	AGE AND BEING	1
10	AGNP SYMPOSIUM	1
11	AMERICAN ASSOCIATION OF NURSE ANESTHETISTS (AANA)	1
12	AMERICAN INDUSTRIAL HYGIENE ASSOCTION JOURNAL	1
13	AMERICAN JOURNAL OF ALZHEIMER'S CARE AND RELATED DISORDERS AND RESEARCH	1
14	AMERICAN JOURNAL OF ALZHEIMER'S DISEASE AND OTHER DEMENTS	1
15	AMERICAN JOURNAL OF CLINICAL HYPNOSIS	1
16	AMERICAN JOURNAL OF CRITICAL CARE	2
17	AMERICAN JOURNAL OF EPIDEMIOLOGY	2
18	AMERICAN JOURNAL OF HEALTH PROMOTION	1
19	AMERICAN JOURNAL OF HOSPITAL PHARMACY	1
20	AMERICAN JOURNAL OF INFECTION CONTROL	10
21	AMERICAN JOURNAL OF MEDICINE	2
22	AMERICAN JOURNAL OF OBSTETRIC GYNAECOLOGY	1
23	AMERICAN JOURNAL OF PSYCHIATRY	1
24	AMERICAN JOURNAL OF PUBLIC HEALTH	3
25	AMERICAN JOURNAL OF ROENTGENOLOGY	1
26	AMERICAN SOCIETY OF INTERNAL MEDICINE	1
27	ANAESTHESIA	3
28	ANAESTHESIA AND ANALGESIA	1
29	ANAESTHESIA AND INTENSIVE CARE	1
30	ANAESTHETIST	1
31	ANNALES FRANCAISES D'ANESTHESIE ET DE REANIMATION	1
32	ANNALS OF EMERGENCY MEDICINE	1
33	ANNALS OF INTERNAL MEDICINE	3
34	ANNALS OF THE NEW YORK ACADEMY OF SCIENCES	1
35	ANNUAL REVIEW OF NURSING RESEARCH	1
36	AORN JOURNAL	10
37	ARCH. GERONTOL. GERIA TR.	1
38	ARCH. INTERN MED.	1

No.	Name of the Journal	NOPQ
39	ARCH. SURG	2
40	ARCHIVES OF DISEASE IN CHILDHOOD	7
41	ARCHIVES OF ENVIRONMENTAL HEALTH	2
42	ARCHIVES OF OPHTHALMOLOGY	1
43	ARCHIVES OF PSYCHTRIC NURSING	1
44	ARCHIVES SURGERY	1
45	ATMOSPHERIC ENVIRONMENT	1
46	BEHAVIOR AND THE NATURAL ENVIRONMENT	1
47	BEHAVIOR THERAPHY	1
48	BEHAVIORAL MEDICINE	1
49	BIO NEONATE	1
50	BIOLOGICAL PSYCHIATRY	1
51	BIRTH	2
52	BJM	1
53	BMC PSYCHIATRY	1
54	BMC PUBLIC HEALTH	1
55	BRITISH JOURNAL OF MUSIC EDUCATION	1
56	BRITISH JOURNAL OF PSYCHIATRY	1
57	BRITISH JOURNAL OF RHEUMATOLOGY	1
58	BRITISH MEDICAL BULLETIN	1
59	BRITISH MEDICAL JOURNAL	8
60	BRITISH MEDICAL JOURNAL	1
61	BUILDING AND ENVIRONMENT	1
62	BUILDING SCIENCE	3
63	BURNS	1
64	CANADIAN INSTITUTE OF MINING AND METALLURGY (CIM)	1
65	CANADIAN INTERIORS	1
66	CANADIAN JOURNAL OF ANAESTHESIA	1
67	CANADIAN MEDICAL ASSOCIATION JOURNAL (CMAJ)	1
68	CANCER NURSING	2
69	CHEMICAL SENSES	5
70	CHEST	5
71	CHILD DEVELOPMENT	1
72	CIFR TECHNICAL REPORT (GRANJi) VALLEY STATE UNIVERTY)	1
73	CIRCULATION	2
74	CLINICAL EFFECTIVENESS IN NURSING	1
75	CLINICAL INFECTIONS DISEASES	1
76	CLINICAL INFECTIOUS DISEASES	1
77	CLINICAL NURSE SPECIALIST	2
78	CLINICS IN PERINATOLOGY	1
79	CONSULTING PSYCHOLOGY JOURNAL: PRACTICE & RESEARCH	1
80	CRITICAL CARE MEDICINE	5
81	CRITICAL CARE NURSING QUATERLY	7
82	CRITICAL CARE NURSING QUATERLY	1

No.	Name of the Journal	NOPQ
83	CRITICAL NURSING QUATERLY	1
84	DESIGN	1
85	DESIGN DK	1
86	DESIGN MANAGEMENT JOURNAL	4
87	DESIGN STUDIES	3
88	DESIGN WEEK	5
89	DIALYSIS & TRANSPLANTATION	3
90	DIMENSIONS OF CRITICAL CARE NURSING	7
91	EARLY CHILD DEVELOPMENT AND CARE	1
92	EARLY HUMAN DEVELOPMENT	2
93	EBM	1
94	ELECTROENCEPHALOGRAPHY AND CLINICAL NEUROPHYSIOLOGY	1
95	EMERGING INFECTIOUS DISEASES	1
96	ENVIRONMENT AND BEHAVIOR	34
97	ENVIRONMENTAL HEALTH: A GLOBAL ACCESS SCIENCE SOURCE	1
98	ENVIRONMENTAL INTERNATIONAL	2
99	ERGOCON 95	1
100	ERGONOMICS	4
101	EUROPEAN JOURNAL OF CANCER CARE	2
102	EUROPEAN JOURNAL OF PHYSIOLOGY	1
103	FX	1
104	GERIATRIC NURSING	1
105	GRAPHICS INTERNATIONAL	1
106	GROUP PRACTICE JOURNAL	1
107	HEALTH AND LUNG	15
108	HEALTH CARE MANAGEMENT REVIEW	2
109	HEALTH PHYSISCS	2
110	HEALTH PSYCHOLOGY	2
111	HEALTH SERVICE JOURNAL	2
112	HEART & LUNG	1
113	HOLISTIC NURSING PRACTICE	1
114	HOSPITAL AND COMMUNITY PSYCHIATRY	4
115	HUMANS FACTORS	3
116	I.D. (USA)	2
117	IMMUNOLOGY AND ALLERGY CLINICS OF NORTH AMERICA	1
118	INDOOR AIR (SUPLEMENT)	3
119	INFANT BEHAVIOR AND DEVELOPMENT	1
120	INFECTION CONTROL	4
121	INFECTION CONTROL AND HOSPITAL EPIDEMIOLOGY	5
122	INFECTIOUS DISEASE CLINICS OF NORTH AMERICA	1
123	INTENSIVE CARE MEDICINE	3
124	INTERIORS	3
125	INTERNATIONAL ARCHIVES OF OCCUPATIONAL ENVIRONMENTAL HEALTH	1
126	INTERNATIONAL JOURNAL BIOSOCIAL RESEARCH	2

No.	Name of the Journal	NOPQ
127	INTERNATIONAL JOURNAL OF HEALTH CARE QUALITY ASSURANCE	1
128	INTERNATIONAL JOURNAL OF MENTAL HEALTH NURSING	1
129	INTERNATIONAL JOURNAL OF NURSING STUDIES	1
130	INTERNATIONAL JOURNAL OF PSYCHOANALYSIS	1
131	J RES MUSIC EDUC	1
132	JAHA	2
133	JAMA	4
134	JOGNN	1
135	JOURNAL OF ABNORMAL PSYCHOLOGY	1
136	JOURNAL OF ADOLESCENT HEALTH	2
137	JOURNAL OF ADOLESCENT HEALTH CARE	1
138	JOURNAL OF ADVANCED NURSING	12
139	JOURNAL OF ADVERTISING	1
140	JOURNAL OF AFFECTIVE DISORDERS	3
141	JOURNAL OF AMERICAN GERIATRICS SOCIETY	1
142	JOURNAL OF AMERICAN MEDICAL ASSOCIATION	2
143	JOURNAL OF APPLIED BEHAVIOUR ANALYSIS	1
144	JOURNAL OF APPLIED PSYCHOLOGY	3
145	JOURNAL OF APPLIED SOCIAL PSYCHOLOGY	2
146	JOURNAL OF ARBORICULTURE	1
147	JOURNAL OF ARCHITECTURAL AND PLANNING RESEARCH	4
148	JOURNAL OF BIOLOGICAL RHYTHMS	1
149	JOURNAL OF BUSINESS RESEARCH	1
150	JOURNAL OF CANCER NURSING	1
151	JOURNAL OF CLINICAL ANESTHESIA	1
152	JOURNAL OF CLINICAL MICROBIOLOGY	1
153	JOURNAL OF CLINICAL MONITORING & COMPUTING	1
154	JOURNAL OF CLINICAL NUTRITION	1
155	JOURNAL OF COMMUNITY HEALTH NURSING	1
156	JOURNAL OF CONSUMER RESEARCH	3
157	JOURNAL OF COUNSELING PSYCHOLOGY	1
158	JOURNAL OF DESIGN HISTORY	1
159	JOURNAL OF DEVELOPMENTAL & BEHAVIORAL PEDIATRICS	1
160	JOURNAL OF ENVIRONMENTAL PSYCHOLOGY	17
161	JOURNAL OF GENERAL PSYCHOLOGY	1
162	JOURNAL OF GERIATRIC PSYCHIATRY	1
163	JOURNAL OF GERONTOLOGICAL NURSING	4
164	JOURNAL OF GERONTOLOGY	1
165	JOURNAL OF HEALTH CARE INTERIOR DESIGN	1
166	JOURNAL OF HEALTH CARE MARKETING	1
167	JOURNAL OF HOSPITAL INFECTION	5
168	JOURNAL OF HOUSING FOR THE ELDERLY	1
169	JOURNAL OF HUMAM STRESS	1
170	JOURNAL OF HYGIENE-CAMBRIDGE	2

No.	Name of the Journal	NOPQ
171	JOURNAL OF INFECTION	1
172	JOURNAL OF INFECTIOUS DISEASES	1
173	JOURNAL OF INTERIOR DESIGN	1
174	JOURNAL OF LIGH AND VISUAL ENVIRONMENT	2
175	JOURNAL OF MARKETING	3
176	JOURNAL OF MUSIC THERAPY	10
177	JOURNAL OF NURSING ADMINISTRATION	4
178	JOURNAL OF NURSING CARE QUALITY	1
179	JOURNAL OF NURSING PRACTICE	1
180	JOURNAL OF NURSING RESEARCH	1
181	JOURNAL OF NURSING STUDIES	1
182	JOURNAL OF OCCUPATIONAL AND HEALTH PROFESSIONALS	1
183	JOURNAL OF PERIANESTHESIA NURSING	1
184	JOURNAL OF PERINATOLOGY	1
185	JOURNAL OF PERSONALITY AND SOCIAL PSYCHOLOGY	4
186	JOURNAL OF POST ANAESTHESIA NURSING	2
187	JOURNAL OF PSYCHIATRY	1
188	JOURNAL OF PSYCHOSOCIAL NURSING AND MENTAL HEALTH SERVICES	1
189	JOURNAL OF PUBLIC HELATH MANAGEMENT & PRACTICE	1
190	JOURNAL OF REHABILITATION COUNSELING	1
191	JOURNAL OF RESPIRATORY CRITICAL CARE MEDICINE	1
192	JOURNAL OF RETAIL BANKING	1
193	JOURNAL OF RETAILING	2
194	JOURNAL OF RHEUMATOLOGY	1
195	JOURNAL OF SAFETY RESEARCH	4
196	JOURNAL OF SOCIAL ISSUES	2
197	JOURNAL OF SOCIAL PSYCHOLOGY	1
198	JOURNAL OF THE AMERICAN GERIATRIC SOCIETY	1
199	JOURNAL OF THE ILLUMINATING ENGINEERING SOCIETY	1
200	JOURNAL OF THE JAPANESE INSTITUTE OF LANDSCAPE ARCHITECTS	1
201	JOURNAL OF THE ROYAL COLLEGE OF PHYSICIANS OF LONDON	1
202	JOURNAL OF THE ROYAL SOCIETY OF MEDICINE	1
203	LANCET	1
204	LANDSCAPE AND URBAN PLANNING	4
205	LANDSCAPE RESEARCH	1
206	LIGHTING DESIGN + APPLICATION	1
207	LIGHTING RESEARCH TECHNOLOGY	7
208	LIPPINCOTT'S CASE MANAGEMENT	1
209	MARKETING LETTERS	1
210	MARKETING NEWS	1
211	MEDICAL CARE	1
212	MENTAL HYGIENE	1
213	METROPOLIS	3
214	MILLIEU THERAPHY III	1

No.	Name of the Journal	NOPQ
215	MODERN HEALTHCARE	1
216	MODERN HOSPITAL	2
217	NAACOG'S CLINICAL ISSUES IN PERINATAL AND WOMEN'S HEALTH NURSING	1
218	NATNEWS	1
219	NEONATAL NETWORK	1
220	NEW DESIGN	1
221	NEWBORN AND INFANT NURSING REVIEWS	1
222	NHS REPORT (ENGLAND)	1
223	NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH	1
224	NURSING ADMINSTRATION QUATERLY	2
225	NURSING MANAGEMENT	2
226	NURSING RESEARCH	13
227	NURSING STANDARD	1
228	NURSING TIMES	4
229	ONCOLOGY NURSING FORUM	6
230	OTOLARYNGOLOGIC CLINICS OF NORTH AMERICA	2
231	OTOLARYNGOLOGY HEAD AND NECK SURGERY	3
232	PAIN	1
233	PATIENT EDUCATION AND COUNSELLING	2
234	PEDIATRICS	5
235	PERCEPTUAL AND MOTOR SKILLS	6
236	PERFUMER AND FLAVORIST	1
237	PHARMACOTHERAPHY	1
238	PLACES	1
239	PREVENTION IN HUMAN SERVICES	1
240	PROQUEST NURSING JOURNALS	1
241	PSYCHIATRY RESEARCH	1
242	PSYCHOLOGICAL MEDICINE	2
243	PSYCHOLOGICAL REPORTS	2
244	PSYCHOPHARNACOLOGY BULLETIN	2
245	PSYCHOSOM. MED. PSYCHOL. (PPmP)	1
246	PSYCHOTERAPY: THEORY, RESEARCH, PRACTICE, TRAINNING	1
247	PUBLIC HEALTH NURSING	1
248	QUALITATIVE HEALTH RESEARCH	2
249	QUALITY IN HEALTH CARE	1
250	RADIOLOGY	1
251	RESEARCH IN NURSING AND HEALTH	5
252	RESEARCH NURSING HEALTH	2
253	SCANDINAVIAN JOURNAL OF CARING SCIENCES	1
254	SCANDINAVIAN JOURNAL OF INFECT. DIS.	1
255	SCANDINAVIAN JOURNAL OF PSYCOLOGY	1
256	SCHOLARLY INQUIRY FOR NURSING PRACTICE: AN INTERNATIONAL JOURNAL	2
257	SCIENCE	1
258	SCIENTIFIC AMERICAN	1

No.	Name of the Journal	NOPQ
259	SLEEP	1
260	SOCIAL SCIENCE MEDICINE	4
261	SOCIOMETRY	1
262	SPACE '90 (PROCEEDINGS)	1
263	SURVEY OF OPHTHALMOLOGY	1
264	TECHNICAL BULLETIN OF THE FACULTY OF CHIBA UNIVERSITY	1
265	TEXTILE RESEARCH JOURNAL	1
266	THE AMERICAN JOURNAL OF ALZHEIMER'S CARE AND RELATED DISORDERS & RESEARCH	2
267	THE AMERICAN JOURNAL OF HEALTH-SYSTEMS PHARMACY	2
268	THE AMERICAN JOURNAL OF MEDICINE	3
269	THE AMERICAN JOURNAL OF PSYCHIATRY	1
270	THE AMERICAN SURGEON	1
271	THE ANPHI PAPERS	1
272	THE CANADIAN MEDICAL ASSOCIATION JOURNAL	1
273	THE CENTER FOR INNOVATION IN HEALTH FACILITIES	1
274	THE DESIGN JOURNAL	1
275	THE GENERAL PSYCHOLOGY	1
276	THE GERONTOLOGIST	6
277	THE HEALTH CARE SUPERVISOR	1
278	THE JOURNAL OF AGING AND HEALTH	1
279	THE JOURNAL OF ARCHITECTURAL & PLANNING RESEARCH	2
280	THE JOURNAL OF BONE AND JOINT SURGERY	2
281	THE JOURNAL OF INFECTIOUS DISEASES	2
282	THE JOURNAL OF PEDIATRIC NURSING	1
283	THE JOURNAL OF PEDIATRICS	6
284	THE MEDICAL CLINICS OF NORTH AMERICA	2
285	THE MODERN HOSPITAL	2
286	THE NEW ENGLAND JOURNAL OF MEDICINE	10
287	THE PRACTITIONER	1
288	THE WESTERN JOURNAL OF MEDICINE	1
289	TRANSPORTATION RESEARCH RECORD	1
290	US OFFICE OF TECHNOLOGY ASSESSMENT, ALZHEIMER'S DISEASE AND ASSOCIATED DISORDERS	1
291	WESTERN JOURNAL OF NURSING RESEARCH	2
292	WORK & STRESS	1
293	WORLD ARCHITECTURE	1

8.3 Appendix 3 - Glossary of Terms

It is acknowledged the fact that many of the terms were defined according to their meaning found in specific dictionaries. Whilst, the meaning provided in dictionaries represent the common understanding about the term and are not academically sound, for the purpose of this exercise, it was considered appropriate.

- Behaviour: (noun). The physical activity of an organism, including overt bodily movements and internal glandular and other physiological processes, constituting the sum total of the organism's physical responses to its environment. The term also denotes the specific physical responses of an organism to particular stimuli or classes of stimuli. US behaviour (Colman, 2001).
- Built Environment: The surroundings or conditions, created and built through human intervention, where a person, animal or plant lives or operate.
- Characteristic: [countable usually plural]: a quality or feature of something or someone that is typical of them and easy to recognize (Longman, 2000).
- Component: (noun). A part or element of a larger whole, especially a part of a machine or vehicle (Soanes; Stevenson, 2004).
- Element: [countable]. One part or feature of a whole system, plan, piece of work etc, especially one that is basic or important (Longman, 2000).
- Ergonomics: (noun). A branch of industrial/organizational psychology or occupational psychology concerned with fitting jobs to people rather than people to jobs. Ergonomists design jobs, equipment, and work places to maximize performance and well-being and to minimize accidents, fatigue, boredom, and energy expenditure. Also (especially in the US) called biotechnology, human factors psychology, or engineering psychology. See also knobs-and-dials psychology, personnel psychology. ergonomic adj. ergonomist n. One who practises ergonomics.[From Greek ergon work + nomos management, from nemein to manage] (Colman, 2001).
- Function: (noun) 1. an activity that is natural to or the purpose of a person or thing: bridges perform the function of providing access across water | bodily functions. [mass noun] practical use or purpose in design: building designs that prioritize style over function. A computer operation corresponding to a single instruction from the user (Soanes; Stevenson, 2004).

- Health: Broadly defined as a "state of complete physical, mental, and social well-being and not merely the absence of disease or infirmity" (WHO 1946).
- Health Outcomes: Mental health seems to be achieved when the patient changes its behaviour as demonstrated in (Higgs, gabb, christenfeld in Groos 1998)
- Physical: (adjective). 1. Relating to the body as opposed to the mind. Involving bodily contact or activity: a physical relationship. 2. Relating to things perceived through the senses as opposed to the mind; tangible or concrete. 3. Relating to physics or the operation of natural forces generally (Soanes; Stevenson, 2004).
- Physiological: Pertaining to chemical and physical functions in a normal, healthy person (Oxford University Press, 1998).
- Physiological functions: Processes carried out by organs, tissues, and cells to maintain health. Major physiological functions include respiration, coordination, excretion, circulation, and reproduction (Oxford University Press, 1998).
- Physiology: (noun). The study of the functioning of organisms; also the working of a particular organism or one of its organs or parts (as in the physiology of the human ear).[From Greek physio- of or relating to nature or natural processes, from physis nature, from phyein to cause to grow + logos word, discourse, or reason] (Colman, 2001).
- Setting: [countable]: 1 the place where something is or where something happens, and the general environment (Longman 2000).
- System: (noun) 1. A set of things working together as parts of a mechanism or an interconnecting network; a complex whole: the state railway system | fluid is pushed through a system of pipes or channels (Soanes; Stevenson, 2005).
- Well Being: Psychological well-being (mental well-being) is a mental condition characterised by pleasant feelings of good health, exhilaration, high self-esteem and confidence, often associated with regular physical activity (The Concise Oxford English Dictionary, 2007).

8.4 Appendix 4 – Evidence data base: data preparation

Problem-oriented description: The original idea of this framework was to identify targets for the improvement of health outcomes and the proposed solutions to achieve the targets.

Objectives	Solutions		
To reduce the numbers of errors make by staffs, doctors, nurses, etc.;	Windows near tasks type; Visual communication improvement Reduce the noise level Improve wards conditions (space organization, facilities, etc);		
To reduce the level of contamination;	Air conditioning – ventilation quality Hand washing Humidity control – humidifier water Private rooms (burned patients)		
To reduce the level of inpatient STRESS, ANXIETY, BLOOD PRESSURE and HEART RATE;	Reduce noise	From equipment From conversation (in and out side) From floor Snoring at night	
	Improve patient control	Noise level Light level Communication Temperature control Social interaction Ventilation control	
	Improve sleep quality	Noise control	Earplugs (failed for some) Sound conditioner (failed)
	Music	Introduce music periodically	
	Social interaction	Furniture sizes Furniture layout Private x social bedrooms	
To reduce the patients accidents;	Type of floor (carpet x vinyl)		
To reduce treatment time and drugs necessities	Windows with landscape view Well furniture that promote social interaction		
To control body temperature	Temperature control Humidity control		

Impact of Colour on Humans: This framework was developed with the objective of compiling information about different colours on humans. The variables presented in the middle are related to the health outcomes identified in the literature review.

Positive outcomes were listed on the left side and negative outcomes on the right side. Coloured squares were used to represent the investigated colour. Filed squares meaning that colour has an impact and empty squares meaning that no effect was identified. The number in the middle of the squares is related to the source of information that is listed below.

	Negative Impacts							Health Outcome	Positive Impacts						
	V	I	B	G	Y	O	R		R	O	Y	G	B	I	v
Psychological								**Depression**							
					2		2	**Anxiety**				2	2		
								Stress							
								Insecurity							
								Fear							
								Panic							
								Confusion							
								Satisfaction							
								Wellbeing							
		4					1	**Arousal**				1, 4			
Physiological			3	3	3		3	**Respiration**	3		3	3	3		
								Coordination							
								Excretion							
								Circulation							
								Reproduction							
Physical			3	3	3		3	**Heart Rate**	3		3	3	3		
								Pain							
								Hypothermia							
								Blood Pressure							

1. Wilson, G., D., (1966)
2. Jacobs, K., W., and J., F., Suess (1975)
3. Jacobs, K., W., and F., E., Hustmyer, Jr., (1974)
4. Nourse, J., C., and R., B., Welch (1971)

Patient related investigation: This framework was developed with the aim of associate the perception canals (5 senses), patients' health outcomes and the route causes of the outcomes.

SN		BE	Underlying	Effect on	What have	Effect on

		Feature	Cause	building	been done	patient
	Vision	Light	Lack of sun light	Shadows, exaggerated images and sensory distortion	Skylights, solariums, atriums and courtyards	Reduction of suffering, reduction of drug confusion
			Light wave frequency		Use of different light wave frequencies	LF (red): less sleep-wake frequency and more sleep; HF (blue) greater sleep-wake frequency
		Window preferenc e	Small dimensions and few transparency	Lack of light and ventilation	Transparency and dimensions improvement	
		Window	Lack of landscape view	-	Care with hospital design in sense of provide a natural view	Shorter hospitalizations, less need for pain medications
		Art	Modern art (abstract images)	Depression	Substituted by landscape paints	
	Hearing	Noise	Conversation and environment (+70dBA), machines on ICU (90dBA); heavy footsteps	Sleeplessness, heart rate and blood pressure increase, perturbation,	Time planning for interaction with staffs and family, reduction of patients and machines per room, acoustic building treatment, soft shoes for nurses, maintenance of squeaky beds and trolleys, dripping taps, plastic urine bottle instead glass, telephones relocation;	Reduction of pain medication;
		Music			Controlled exposure	Infants weight increase, stress reduction, shorter hospitalization;
			Machines (e.g. haemodialysis machine);			

	Touch					
	Taste					
	Smell	Air	Air system	Infection rates alternate (increase and decrease)	Air systems have been analysed	Infection rate decrease after hit replacement and increase after knee replacement (52).

Illness related investigation: This framework was developed with the aim of associate health outcomes with illness.

Illness	What have been done	Effect on building	Underlying Cause	Effect on patient
Alzheimer and dementia	Visual access stimulation through signage (e.g. floor patterns)	Use of signposts and signage in the building	Way finding disorientation	Personal autonomy and quality of life increase
Geriatric rehabilitation	Changes on the type of flooring (vinyl substituted for carpet)	Reduced housekeeping floor maintenance		Satisfaction related to safety, access and aesthetics were improved
Children with psychiatric problems	Density per room have been controlled	Resize the bedrooms	Density psychological condition on patients	Improve behaviour
Psychiatric related	Room size	Private rooms substituted multiple occupancy		Multiple rooms increase isolated passive behaviour

Performance related investigation: this framework was developed with the aim of associate the performance of physical built environmental characteristics with health outcomes.

	Problem	Underlying Cause	Effect in health	What has been done
Ventilation	Quality of air in rooms	Windowless or poor dimension	Non commented	Windows size increase
	Quality of air in wards	Design's criteria are non reliable (43)	Non commented	Ventilation standards have been reviewed
	Infections by aspergillosis	Lack of infection control during construction phase	During construction the level of infection by aspergillosis increase	Use of Portable High-Efficiency Particulate Air (HEPA) filtration

	Problem	Underlying Cause	Effect in health	What has been done
	Infections by Staphylococcus (48)	Conduction through exhaust ducting and opened window	Before to solve exhaust problem patients were continuously infected	Orientation for ITU designers that architectural design should take into account the position of external and internal ventilation structures such as ventilation exhaust grilles and windows that can be opened
	Infections by Acremonium in surgical centre	Ventilation system were switched on once a week and allowed Acremonium development in the humidifier water	Before to solve the problem, patients in surgical centre were infected mainly after to turn on the ventilation system	Implementation of established hospital infection control practises in the outpatient setting.
	Air quality in surgical centre	Bad air conditions	Sepsis development	Operation in surgical centre with ultraclean air associated with prophylactic use of antibiotics (50,58)
Humidity	Humidity in infants incubator	Lack of humidifier or humidity control	Loss of water in infants at low level humidity	Utilization of vapour pressure
	Relation between humidity and body temperature	Increase of humidity level	Body temperature increase	Systems to control humidity
	Humidity level definition		Between 80-90% rapid respiratory rates, higher body temperature and lower death rate (57)	
Temperature	Water loss through convection	Heat system	Water loss in infants	Radiant warmers influence evaporating through convection and the use of plastic blanket reduced radiant power demand. (53/54)

Setting related investigation: this framework was developed with the aim of associate health outcomes to specific settings within hospitals.

Unit of treatment	Environment	Population Studied	Research	Health outcome or finding
Heart Treatment	CICU (Cardiac Intensive Care Unite)	628 first attack of myocardial infarction (66)	Sunny versus dull rooms	Patients stayed short time in sunny room; Mortality was higher in dull rooms;
	Coronary care units	11 patients treating myocardial infarction (70);	Effects of environment in delirium	People moved to environment of nearly normal surroundings presented less delirium and anxiety.
		75 patients with suspected myocardial infarction (84)	Effect of music and synthetic silence in anxiety and physiologic parameters (heart rate, blood pressure and skin temperature)	Significant improvement in physiologic parameters
Babies treatment	Neonatal Intensive Care Unit (NICU)	41 preterm infants (67)	Lighting (cycled and non-cycled lighting) in infant growth and development	In lighting conditions: great rate of weight gain; less time on the ventilation and on phototherapy; enhance motor coordination.
		290 infants (91)	Lighting 55 foot-candles and 15 foot-candles in incidence of retinopathy	No difference was observed in the incidence and severity of retinopathy of prematurity or visual damage.
	Non specified	96 babies (69)	Exposes infants under 90 foot-candles and 10 foot-candles	Infants under high level of illumination showed reduced levels of hyperbilirubinemia or prematurity
	Nursery	41 infants (85)	Light and noise in infants	Longer time sleeping, less time feeding and weight gain on infants in controlled light and noise environment
		Non specified (65)	Effects of high level illumination in retinopathy of prematurity	Contribute for oxygen-induced retinopathy of prematurity
	Premature babies room	Non specified	Effects of warm and cold environment on infants	Improved clinical behaviour on war setting and the contrary on cold settings

Unit of treatment	Environment	Population Studied	Research	Health outcome or finding
Hospital	Non specified	Patients, staffs and visitors (77);	Effect of visual and performing arts in healthcare - through interviews	Diminished stress level; better mood and absent minded related to worries concerned to medical problems.
	Non specified	100 critical care nurses (81)	Stress related to noise	Some individuals have a greater degree of stress resistance resources
	Non specified – probably room	24 post-operative patients (gynaecological and obstetrics) (86)	The effect of music on pain	Blood pressure, pulse rate showed significant results; respiratory rate and pain was not significant;
	Floor	Non specified	Comparative study relative infection rates in carpeted and vinyl environment	Carpet not rise the contamination level
	Bedroom	Non specified	Social and non social interaction through design of furniture (seating) patterns	Satisfaction increase and anxiety reduction
	Corridors	Non specified	Utilization of maps you-are-here to assist people (way finding)	Better orientation
		Nurses	Causes of poor efficiency in way finding	Is still a research topic
	Staff bedroom	Resident staff	Effects of room size in staffs	Small rooms increase levels of noisy, darkness and narrowing perception and reduce satisfaction
	Ward	Non specified	Effects of changes in design ward (bay ward and nightingale)	Noise reduction and satisfaction increase
CCU (Critical Care Unit)	Non specified	105 patients (80)	Sleep using sound conditioner to block out unwanted sounds	Noise pollution may not be controllable on individual basis.
	Non specified	100 nurses (82)	Most distressing noises	Beeping monitors; alarms or equipment and telephones
	Non specified	Inpatients in CCU	Comparative studies in windowed and	The incidence of disorientation, depression,

Unit of treatment	Environment	Population Studied	Research	Health outcome or finding
			windowless ITU	hallucinations and delusions was more than twice in the windowless unit.
Burnt Hospital	Ward	Burnt patients	Infection rates in patients in private rooms versus patients in wards	Improves survival in patients in private spaces.
Eye Hospital	Bedroom	Post-operative patients	Flexibility on choose bedrooms design (private and multiple occupancy)	Lack of satisfaction in private bedroom

Non-building related investigation: this framework was developed with the aim of compiling research results related to devices, treatments and therapies associated to health outcomes.

Subject	Population Studied	Research	Health outcome and or findings
Drugs		Perceived effect end effectiveness in drugs with different colours	Green and blue may have more sedative effect; red and orange may have more stimulant effect (68);
Music	Non specified (78)	Effects of music therapy on anxiety	Reduction of anxiety level
	20 subjects (83)	Pain reduction through music listening and imagery stimulation	Significant time effect for heart rate, systolic and diastolic blood pressure. No significant results were found in pain reduction;
Earplugs	Non specified (79)	Effect of earplugs on sleep	Helped patients to sleep but may not be suitable for every patient.

Non-health outcomes related: this framework was developed with the objective of compiling information from studies presenting non-health related impacts of the built environment on humans.

Environment	Population Studied	Research	Findings
Office	36 paid subjects (71)	Examine the effects of red versus a blue office environment on a typing task and mood	Red: more anxiety and stress scores; blue: more depression score; people who switched showed more arousal score.
	70 employees (93)	Privacy and it correlation with the degree of physical enclosure	There is correlation between privacy and physical enclosure and satisfaction. Masking

Environment	Population Studied	Research	Findings
			sound system, carpeting and semi-sound absorbing panels do not create speech privacy enough
	Non specified	Task performance in windowed and windowless offices	Non conclusive
Non-specific environment related	20 subjects (72)	Arousal level under red and green colour	Red induces to a higher arousal level;
	14 subjects (76)	Arousal level under violet and green light	Violet to green showed more arousal level than green to violet.
	48 subjects (73)	Colour (red, green and achromatic) environment effect on activities requiring psychomotor and judgmental functions	Subjects exposed showed hand tremor and motor inhibition;
	40 subjects (74)	Effects of colours (red, yellow, green and blue illumination) in anxiety.	Red and yellow showed higher scores than blue and green;
	Non specified (75)	Effects on Galvan skin response (heart rate and respiration)	Non-significant results in heart and respiration rates.
	80 subjects (87)	Effects of noise under active task involvement as opposed to passive exposure	The ability to engage and improve in task performance under noise conditions does not change
	Non specified (92)	Effects of illumination in noise (generated by conversation) stimulation.	Low levels of noise were measured in low-illumination conditions

Non-building-related studies:

- Hospitalization increase stress – cause: financial problems and lack of information related to illness and their consequences (59);
- Stressed patients developed respiratory infection, clinical colds and infection more than those non-stressed (60);
- People exposed to fluorescent light showed relative excess of melanoma lesions on the trunk (63);
- Non-healthy related:
- Sunlight: window size did not affect the occupant emotional state or degree of satisfaction, but increase the feeling of relaxation (61);
- Sunlight: significant effect for sunlight penetration on job satisfaction, intention to quit and general being (64).

8.5 Appendix 5 – Observation of Design Meetings

Design Meeting 1

Fracture Clinic (L4)

Attendees: CR1 and DT1

CR1: There is no big space for coffee where people can sit and wait.
I should be involved, as I'll be using it in the next 25 years.
You can go endless in the layout of the room, as we don't know where the X-ray is going to be.

DT1: The drawing - all got problems within it.
Eg. Cul-de-sac

CR1: Wouldn't have time to communicate.

DT1: Review of minutes - Whatever the brief says should be kept.

CR1: OK with respect to nurses - but what about the clinicians - have they been listened to.

DT1: (Going through the brief)
We changed the brief so many times.

CR1: 2 or 3 checks.

CR1: Oxford hospital as a model.

DT1: Because it is not PFI the scale is 15M2 per patient waiting.

CR1: Minimise reception area, as it is not needed.

DT1: The schedule size is 68m2 to seat 40 people.

DT1: The numbers, we should forget them because we don't know how many patients we are going to get - we don't know how many we get now.

CR1: There will be other clinics
More clinics
The numbers are wrong!
One patient doesn't visit once because there are multiple processes.

DT1: Briefing: 2 receptionists
Typical morning is 70 or 80 patients
By 11.30am they have been through
But 9.00 - 11.30.
3 people for each time slot
2 X-ray, 1 dressing
6 people for every 10 minutes
At least 36 waiting

CR1: For 2 clinics - 2 times more people

DT1: People for plasters - independent
People for therapy also

CR1: What impact?

DT1: The flow.

CR1: Why don't you let me do the drawings - I know what the flows are!

CR1: All depends on where the imaging is.
We don't need people mingling around.

DT1: We are limited in terms of window.

CR1: Having a window in plaster seems not right.
DT1: Hierarchy - physiotherapy with the window
DT1: (The model is brought to the room)
CR1: Flow (draws a dependency diagram) in and out.
Staff room with lockers for handbag.
CR1: Store location.
One close to plaster.
Stationery store? Photocopier?
DT1: Plasters
Orthotics
Another - physiotherapy
DT1: (need) to up date the brief and send them out
CR1: Why has he got an office twice as big as ours?
DT1: Schedule (briefings)
…
CR1: Re explanation of services flow.
DT1: Relocate - photocopier space close to offices
In summary - patients, they always go back to the waiting (room)
(Diagram) like a rose

Design Meeting 2

Ground Floor - L1 / Nuclear Medicine - L2 / Patient flow (L2 to L6)
Attendees: DT2, CR2

DT2: Present the model
DT2: Flow and process
Main issue - to get rid of a big bin of waste - there is control - it needs to be signed
What can be moved to the front - the part in the front should be in the main area - the layout will be re-configured
They are selecting the one who can be moved.
3 zones: staff/cold/hot
Issue: radioactive waste
Toilets: 2 adult hot/cold
Mix 1 child / hot
1 cold waste / can be 2 (?) Yes.
Pet switch - 3 infection rooms
With a loo
Segregate Pet (separate flow better, esp. corridor) patient from others
Much stronger radiation
They lie (down) for one hour
CR2: Cluster of pharmacy and injections
If it can be achieved it would be nice
In the brief there is a diagram on page 17 .

We don't know what types of software we are going to have in the future but we hope that we will be able to collect and process and dressing at the same time - does allowing staff to 'scan' (watch) patients all the time they go through the corridor impact on patient privacy?

Processing room between 2 Gama rooms but observation only in 1

DT2: Thank you for the pre-work.

Design Meeting 3

Level 3 / 2nd phase

Attendees: DT1; DT2; DT3, CR2

DT3: High level windows

Day light through the atrium

Open plan is not ideal - it seems not ideal but

DT2: Need for cabinets - storing files of patients

DT3: 1000m2 - can be more

It can be broken into different areas within partitions

DT2: confidential conversations

DT3: not everything is confidential

DT2: shared offices should be used for more confidential work

CR3: files have been kept at home and it should be brought back

(?) Photocopier - central/shared

(?) Windows in the office?

DT3: High level windows

CR3: (?) sound observation (phone calls/talk/ etc.)

DT3: Don't know yet.

Culture change.

CR3: Trust HQ?

Is there a lot of flow between these 2 departments - floor/level 5.

DT3: What is above?

DT2: medical school / audiology / day care

CR2: there are people who work in the office the whole day (not like her) did they get a good environment?

Comparison with PCT

Division with glass / a bit of partitioning

They are now good and quiet

DT2: How can you move out if you need to have a meeting?

DT3: central meeting rooms available

CR3: they are 15-20 minutes meetings

Drawings available on the Internet

DT3: needs more detailing

DT2: DT2 allocated 66M2 / there might be some flexibility

CR3: Privacy is an issue in an open plan

Photocopy room close to coffee making area

DT3: People can talk comfortably and exchange ideas.
Next meeting ->

Design Meeting 4

Macmillan nurses: 3rd floor

Attendees: DT2 and CR4

DT2: Explain 2 phases - this building is located in phase 1 - podium kind of
Clinical and anaesthetic are separated
Open plan space - shared with clinical nurses and staff
Drawings are not ready
Open plan due to maximise use of daylight
Neighbour car parking which might compromise natural light from the left end site
How appropriate it is - first impressions

CR4: confidential conversations
In the current office the 3 persons do the same work
It might be disturbing to other staff
Highly emotional conversation - can't have background noise

DT2: In the other office - client required a type of partition in soundproof area

CR4: The brief can suffer alterations

DT2: Currently they are allocated 4-person/office

CR4: They might expand to 7 i.e. 3 additional people

DT2: Friday - she needs to be aware of that
3 people means 18M2 additional

CR4: Who are the specialists?

CR4: The 3 specialist nurses would be better if allocated with them - swapping

DT2: In this phase (1:200) is still difficult location of the department in relation to the palliative care / oncology.

CR4: The Macmillan nurses in the current design are the same of the palliative care
(* document to get schedule of accommodation)

DT2: If the nurses need to spend more time in the palliative then space can be used for the 3 extra people required

CR4: locality is fine

Who is above us?

DT2: Imaging.

DT2: Action to clarify whether the nurses can be relocated in palliative
Design meeting on Friday to sign off
Who signs off?
Open plan is OK as it is sound proof.

CR4: Where are the secretaries coming from?

DT2: Halley and Latilla buildings - managers
All in the one area from

CR4: drawings?

DT2: It is quite complicated

You will have a home for some
You will be able to move in 3 years after approval
AOB comment on meeting on Friday

Design Meeting 5:
Endoscopy Administration - L3 / Anaesthetics office
Attendees: DT2, CR5 and CR6

CR5: No contact with patients
Occupancy 2 (people) in the office based full-time
The clinical staff in and out
Need 2 and 3 clinical
DT2: allocated 6 people
CR5: 6 should be OK
DT2: open plan idea and has natural light - it is appropriate?
CR5: part of the work is done through the phone which are not too sensitive (patients and nurse)
For cases of cancer diagnosis, patients are invited to return to the hospital for a face-to-face conversation
DT2: glass divisions are necessary
CR4: not necessarily but some privacy is needed when having clinical conversations through the phase
DT2: sharing with specialist nurses is OK?
CR5: seems ok.
DT2: Explain where they are - stage 1
Floor by floor
Is the location practical?
CR5: Yes!
CR5: We are moving
DT2: Why?
CR5: -
DT2: decant plan
CR5: timescale?
DT2: summer this year OK
Planning permission
1 - 1.5 years to delineate the decant
DT2: car parking issues
Negotiation with horse club - park and ride alternative
CR5: being close with colleagues is very helpful

DT2: started it again
There will be 2 versions - open plan and the other with partitions

Which areas really need to be sound proof?

CR5: briefing - 6 nurses - they are never at the same time there - they can keep 4 in open plan and 2 in private

CR6: sensitivity of the conversation is our issue - needs privacy

Nurse coordinator + ??? = admin team

Because they are admin team and the nurses need to be together because they will have sensitive conversations

DT2: Glass (sound proof) is ok?

CR6: yes.

If you are a manager you should have your own office because you need to talk to staff in private.

CR6: open plan - somewhere - satisfaction levels are low - ‘they hate it’.

We are talking about year ahead, aren’t we?

DT2: Yep.

CR5: Clusters - Admin / clinical staff / nurses

CR6: Why that person got an office - she is in the community all the time.

Those two could share.

DT2: they are all 2 people offices.

Revisiting the schedule.

CR6: What about temp accommodation?

DT2: decant plan has been discussed and has not been approved.

CR6: There is a person to stop the planning

Neighbours haven’t been consulted

DT2: When it will happen

Might have in the Internet

CR7: what if we don’t get the money

DT2: the money may not be released at once

There is a sign that we will get the money - 3T is priority

CR7: We need to be decant on this site

CR6: some staff might just leave during the decant

Huge issue about summer

Like to move to Brighton General

CR6: concerns for services that does not generate income

CR6: a lot of people will be retired by the time.

Design Meeting 6

Therapies

Attendees: DT2, CR8, CR9, CR10, CR11 and CR12

CR8: No big gym upstairs - only in the neuro area.

CR8: There is an important issue - no. of beds.

DT2: Explanation of the site / phases

Decant plan is mentioned. Prep physic / Latilla , HQ

CR11: (?) Chapel - disassemble

CR11: (?) Where people will be decanted
CR8: Depends - the area to be decanted there is no patients - only admin people
CR8: Is over 3 years - quite long
CR8: Audiology is staying?
DT2: Yes - part of it.
CR8: Imagine with all the light going to them? They don't need
CR11: Therapies got no light? That is what happened in the Children's Hospital.
CR11: How many beds?
DT2: Don't know - difficult to evaluate but it is not less
DT2: Elton John is not moving (stays here)
DT2: Therapy space
CR11: There is only one CT room in the Neuro floor and it does not even meet the OT needs
Not sure if OT knows
DT2: This is an issue between OT and Neuro not 3T and OT
CR8: 3T responsibility is to provide a space which is appropriate for service
DT2: Neuro has to talk to OT
Important wards / medical wards
CR10: Ward design - should we be involved with the design team?
DT2: Yes, probably.
DT2: Physio/OT has spaces in 3 floor and how is going to split and function is up to the Physio/OT team.
CR12: Dining / sitting area for staff in the wards?
DT2: Yes!
DT2: The drawings used are not the last version
CR11: 4 Bariatric beds - not too bad!
CR8: Hot desk for everybody not just physicians
DT2: Therapies Level 1
Need a schedule of accommodation
CR8: Although we lost the gym we didn't get any other room - for diabetes for example.
The schedule was fixed
DT2: Principles - if you don't need the space you don't need (it)
CR12: Concern
DT2: Dietician - John's dietician was removed
DT2: Education - having diabetes should be close
We have not agreed with what has been given
CR11: MSQ / Physiotherapy Therapy & dieticians
No but there is not an issue
DT2 Open plan - more light - more people in less area
You can choose to go close - but would affect light
CR11: What about confidential conversations
At least one office for confidential conversations
CR11: When you pick up the phone you don't know what the conversation will develop
DT2: 9M2 for 1 person / 12M2 for 2
CR8: Go to Anaesthetics now and see that all the offices / majority are empty
CR11: Staff getting together - should be in a secured area rather than in a large café area
They need a constant professional base

CR11: They all have lunch at the same time because patients have lunch at the same time
You might end up having 50 people together

CR8: It can be phenomenally noisy area

DT2: Changing soon - 60 female/20 male

CR11: ? lockers ?

DT2: Not sure - will check

CR8: Area for staff to leave their bags / coats

CR11: Why such a big wait?

DT2: The area you've got is what your asked for.

CR11: If the waiting area was removed there will be more space?

CR11: That will not meet our needs.
Can we change the layout to accommodate diabetes?

CR11: No need for reception - no inpatients coming down to this space

CR8: Small reception area

DT2: Speech therapy - is she OK with what was given to her?

CR8: However, because she thinks that there is our space in the therapies areas

CR8: Reception can be reduced
Not happy with the space given but we need to think positively to make the most of it

CR10: No need for reception area

DT2: If you need more space - you need to write a letter to the change management team/core team from the heads of therapy
11.00 meeting with Level 1.

DT2: Central meeting space (?)
There are some central meeting spaces

CR11: Why do we need laundry and DV?

DT2: Because it is in the schedule.

CR8: Do you have to have it due to infection control?

CR8: We need to clean things - if we send them over, they get lost.

CR8: Get in touch with JC; check washing machine

CR8: When we have been asked to fill the schedule - we're told to tell them what you've got - no growth - and from the original this has been eroded.

CR11: The ADK know is not big enough for the demand.

CR11: We need to have more ADL kitchen.

CR11: They need to talk between themselves about the shared spaces
Speech and language - treating by the bed-side - they will be happy

CR11: They did very well!

DT2: Therapies is spread all around the new facility and it is difficult to visualise and explain what they have got!

CR8: Office base!

DT2: Need to talk with Fractures to see what space is given

CR11: Speech and language get xxx space somewhere else, they don't need to be in the therapies area

DT2: Someone needs to talk to Speech and Language (: J)

CR10: I will.

DT2: Which chair rooms don't need light can be swopped with staff Rest Rooms.
Quiet and treatment needs light.

CR11: Amalgamate laundry/DV and disposal.
Hold.

CR8: Can the architects change the colours so we can see what is patient area and what is staff/admin area?

CR11: Can we have glass walls?

CR8: We need flexibility in the office more.

DT2: How many people are permanently in their offices?

CR8: All of them.

CR8: We need more space!

DT2: You need to focus on how much area you need instead of where is going to be and demonstrate that.

CR11: eg. We don't have a space there at all (diabetics).

DT2: Office space - in level 7 there are 7 desks (neuro/stroke) for therapies - if that needs to come down - somewhere would that be OK?
There is an issue because not all the clinical space has been achieved.

CR11: Not really - preferably.

DT2: Patient / staff split
Light
Not enough area
Remove Disposal
Size of ADL kitchens and wheelchair
Not happy with open plan - noisy and confidentiality

CR11: There is an issue of space - not being enough .
Students? / growth
What if we increase our staff levels?
Meeting tomorrow at 10.00/11.00

CR11: There is no space in the corridor area.
There will be a lot of travelling time

DT2: You need to talk to Cardiac if you need a space within their area.

CR11: Decant issues.

? When are the decant plans being discussed?

Design Meeting 7

General design meeting communication changes in the programme and in the design

The plan of the building has been altered. Most of the drawings will have to be done again. The total area has been reduced to what was expected previously.

The protocol was set as architectural meetings with department meetings. There were two sets of meetings arranged: in the first one major adjustments would've been asked and in the second one only minor adjustments; not been possible to make new requirements. With the changes in the site they don't know what is going to happen because ' they can't have more meetings ' (?) to confirm ! The difficulty is, now the stakeholders have seen the drawings and they assimilate in their minds the plans and the floors they've been put. With this change you have to present all again and 'we' don't know whether or not they will be able to make changes or if they are going to like it.

Manoeuvrability between physicians and therapists

Design Meeting 8

Therapies

Attendees: DT4, CR8, CR13, CR14, CR15, CR16

DT4: Explaining the changes.

CR13: Areas missing - needs a copy of the schedule

CR8: Diabetes is not there.

DT4: Originally it was intended to more diabetes floor ----- close to therapies. Diabetes is not 3Ts. The reason Therapies is because it is currently in the demolition zone.

CR13: What about hand therapy?

DT4: it has to be reduced because of costs.

No doubt about the need, but the money is not enough.

There is diabetes office in Oncology.

DT4: We do need at least one dietician within the Physio area.

DT4: 2 rooms - one in the clinic / one in the office.

Going through the schedule.

The schedule - area in the wards

If you have therapy in the floor improve accessibility - but if they are all different is more likely to be used in each floor, why do they have to be in the floor.

She mentioned new ways of delivery - giving some examples.

CR13: It might be good to go there and see if they are good.

DT4: Decisions need to be made very quickly - the area has not been used - not good investment. 5 medical wards. 3 spaces of 30M2. HDL kitchen - OK where it is.

CR13: If the one bedroom with en-suite bathroom are more like home - that would OK for OT, Physio

DT4: In two buildings they tend to use the stairs instead of the step up .

CR13: The problem with that is that they cannot hold in both sides

DT4: It's the light in the stair height for Physio. The fine ones are here and it can be adapted to their needs.

CR13: 'Territorially' - Physio doesn't want to do it in front of everybody because they spit and Their condition.

CR13: Step and parallel bars / balls

There is an area in Barry building

DT4: It should be fit for purpose - I don't want to do something that is not.

The new gym for inpatients has increased from 9 to 30M2.

Quiet rooms - can be used for OT and Diabetes because these are single bedrooms

CR8: Storage space - for equipment and for confidentiality?

DT4: We don't call them Imp gym - something rehabilitation

CR15: Laundry is good for infection control.

DT4: In the Neuro they are struggling with space - would be OK to have team in the same space?

CR13: Yes, as soon as area is not reduced, it is beneficial.

DT4: There is a therapy room. I think this is their treatment room. * Different names - confusing. In the future, hand-held instead of a desk with PC.

DT4: Neuro wanted a space for therapy but didn't put (down). Stroke has an office for therapy. Neuro/Stroke got a big gym.

In 5/6 years time.

CR14: General medical -

CR13: The office need to be relocated so 'they' can join.

DT4: Schedule

DT4: The disposal area might not be necessary.

CR14: Laundry space / for xxx of the wheelchairs

CR13: (laundry space above) - will check if they are allowed to

CR8: wheelchair rooms and HDL rooms don't need light

DT4: Can wheelchairs go to FM

CR8: No they want to keep it together.

Frosted glass - light - but privacy.

DT4: Windows need to be sorted.

CR13: Is it going to be worse?

DT4: Nope, there is acoustic treatment.

CR14: 4 - 2 person office in the open plan

CR13: staff rest room - for staff to eat - public coffee - level 6

Design Meeting 9

Anaesthetics

Attendees: DT4, DT4, CR17, CR18 AND CR19

DT5: Inside out/outside in

Changes in the building

Better structure

Same area - no space lost - but different position

Go through the principles because the 1:200 drawings have not been updated

CR17: The area provided currently has not achieved their needs: 50 consultants + 50 trainers

CR17: Boxed and coxed

Interview - briefing library and little meeting

Loose one loo

Cleaner is FM room - in the lost loo

DT5: Schedule

4 loos and 1 assisted - they want 2 loos and 1 assisted

Photocopier - out

CR17: we've got 40 people coming from Neuro to us and they are not in Neuro

DT5: Drawing will change anyway.

College tutors instead of

CR17: 5/6 people - hot desk

DT5: hot desk and rooms for private meetings and pigeonholes

What do you call a desk?

For students / a straight line bending with PCs
For clinicians 'L' shapes
?Open plan?

CR17: No - too noisy / why you cannot fit 4 desks

DT5: We need to design wider
Modern standards - we need to make a person in a wheelchair to have access
How many rooms of 20M2 I need to fit 50 consultants?
* Forget that

DT5: What do you need - 50 Junior doctor benching
Is it a problem to split the space in 3

CR17: The only thing we have concern is that we don't have a big space for meeting

DT5: The meeting room is moved to an actual area where you book (maximise use)

CR17: Issues with booking system

CR17: ad-hoc meetings are often
The department is growing - future-proof

DT5: different approach to the offices is what we need.
You are very visual - * interesting

DT4: It seems it is more labelling than anything.

DT5: No it is not, is reconfiguration
The whole meeting room thing needs to be discussed

Design Meeting 10

Facilities Management

Attendees: DT2, DT3 and 5 CR (Waste, Security, 2M&E and IT – CRFM)

DT3: Floor by floor
Endoscopy - decontamination is centralised

CRFM: If is 'out' there is a problem because a trolley with durties might be crossing public areas - There is not a service circulation
Swift are they enough in floor 1 ->
Is the area OK
Service link through the Therapies area to the (?) ______ area

CRFM: the stairs / public are they open or closed?
If they are open they compromise team security

DT3: Still in debate

CRFM: Cashiers / public - security issues have been considered?

DT3: Yes.

CRFM: cash-point - where is it?

DT3: 6 th floor, preferably close to the entrance because it reduces security issues - people don't need to get inside the building

CRFM: lockers for outpatients - they need to get enclosed

DT2: Yes

CRFM: Type of doors - may compromise temperature, also security issues

CRFM: location and shape of the storage room - should be squared - 10M2 is fine but - size of barn

CRFM: radioactive waste is an issue

* DT2 and Gary don't know that they layout has changed

CRFM: power supply across the bridge

CRFM: room for medical gases - isolated?

M&E - about 30M2

CRFM: Air condition? How long it would take to make the building air tight in case of epidemic.

CRFM: In modern buildings they have an area for electrical distribution in each floor which cannot be seen on these drawings

DT2: They are in the schedule

CRFM: Machines and stuff needs to have extra meetings in separate

CRFM: Wireless devices and hand-helds

Some space for storage and trolleys is needed

CRFM: Space to lock the trolley for PCs or wireless devices.

Level 3

CRFM: is there one external door for

- Areas for 'big' stuff - tubes / electrical cables
- Electrical and mechanical store is missing

12M2 for plumbing store ~ 20M2 for M&E

CRFM: Move the reception of supplies nearer the entrance

- Congestion in the area because is the same area where delivery is done for the other building

CRFM: the layout needs to be changed a little bit to reach the flow

- Toilets - no need
- Need to segregate the flow to the library from the rest to avoid people coming to the wrong area

CRFM: I don't like all my people in one area and managers in another area - useful if they can be put closer - swap - M&E to discuss

CRFM: The data centre - to receive the PCs

DT3: IT room?

CRFM: Estates & Facilities and M&E&B clusters - they need discussion

DT2: What is the message to the architect

CRFM: My people together doesn't matter where

Is that a second entrance?

Junction of phase 1 and 2 can be for smokers

CRFM: Where is the disposal room

There will be loads of waste there

CRFM: Is there a waste person

DT3: There is

CRFM: Needs to talk to waste people

DT2: There are a couple of things that are in the schedule but not in the drawings!

Level 4

CRFM: Cameras for security
Unify to capture movement around the corner - instead of cameras
CRFM: Power / waste / security
CRFM: Is circulation space enough
CRFM: The disposal room close to the FM lifts
CRFM: the biggest life should be big enough
CRFM: Flow - heavy in terms of PTF - heavy flows
DT2: They will never go from A&E to fracture clinic
CRFM: BSMs ? Loads of IT and power
CRFM: 1:50 for phase 1 and 2?
DT2: 1:200 for FBC

Level 5 Neuro / Trauma

DT2: The layout will change a lot/dramatically due to comments from the department
CRFM: Power / waste / security / IT Hub
DT2: Clarification on how lifts are going to work is needed - dirty/clean
CRFM: Is there a flow planned - tec service - How is going to work?
CRFM: We would like a flow for dirty separate from clean
CRFM: security - patient flows on both sides?
DT2: Yes
CRFM: reception 24 hours?
CRFM: endoscopy store - secure store 30/40 grand

Level 6

CRFM: Café and retail is the wrong place
No-one will come there
Considering where the car park is you will not get people there unless they take the lift
DT3: views might attract them
CRFM: We are not happy - may be a gym area ?
DT2: debate about centralising the staff rest room - located in the 6 th floor
CRFM: might bring people in the café then!

Phase 2 - Private patients in a public building - Level 7

CRFM: Waste - ok
Power - ok
Trolleys, computers on wheels
DT2: they reduced the 'area' for nurses as they used to congregate
DT2: more mobile space
CRFM: I just don't want staff (staff base) complaining to me that they want more PCs and I don't have space to place them

Security - ok
DT2: are change for linear per floor
CRFM: doesn't work
DT2: Nurses raised the issue already

Level 8

CRFM: 10 more night beds? Where?
DT2: 2 instead?
CRFM: where they are going to sleep
CRFM: where the plumbing
CRFM: concerns about the size of the area for nurses

Levels 9/10/11 - medical wards / Level 12 – HIV / Helipad

CRFM: - lifts dedicated and linked to trauma
- five flight issues - what they need to bring one in
CRFM: Doctors mess?
Fire fight - issues within the meeting
- 75% single bedrooms
CRFM: Multifactor
EBME? BSMS?

Design Meeting 11
Espec Services / Clinical offices / Non clinicians
Attendees: DT2, DT3, DT4, DT5, CR2, CR16, CR20, CR21 and CR22

Level 3

DT5: Inside out/outside in
Reshaping!
Swap in position from previous version
DT2: Structural is best – volumes going straight down
There isn't a separated entrance for staff.
DT5: more space for - care for older spiritual nurses /
DT2: open plan was a bit of shock first
Privacy / confidentiality /
Partition and sound proof
DT5: * people / staff wearing two hats
DT5: specialty zones - clinical and nurses zones
Mix of open plan with quiet offices
Hierarchic divisions
DT2: medical secretaries

CR2: all together is OK but not much mixed with surgery secretaries
DT5: open plan -> more light
CR2: glass partitioning
DT5: the partitioning should give you acoustic insulation
DT4: the fabric absorbs the sound
Clarifications about storage for each person
DT5: The NHS is the only place where space plan doesn't work
CR2: Bristol Hospital has an open plan
DT5: light and flexibility - in case more staff came in the impact is minimum
CR2: separate zones - I can't see where we are
It seems we are breaking in(to) groups
DT4: we need (to know) who needs to be close to whom?
CR2: in the current layout
CR2: they didn't understand where they were in the drawing
They need clusters in zones
CR16: loads of phone calls, noise
- open plan?
DT5: to get people to visit open plan layout
DT2: grey doors and walls for the offices in the core of the open plan
DT5: Smoking persons - into open plan
6M2 for storage / meetings / beverage

Storage

CR20: notes on the wall ------------- diagrams
The desks are 'L' or squared?
DT5: depending on who we are buying it from
Client: courier point - tracking documents
DT5: ? A second area for all?

Phase 2 - Level 3

DT5: light of phrase 2 is reducing - more compact building
CR2: Quiet room - to talk to patients and family to be used at times
DT2: they have patients coming to this - see floor
DT5: separate in the current plan areas where they will have patient comings
* they will try to make it in a way that patients don't need to go inside up the building
DT5: we are getting to a point where all the shared offices are not shared anymore as they are getting 'labels'.
We need to design according to schedule of accommodation
DT2: the only people who really have confidentiality are the medical legal clinical and subject access to the office.
Occupational health - is open plan - not sure if they will be OK with open plan didn't meet them yet
CR2: occupational health does not have security / issues
Meeting rooms close the entrance so headquarters can be there

Division department

DT2: OH - separate - their own entrance

CR20: ideally they need 3 entrances

DT3: switchboard needs a separate entrance

DT5: OK if there is space in the level

Would be better?

All: Yes

All: but it is not a problem if they are there

DT5: If they really want 'L' shape it can be worked out.

8.6 Appendix 6 – Design process models

8.6.1 Markus and Maver process model

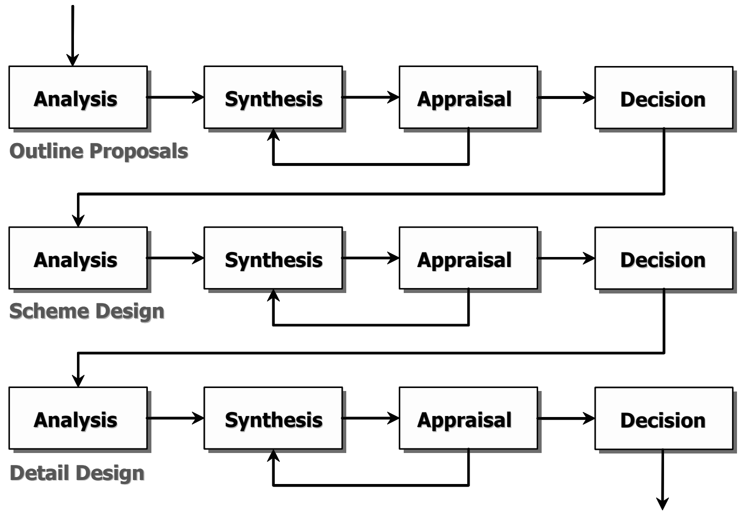

Figure 25 - The Markus/Maver map of the design process (Source: Lawson, 2006).

8.6.2 Archer process model

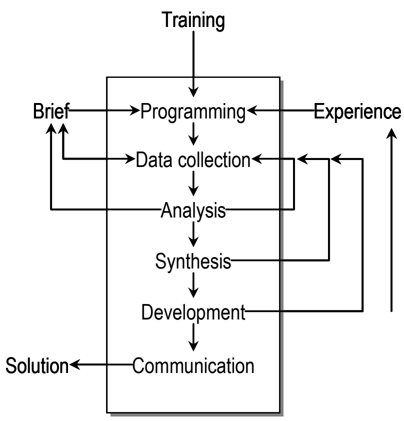

Figure 26 - A breakdown of basic design procedure

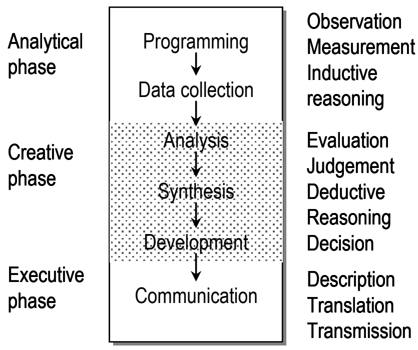

Figure 27 - The main phases of design

8.6.3 Hubka and Eder process models

Level 1 – General model of design

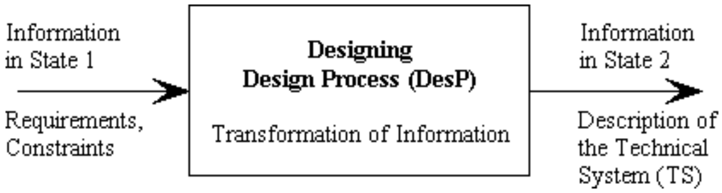

Figure 28 - "Black Box" Block Diagram of the Design Process (Hubka and Eder, 1996)

Level 2 – Transformation system

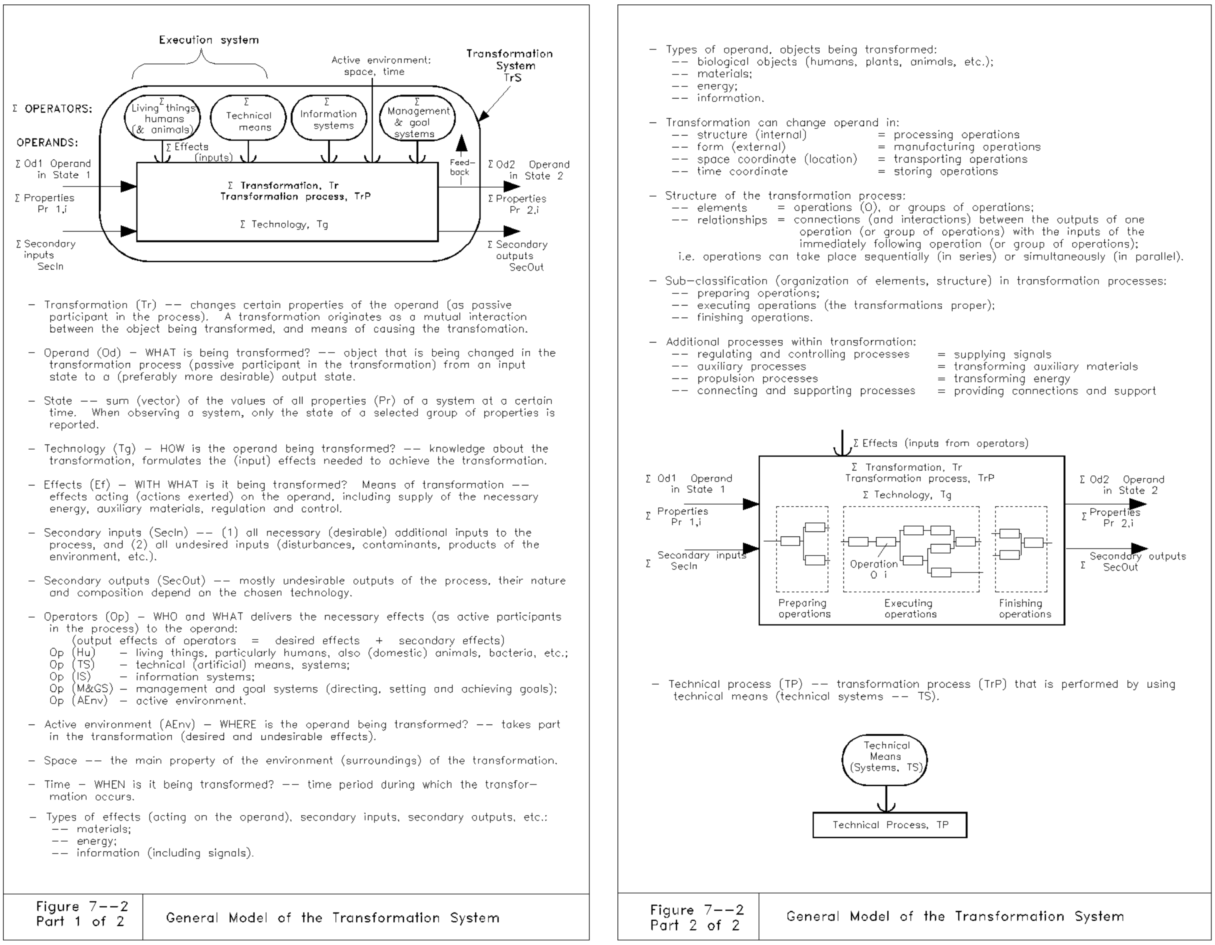

Figure 29 – General model of the transformation systems – parts 1 and 2 (Hubka and Eder, 1996)

Level 3 – Technical system

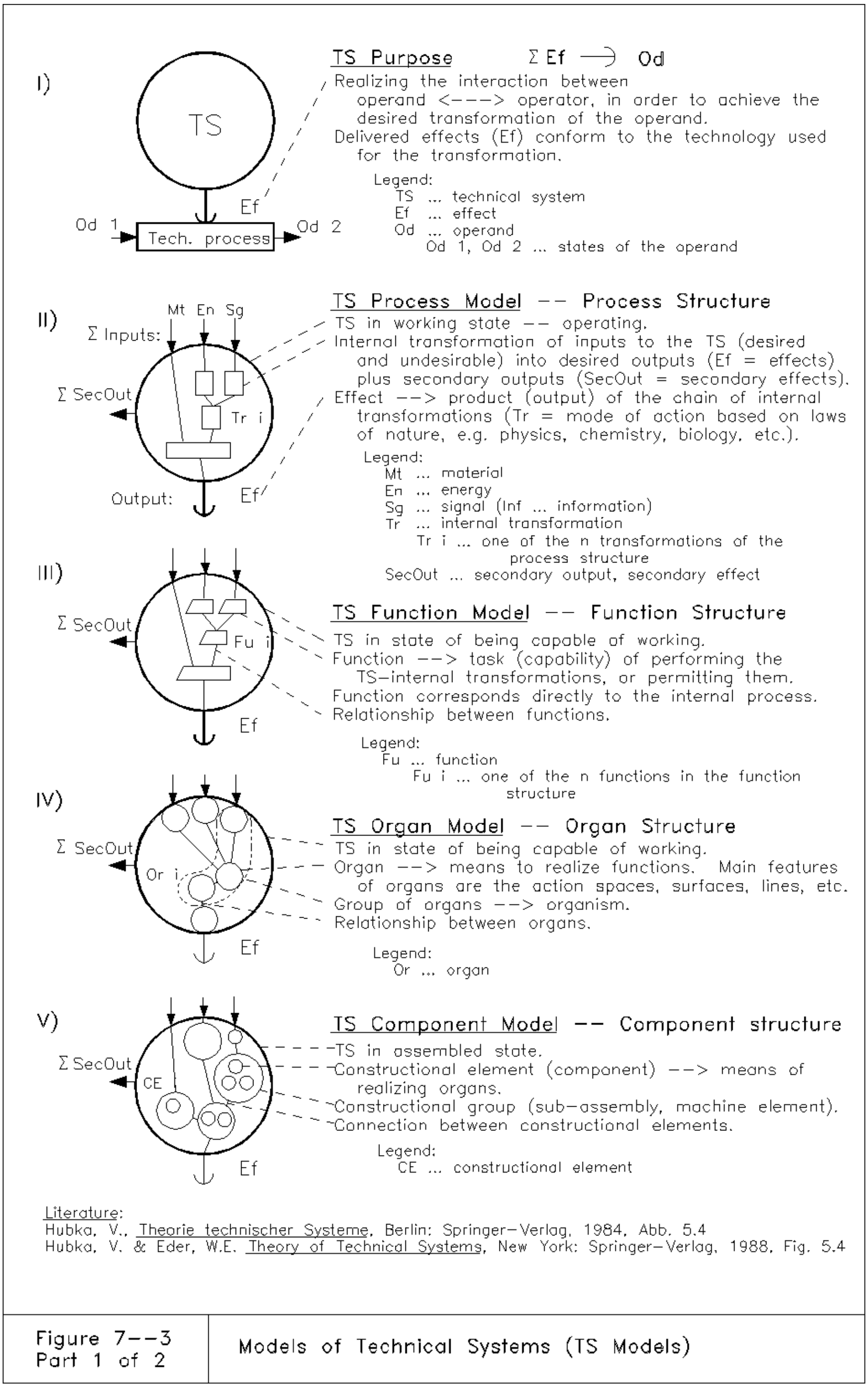

Figure 30 – Models of technical systems (TS Model) (Hubka and Eder, 1996)

8.6.4 Forsberg and Mooz process model

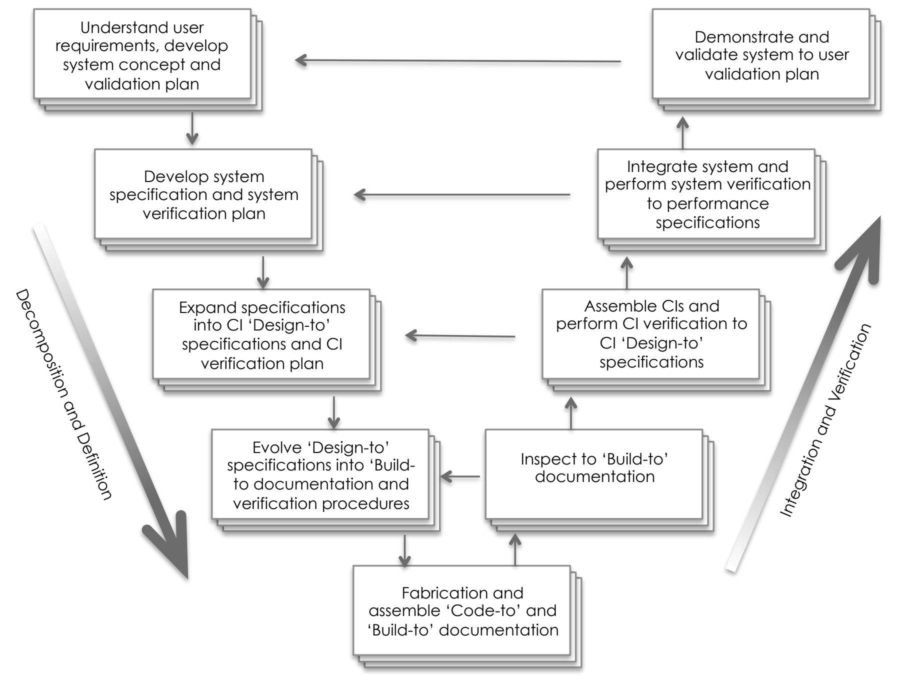

Figure 31 – Overview of the technical aspect of the project cycle (The "Vee") (Adapted from: Forsberg and Mooz, 1991)

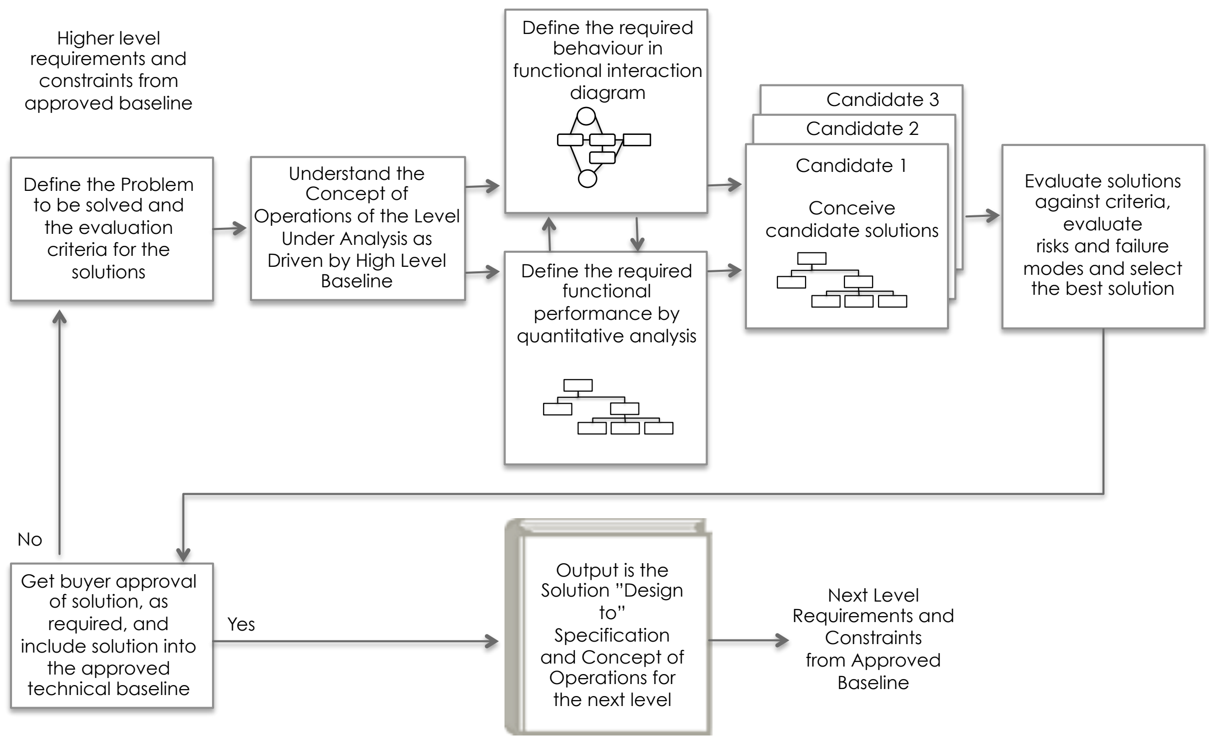

Figure 32 - System Analysis and Design Process (Adapted from: Forsberg and Mooz, 1991)

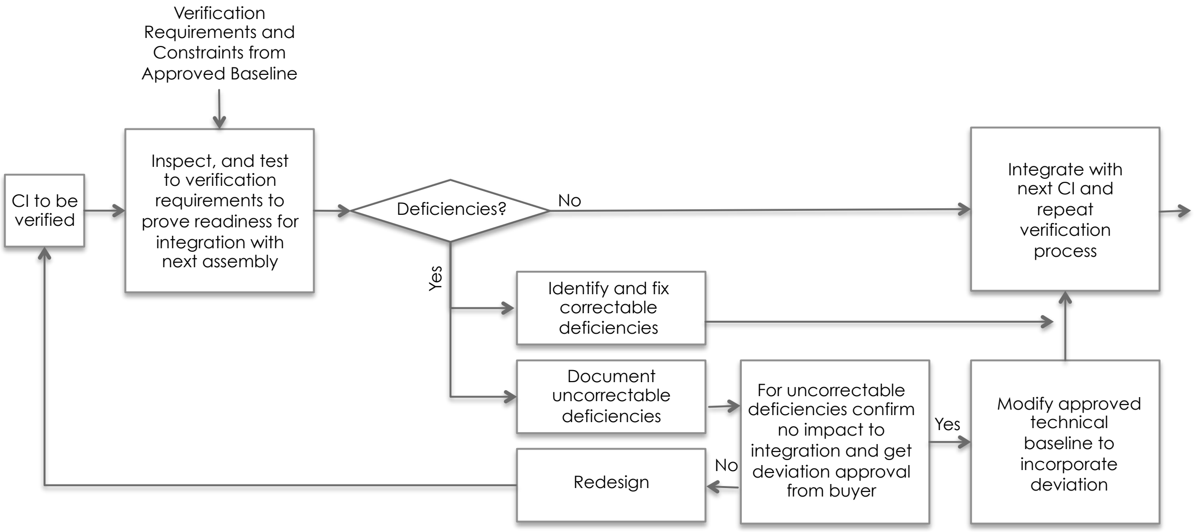

Figure 33 - System Verification and Integration Process (Adapted from: Forsberg and Mooz, 1991)

8.6.5 Nam Suh process model

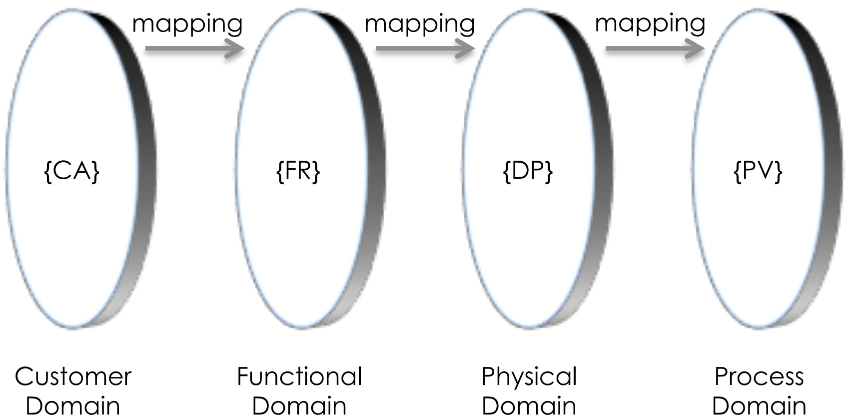

Figure 34 – Four domains of the design world (Suh, 2001)

8.6.6 Bryan Lawson process model

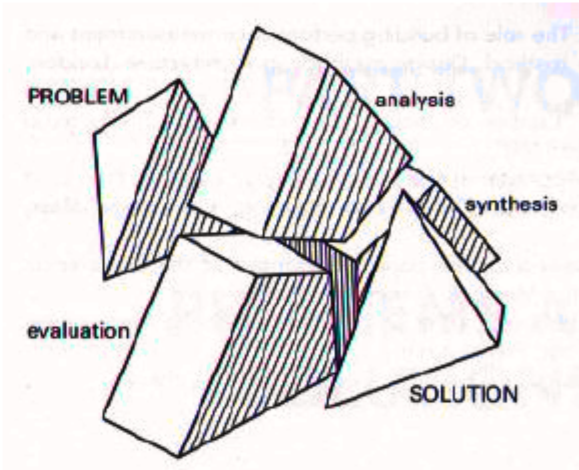

Figure 35 - The design process seen as a negotiation between problem and solution through the three activities of analysis, synthesis and evaluation (Lawson 2006).

8.7 Appendix 7 – Better informed decisions through evidence-based design

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The Use Of Evidence In Design

The design of healthcare environments is complex and challenging. Issues to be addressed include the number and variety of users; the constantly emerging technological changes in diagnosis, treatment and support services; and the high costs involved in providing healthcare services. In addition to that, the nature of healthcare services, which is to care for people's health and wellbeing when they are most vulnerable. In this regard, architects, engineers and healthcare planners do their best in creating design solutions that accelerate positive impacts and mitigate negative impacts that the facility might have upon its users.

Investigations about how the built environment affects individuals' behaviour have adopted several perspectives generating considerable amount of information. For instance, numerous studies compiled evidence related to how characteristics of the built environment affect its users (e.g. Evans, 1998; Lawson, 2003; Ulrich *et al*., 2004; Joseph, 2006; Ulrich *et al*., 2008; Codinhoto *et al*., 2008; Cooper *et al*., 2008). Existing evidence has been increasingly used, to a certain extent, to inform decision-makers.

The systematic use of evidence to support decision-making is an approach that has its origins in medicine. In the medical field, this approach became known as evidence-based medicine. The success of this approach led, in the 1980's, to the start of discussion related to the adaptation of the evidence-based medicine to the field of design, given origin to evidence-based design (EBD). Ever since the 1980's the use of EBD has increased as a way to support the decision-making related to the design of different types of buildings such as hospitals and schools.

EBD as an approach has significantly progressed and studies about the relationships between the built environment and user's behaviour are currently abundant. However, as argued by Codinhoto *et al*. (2008) the evidence-base is still sparse and fragmented, causing difficulty in using such evidence in research and practice.

Therefore, the major aim of this paper is to discuss the issue related to the sparseness and fragmentation of evidence. In this context, a framework for mapping evidence and a tool for informing decision making are presented. This research builds on and further explores the results of a 3 year-research project focused on how to better inform decision makers in the design of healthcare facilities.

Design Considerations In Healthcare Facilities

The work presented in this paper was conducted with a focus on the impacts of the built environment for healthcare delivery on health outcomes. Before presenting the proposed framework, three concepts are defined including the built environment, healthcare environment and health outcomes.

In this research, the built environment is considered to include the surroundings or conditions designed and built through human intervention, where a person, animal or plant lives or operates. The built environment refers to the boundaries that define the "envelope" of built spaces as well as the inside and adjacent spaces generated and connected to those boundaries (Codinhoto *et al*., 2009). In the healthcare delivery context, healthcare environments are defined as any specialised building or space where healthcare is delivered and its surroundings such as (but not restricted to) hospitals, primary care centres, hospices and nursing homes.

In regards to the definition of health outcomes, two inter-related concepts need to be highlighted: health and well-being. Health is broadly defined as a "state of complete physical, mental, and social well-being and not merely the absence of disease or infirmity" (WHO, 1946). Psychological well-being is a mental condition characterised by pleasant feelings of good health, exhilaration, high self-esteem and confidence, often associated with regular physical activity[61]. In this paper, both

[61] "psychological well-being" The Oxford Dictionary of Sports Science & Medicine. Oxford University Press, 2007. Oxford Reference Online. Oxford University Press. University of Salford. 9 July 2009 http://www.oxfordreference.com/views/ENTRY.html?subview=Main&entry=t161.e5636

concepts are used to define health outcomes which refer to positive and negative measures of physical, mental and social health and wellbeing such as levels of depression, anxiety and health related quality of life (HRQL).

Evidence-Based Design: Issues Related To Gathering And Interpreting Evidence

Using scientific evidence to support decision making is a simple and powerful concept. In medicine, for instance, this approach has been used to decide on the best treatment alternative for the patient. This involves identifying, for example, which treatment has the shortest healing time; which ones causes the least side effects and impacts on patients' quality of life and which ones are affordable (Mulrow, 1994).

The evidence-based approach has been used within other areas rather than medicine, including for instance, education (e.g. Reed *et al*. 2005), economics (e.g. Pignone *et al*. 2005), management (Tranfield *et al*., 2003) and Design (Malkin, 2008). Likewise evidence-based medicine, the EBD aim is to better inform decision-makers when a decision needs to be made in relation to different design solutions. EBD is defined as "the deliberate attempt to base building decisions on the best available research evidence with the goal of improving outcomes and of continuing to monitor the success or failure for subsequent decision-making (Malkin, 2008).

According to Fischl (2006) this approach aims to provide scientific evidence to fill the designer's knowledge gap about humans' social and behavioural attitudes. In this sense, the researcher works as an interpreter investigating and describing human behaviour, wants and needs. By following this route, risks of adopting design solutions can be reduced once evidence is available to demonstrate its efficiency and effectiveness. Furthermore, some consequences of adopting a design solution can be anticipated.

The idea of using evidence to inform decision-makers in design is not new in the context of healthcare buildings. Early on, in the 1960's the UK National Health System (NHS) started developing the Health Building Notes (HBNs) and Health Technical Memoranda (HTMs) with a basis on evidence. Although these series of documents provide guidance for the design of healthcare facilities in the UK, there is a lack of transparency related to the source of evidence used to support such guidelines. The same problem occurs in relation to more recently developed tools such as the NHS Environmental Assessment Tool (NEAT), Achieving Excellence Design Evaluation Toolkit (AEDET Evolution) and A Staff /Patient Environment Calibration Tool (ASPECT). These tools were developed with state-of-the-art evidence which, however, is not explicit.

In the context of healthcare projects, evidence-based design has been used by designers in different ways. According to Hamilton (2007), architects can use the evidence-based approach on four levels. At level 1, practitioners make an effort to stay up to date with the existing literature and design specification is based on current available information. At level 2, practitioners go further hypothesising the outcomes and measuring them. The results are used to evaluate their design proposals and improve future proposals. At level 3, additionally to the previous steps, practitioners publish their findings in the public arena. Finally, at level 4, practitioners also publish their findings in quality journals that require review by qualified peers. Hamilton (2007) has also mentioned the existence of a level 0, which relates to the misuse of the evidence-based approach. In this sense, practitioners use disconnected pieces of evidence to support the bias in their design proposals.

Regarding the role of designers, it is clear that the process of translating research into useful designs is crucial. The verification of whether these translations deliver the intended outcomes is equally important (Hamilton, 2007). The evidence-based approach has been used to support design decisions in early stages of the development process (e.g. in the concept generation). At the concept generation stage, scientific information has been used to help designers and stakeholders to establish the building program configuration (i.e. the number of bedrooms, wards, waiting areas and their characteristics). Evidence has been also used in later stages such as project evaluation to assess the design solutions.

The idea behind the evidence-based approach is very logical and powerful. However, its application to the design of healthcare facilities raises several issues. As agued by Codinhoto *et al*. (2009) the most significant concern arises from the intrinsic epistemological limitation in the field. Research methods are simply limited in terms of gathering knowledge from such a complex and dynamic phenomenon. Moreover, there are also other (more practical) issues, as summarised below:

- The lack of explicit cause and effect relationships
- The different strength levels of the evidence
- The multidisciplinary characteristic of the field
- The fragmentation and sparseness of the knowledge base
- The lack of theoretical consensus
- The multitude of measurement methods
- The limited number of design variations that can be possibly tested, and
- The translation of scientific results into practice

In fact, these issues are inter-connected and may be related to the fact that, until recently, evidence has not been applied in such a direct manner into practice. Therefore, it is clear and understandable that most of current reports of scientific findings are not consistent with an evidence-based approach. The adoption of the evidence-based approach requires that information is structured in a detailed manner allowing the decision-maker to draw comparisons.

In relation to the impacts of the built environment on its users, for example, the evidence base must provide explicit account of three main sets of information. The first set of information relates to the user's profile, whether an individual or a group; the second relates to the built environment characteristics in which the study was conducted; finally, the impacts observed – for instance, in terms of the health outcomes of patients in a healthcare environment; work efficiency and effectiveness of staff working in an office or factory environment. To further explore these sets of information, in the next section, a framework to map information linking the built environment to health outcomes is presented.

The Impacts of the Built Environment on health Outcomes

The framework presented in this section was developed within a 3 year-research project focused on developing an overview about the characteristics of the built environment that impact health outcomes. Throughout this research project, an extensive literature review was conducted which was multi-disciplinary in focus (i.e. ranging from architecture and engineering to medicine and psychology) and diverse in scale (i.e. from the small scale - e.g. objects - to the large-scale - e.g. a hospital unit). More information about this research project can be found in Codinhoto *et al*. (2008).

The review considered some aspects of systematic literature reviews including the establishment of key-words (50 in total) and criteria for inclusion and exclusion of papers. In total, 1264 abstracts were analysed leading to the inclusion of 153. The framework developed has 196 variables related to the three main sets of information and data was compiled in a spreadsheet. These main categories within each group and examples are mentioned below.

The first set of information compiled in this research was related to the patient profile. In the existing literature, it is considered that each patient may react differently to the surrounding environment depending on their condition. However, it is most likely that patients with similar profiles react in a similar way. In this research, the variables used to describe patients characteristics included: age group (e.g. adult, elderly); gender (male or female); patients' illness (e.g. cancer, depression, diabetes); and patients' condition (i.e. whether pre or pos-operative; pregnant, in treatment, etc).

The second set of information relates to the built environment characteristics. In this respect, a systemic approach was adopted to break-down a healthcare environment into its sub-systems, components and sub-components, parts and sub-parts. The final framework considered the following: specialist building (e.g. general hospital, community hospital and primary care facility); care unit within the specialist building (e.g. coronary care, maternity); setting within the care unit (e.g. bedroom, ward, corridor); components (e.g. ceiling, floor, walls); furniture and equipment (e.g. sink, TV, shower); system (e.g. ventilation, heating); function (e.g. layout, usability, accessibility); and characteristic (e.g. yellow colour, natural light, temperature, depth, size).

The third and final set of information relates to observed health outcomes - whether positive, negative and/or neutral. Four categories were considered: psychological (e.g. anxiety, stress, insecurity); physical (e.g. heart rate; retinopathy); physiological (e.g. respiration, coordination); others (e.g. healing time, wellbeing, substance use reduction).

Findings of this research and the proposed framework were presented to academics and practitioners such as designers and health care planners in three workshops. The workshops were conducted with the objective of validating the framework and providing in-depth understanding as to how such information could be used to better inform decision-makers during the design process.

One of the positive aspects highlighted is that making explicit all the variables related to an investigation through the presented framework allows the construction of evidence models. Evidence models are diagrams that inform the decision-making process by linking several factors impacting on one outcome as well as connecting several outcomes to a specific cause/factor (Mulrow *et al.*, 1997). Below, Figure 1a and 1b shows two simplified evidence models. Figure 1a shows different built environment characteristics impacting on the levels of stress of patients in a stroke unit setting positively and negatively. Figure 1b shows the links between artificial light and the development of depression, melanoma and retinopathy. The numbers listed represent the sources of evidence.

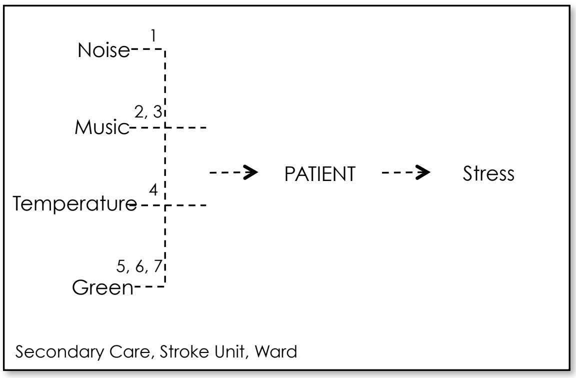

Figure 1a. Built environment variables impacting stress

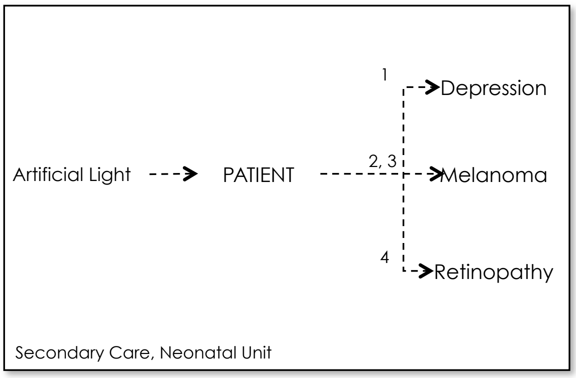

Figure 1b. Artificial light impacting several health outcomes

In addition to that, from the participants point of view, the perceived benefits, disbenefits and value of the framework and concerns are related to: (a) the provision of a systematic way of keeping track of the literature; (b) the generation of a roadmap for research highlighting the areas where research has been conducted as well as areas where research is needed; (c) increased transparency related to the investigated subject matter of the studies providing easy access to specificities and details of each study; (d) difficulties related to maintaining the evidence-base up to date; and (e) the use of such information within the design process. Considering the issues raised during the development of this research, the concept for an IT system/tool to support better in formed decision making has been developed. Further details about the system are presented in the next section.

Online Decision Support For Designers And Healthcare Planners

The development of the online system considers two phases: Phase 1 relates to the development of an online incremental database with a basis on the framework presented above whereas phase 2 relates to linking the online database with Building Information Modelling software through an information extractor system (Figure 2). These two phases are further described in the following section.

Phase 1 - Online Incremental Database

The online incremental database consists of a web-based system containing deployed information (evidence) about the effects of the built environment on its users. This system should be developed with the concept of "yellow pages" for evidence, i.e. variables with similar definitions will be clustered (e.g. light, lighting, natural light). A glossary of terms will be developed. The system will ensure precision and transparency for the searching process by making explicit all the variables and their relationships. Data entering should be made by researchers in this area through the completion of an online form. This form will allow the researchers to specify the identified variables or entering new ones.

The online system will run independently of CAD systems. Reports and evidence models can be generated by filtering the existing information within the system. In relation to the filtering system, users will be able to extract information according to the type of evidence (i.e. context, cause and effect) required. The user interface should provide options for selection of the desirable variables. The system will only store the abstract information of the variables and an external link to the original source (i.e. journal) will be provided. The users will be responsible for the access to the original source of information. This system will be developed for informative purposes only.

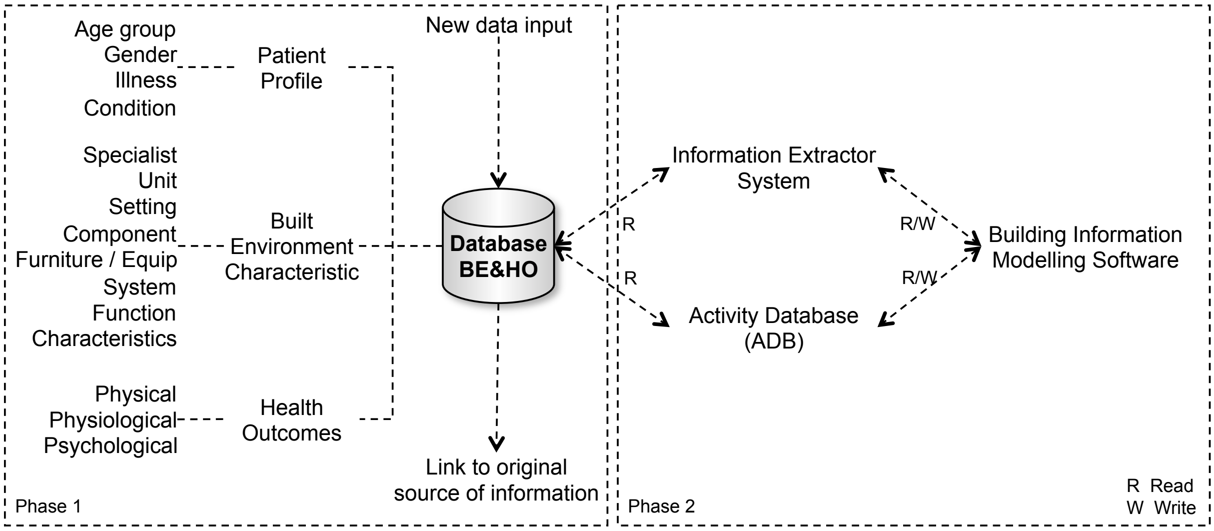

Figure 2. Schematic representation of the evidence-based IT system to support decision-making

Phase 2 – Information Extractor System

The second phase consists of the development of an information extractor system. This system will be developed to integrate the online incremental database with a BIM software. It aims to support designers to improve their design by associating the evidences from the online database with actual building components. Initial development will be conducted by linking the database with Autodesk REVIT and the Active Database (ADB) developed by the NHS in the UK. However, links with other BIM software will be developed once the overall concept of the extractor system is fully developed. BIM are software that bridge the interoperability-gap (Holzer, 2007) between building schedules, databases, and budgeting software into 3-D modelling (MacDonald, 2005). This new technology presupposes new ways of thinking and despite the fact that they are not yet fully developed; they have been used successfully in construction.

Operationally, the extractor system should be able to read information in both BIM environment and online database. This means that, whenever an object is specified within the BIM environment, it will be possible to identify whether there is evidence related to that object within the database. The information extractor system should also be able to write information within the BIM environment. In other words, if an object is specified in a way that contradicts the existing evidence, an alert should be activated within the BIM environment. Reports and evidence models will be linked to the objects created in BIM and they will be generated by filtering the existing information within the online system.

Final Conclusions

Evidence-based design is an approach to support decision-making which emphasizes the use of state-of-art evidence. The use of evidence is important for critical decisions where a set of vital information about the impact of design solutions upon users and maintenance may influence the way design evolves. Disconnected pieces of evidence should not be mistakenly used as EBD to justify bias within design solutions. Rather, evidence should support decisions and whenever possible, designers and healthcare planners should collect relevant information from completed projects in order update the evidence-base. In other words, this means to check whether or not their decisions efficiently and effectively improved the quality and use of the space.

Currently there are limitations in terms of maximising the utilisation of EBD. These are related to the lack of explicit cause and effect relationships, the fragmentation and sparseness of the available information and methodological limitations. However, EBD is evolving in a fast manner with a rapidly growing body of evidence.

In this paper, a tripartite framework that maps research related to the effects of the built environment on health outcomes was presented. The three main factors structuring the framework are the patient profile, the built environment characteristics, and the health outcomes. This framework was developed through an extensive literature review focused on healthcare environments and validated through the realization of three workshops involving academics and practitioners.

The benefits of using such frameworks are mainly related to the generation of a road map of existing research that makes explicit the gaps of knowledge. However, operational issues related to up-dating such framework still remain. Based on these benefits and difficulties, an IT system to better inform decision-makers is proposed.

Further research should investigate the implications of EBD to the design process. Furthermore, discussions about whether EBD aligns or contradicts new design and production theories and methods, such as lean design and production and the link between parametrical design and EBD are also emerging.

References

Codinhoto, R., Platten, B., Tzortopoulos, P., and Kagioglou, M. (2010) Supporting evidence based design. In: Tzortzopoulos, P. and Kagioglou, M. (eds). Built Environment for healthcare. Publisher. In press.

Codinhoto, R., Tzortzopoulos, P., Kagioglou, M., Aouad, G. and Cooper, R. (2008), “The effects of the built environment on health outcomes”, Research Report, HaCIRIC (Health and Care Infrastructure Research and Innovation Centre).

Codinhoto, R., Tzortzopoulos, P., Kagioglou, M., Aouad, G. and Cooper, R. (2009) The effects of the built environment on health outcomes. Facilities, Vol. 27 No. 3/4, pp. 138-151

Cooper, R., Boyko, C. and Codinhoto, R. (2008), “The effect of the physical environment on mental wellbeing”, State-of-Science Review: SR-DR2, Mental Capital and Wellbeing: Making the most of ourselves in the 21st century, Government Office for Science, London.

Evans, G. W., McCoy, J. M.. (1998). When buildings don’t work: the role of architecture in human health. Journal of Environmental Psychology, 18, pp.85-94.

Fischl, G. (2006). Psychosocially supportive design in the indoor environment. Department of Human Work Sciences. Lulea, Lulea University of Technology. Doctor: 135.

Hamilton, K. (2007). The four levels of evidence-based practice. Healthcare Design Magazine - designing, building and renovating healthcare buildings. http://www.healthcaredesignmagazine.com/Past_Issues.htm?ID=2922. Last access: 05/03/2007.

Holzer, D.: 2007, Are you talking to me? Why BIM alone is not the answer, Association of Architecture Schools Australasia Conference.

Joseph, A. (2006). The Impact of Light on Outcomes in Healthcare Settings, The Centre for Health Design: 14.

Lawson, B., Phiri, Michael (2003). The architectural healthcare environment and its effects on patient health outcomes: a report on an NHS estates funded project. N. Estates. London, NHS Estates and University of Sheffield: 22.

MacDonald, J. (2005) The next dimension: Harvard experience. The Architect’s Newspaper. New York Architecture and Design. Issue 10, 06.08.2005.

Malkin, 2008) A visual reference for evidence-based design, The Center for Health Design)

Mulrow, C.D. (1994) Systematic Reviews: Rationale for systematic reviews. BMJ 309(6954):597-599.

Mulrow, C.; Langhorne, P., and Grimshaw, J. (1997) Integrating Heterogeneous Pieces of Evidence in Systematic Reviews. Annals of Internal Medicine, Academia and Clinic, Systematic Review Series; 127:989-995

Pignone, M., *et al.* (2005). "Challenges in Systematic Reviews of Economic Analyses." Ann Intern Med 142(12_Part_2): 1073-1079.

Reed, D., *et al.* (2005). "Challenges in Systematic Reviews of Educational Intervention Studies." Ann Intern Med 142(12_Part_2): 1080-1089.

Tranfield, D., Denyer, D. and Smart, P (2003) Towards a methodology for developing evidence-informed management knowledge by means of systematic review. British Journal of Management 14:207-222.

Ulrich, R. Quan, X. Zimring, C. Joseph, A. and Choudhary, R. (2004). The role of the physical environment in the hospital of the 21st century: a once-in-a-lifetime opportunity, Center for health design for the designing the 21st century hospital project: 69.

Ulrich, R., Zimring, C., Zhu, X., DuBose, J., Seo, H., Choi, Y., Quan, X. and Joseph, A. (2008), “A review of the research literature on evidence-based healthcare design”, Health Environments Research & Design Journal, Vol. 1, No. 3, p.61-125.

WHO. Preamble to the Constitution of the World Health Organization as adopted by the International Health Conference, New York, 19-22 June 1946, and entered into force on 7 April 1948.

8.8 Appendix 8 - The method of analysis in production management

The following article was published in the proceedings of the 15th Annual International Conference of the International Group for Lean Construction, East Lansing, USA.

THE METHOD OF ANALYSIS IN PRODUCTION MANAGEMENT

Ricardo Codinhoto, Lauri Koskela, Patricia Tzortzopoulos, and Mike Kagioglou

ABSTRACT

The method of analysis was developed by ancient Greek geometers to identify and solve problems related to geometry. From that period, well known scientists such as Newton and Descartes have applied the method. More recently, Polya has presented the method of analysis as a heuristic template to solve mathematical and other problems. Despite its continual epistemological dilution, the method has also been used to explain the cognitive process of designing. In this paper it is claimed that the method of analysis can also explain production management. It seems that the method of analysis has been used across different levels of management in production, i.e. from a holistic/strategic perspective through to detailed levels. Therefore, the aim of this paper is to discuss whether the method of analysis provides a partial theoretical foundation for production planning. The research approach is literature review with an emphasis on the method of analysis and synthesis. The conclusion is that the method of analysis and synthesis adds to the theoretical explanation of both design and production.

KEY WORDS

Analysis and synthesis, production planning

Introduction

The importance and need for clear theoretical foundations for production has long been recognised. Although considerable steps have been recently taken forward, there are still issues that can add to the generation of a more holistic understanding of production management. The development of the theoretical basis for production management is necessary to advance our understanding and conceptualisation of production processes and, therefore, to support the improvement of production planning practice.

Production planning has been articulated with a dominant focus on the transformation of inputs in outputs (Koskela, 2000). It has been argued that flow and value are relevant features of production that have been poorly considered in the current practice of planning (Koskela, 2000). Despite contributions in the area of flow management (e.g. Bertelsen *et al.,* 2006), a consistent understanding has not yet been achieved.

This paper explores whether the ancient method of analysis and synthesis, developed originally by Greek geometers, is able to provide new insights to aspects of production management.

In prior research, Koskela and Kagioglou (2006) pointed out that the ancient method of analysis and synthesis can be explained by five main features, as follows.

- Types of analysis: there are two types of analysis: theoretical and problematical. In geometry, theoretical analysis aims at proving a theorem whereas problematical analysis aims at constructing a wished geometrical figure.
- The start and end points of analysis: The start point in theoretical analysis (i.e. the "desired thing"), is something we do not know whether it can be done or achieved. The end point consists of something admitted, that is, already known. In turn, synthesis provides the definitive proof that the "desired thing" is possible. Correspondingly, in problematical analysis, we do not know the desired thing, but assume it to be known.
- Types of reasoning: at least three types of reasoning are involved in the method of analysis and synthesis. Decompositional reasoning involves breaking down the "whole" into its parts and interrelationships. Regressive reasoning involves assuming the solution (as known) and then questioning what would be necessary to get to the solution. The enquiry goes on until something which is already known

is considered as being first in order (e.g. for a design problem, this would be an existing requirement). Finally, transformational reasoning relates to a process of expanding the knowledge associated to the problem.

- The two directions of reasoning: there are two directions of inferences needed: backwards for the solution, and forwards for the proof.
- The strategy of reasoning: in the method of analysis reasoning is a heuristic, iterative process, i.e. there is no guarantee that a solution can be found in the first attempt, therefore, the method of analysis involves returning to the problem and revising it and starting again.

These features do not exhaust the understanding of the ancient method of analysis, but provide a concise starting point for our present purposes. One of the reasons why the method is not fully understood relates to the fact that the only existing wider description of the method is a text fragment from around 300 AD, which has been the subject of long discussions in philosophy and history of science (Hintikka and Remes, 1974).

Another reason relates to the fact that the ancient core understanding of analysis and synthesis has somehow been corrupted. It seems that after the great scientists, who propelled the Enlightenment, the term 'analysis' has been used to refer to different methods and, in some instances, without appropriate reference to its original concepts (as detailed in Codinhoto *et al*., 2006). Consequently, the method of analysis was transmitted in a rather superficial and impoverished form, as a generic method. The term analysis itself was "captured" to refer to algebra, especially analytical calculus.

Also, the historical connections on how the concepts have been understood have largely been lost during the modern times. It is argued in this paper that this state of affairs is not only an interesting finding in the history of managerial thought, but also, and more importantly, a major opportunity to consolidate and advance the theoretical and methodological basis of production disciplines.

Hence, this paper, which aims to discuss the method of analysis and its contribution to production, is structured as follows. First, the introduction highlights the features of the ancient method of analysis and synthesis. Next, a discussion of the relevance of analysis and synthesis as a theoretical basis for production management is presented.

Finally, after discussing the significance of the findings, some general conclusions are provided.

Relevance of the method of analysis to Production

What is the relevance of the method of analysis to production management? It can be hypothesised that if the features of analysis are theoretically relevant to production planning, those features would have surfaced in recent empirical and conceptual literature on production planning and management. Thus, our first approach is to check whether we can find statements from prior literature that would support the claim that the different features of analysis, separately, provide theoretical ingredients for understanding and conceptualising production planning and management in construction.

The Types of Analysis

As discussed earlier, there are two types of analysis: theoretical and problematical. These are, in Polya's (2004) terms, the problem to prove (in geometry, a theorem) and the problem to find (a solution to a mathematical problem). Now, the task is to investigate whether this dichotomy corresponds to empirical or conceptual statements on production planning.

In production management the two types of analysis can be recognised in strategic and detailed planning. In this sense, the problematical analysis aims at proving a strategy, whereas theoretical analysis aims at outline a plan.

For instance, Wideman (1990) says in relation to strategic planning:

"In large complex projects there is a need to do initial project management planning - in short, planning the plan."

In this sense, Wideman describes the process of finding a solution. Therefore, the resulting strategic plan is the starting point of the theoretical analysis which will be carried out, for instance, by planners in the construction site.

Thus, the occurrence of the two types of analysis can be recognised in production management.

The Start and End Points

In production planning the start point of analysis relates to the goal to be achieved, which is the end point of the schedule, or a predetermined cycle time. The former relates to the calendar and the focus of analysis will be to discover if (considering the existing company's resources/capacity) the time between now and the deadline is enough to achieve the goal. The latter does not have relation with the calendar and the focus will be to discover if the predetermined interval of time is enough to achieve the goal. In this sense, although the planning goal is known (the desired thing) its feasibility remains unknown.

On the other hand, the ending point of analysis is something already known and in terms of production planning refers to the starting point of the schedule. In the case of production planning, the end point of analysis can be either the day in which production starts (considering a time window between now and a point in time in the future), or the information regarding the necessary "resources" to produce something in a predetermined period of time.

In relation to the start and end points, the method of analysis can be viewed as corresponding well with production planning.

Types of Reasoning

Decompositional Analysis

A configurational (or decompositional) analysis is usually also involved in the method of analysis (Hintikka and Remes, 1974). In geometry, decomposition is used to break a geometrical figure on its parts. In production, decomposition is used to breakdown the product into its constituent parts as the production process is broken into its related operations, activities and tasks.

In the Work Breakdown Structure (WBS) technique, each planned outcome across each root node within each different level can be considered as the desired end (Wikipedia Contributors, 2007) (e.g. the whole building, the conclusion of one store or simply a wall). Therefore the plan obtained by using WBS is the result of a decompositional approach to the problem. It is not difficult to see the similarity of the ancient and modern views on decomposition.

Regressive Analysis

In planning Kahkonen (1993) describes:

"In practice, the planner attempts to produce a feasible plan or schedule. While preparing a plan or schedule, he or she needs to take all relevant factors into account in order to ensure that the plan or schedule is logically correct. Within this process, the identification of activity dependencies is very important. Activity dependencies set constraints on the order of activities, the start and finish of activities and the overlap of activities."

In production, the idea of starting from the end and working then in the identification of the sequence and dependencies of the tasks, activities and operations to achieve the long term goal is well known. This form of reasoning has been the basis of well known techniques in production planning, such as Gantt charts, PERT networks (Program Evaluation and Review Technique) and critical paths. The common feature in these is that they endeavour to provide the chain of means and ends. Again, the similarities between the ancient and the modern conceptions are plain.

Transformational Analysis

The transformative or interpretative reasoning may be the least understood feature of analysis, at least of those discussed here. The use of auxiliary lines in geometrical analysis (Hintikka and Remes 1974) can be viewed to fall into this type. Beaney (2003) refers to the work of Frege and Russell, who suggested transforming statements to be analysed first into their correct logical form.

However, in contrary to Beaney, Polya (2004) relates all these issues as a process of expanding the knowledge associated to the problem (or theorem). Namely, a transformation of information or knowledge does not destroy the input, as is the case regarding physical transformations. Thus, any transformation or new interpretation leads to expanded knowledge.

The use of transformational analysis is necessary when the information provided to solve a problem is not enough to solve it. Therefore, the analyst job is: a) to identify which is the missing information, i.e. the analyst deviates his/her attention from the original problem to a secondary one; b) to identify if the missing information can be gathered, derived or generated from the information provided or from similar problems already solved (e.g. using existing theorems); c) to solve the secondary problem aiming to find the missing information; and d) to return to the original problem.

Polya (2004) provides an example of what is meant by transformational analysis in geometry. Considering that the original problem is to identify the length of the segment 'x' being provided 'a', 'b' and 'c' (Figure 1a). The obvious solution is to use Pythagoras theorem i.e. $a^2 + b^2 = c^2$. However, the missing information is the length of the segment 'd' (this is the auxiliary line), which can be obtained from solving a secondary problem i.e. the triangle 'abd' (Figure 1b) by using Pythagoras. Thus, once the secondary problem has been solved, the analyst can return to the original problem.

Accordingly, transformational analysis is clear in geometry, but less so in other fields. However, the following advice of Shingo (1988) can perhaps be seen as an instance f transformational analysis: "*It is important not to limit ourselves to considering only immediate goals but rather to remember that one objective is but a means for achieving higher level goals. This attitude, which frequently leads to truly dramatic improvements, should not be forgotten*."

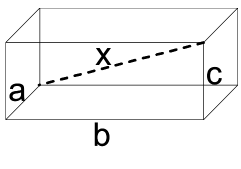

Figure 1a

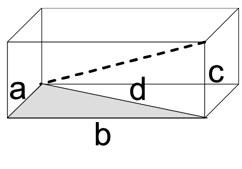

Figure 1b

Two Directions of Reasoning and Their Unity

Hendrickson and Au (1998), discussing basic concepts on the development of construction plans, present a example from Sherlock Holmes of what can be considered reasoning backwards: "Most people, if you describe a train of events to them, will tell you what the result would be. They can put those events together in their minds, and argue from them that something will come to pass. There are few people, however, who, if you told them a result, would be able to evolve from their own inner consciousness what the steps were which led up to that result. This power is what I mean when I talk of reasoning backward (Doyle, 1930)."

Furthermore, in relation to the cognitive process related to planning, Morris and Ward (2004) referring to Simon (1978) describe:

"…planning can be likened to a search through a space of connected problem states, with the efficiency of the search improved by using a range of different heuristics to think forwards from the given information of a problem and backwards from the goal of a problem."

The consideration of two directions is evident and can be seen in different approaches to production management. As argued by Koskela and Kagioglou (2006) the Vee model is one example which implies the use of the two directions of reasoning. In terms of design and production, an application regarding the Vee model can be drawn. In Figure 2a the left tail refers to design and represents the specification stream. The right tail refers to prototyping and/or production and represents the test, verification and validation stream. The same analogy can be drawn in relation to production planning (Figure 2b). The left tail represents the planning activity across different levels of plans and the tip of V refers to the assignment stream. The right tail represents the monitoring stream.

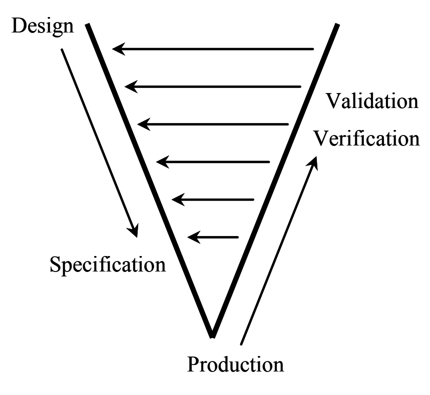

Figure 2a – The Vee

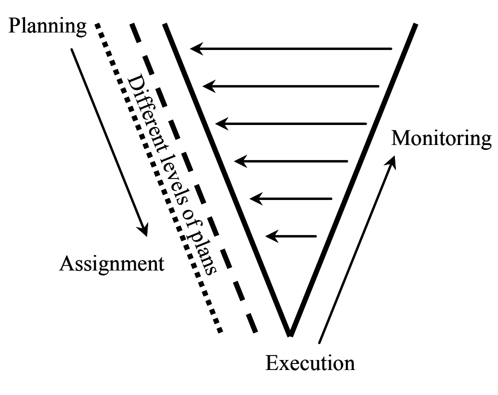

Figure 2b - The Vee

model applied to design and production	model applied to planning and execution

Another example relates to the use of simulation or virtual prototyping through 4D or nD modelling (Lee *et al.,* 2003). This technology aims at making possible to revise, redrawn, re-plan and mainly testing the combination of solutions against the overall objectives and constraints of the project before the execution starts.

Considering these examples, it is clear that the idea of two streams is evident in the method of analysis and in production management.

Strategy of Reasoning

The method of analysis does by no means ensure that a solution can be found. Rather, the method leads to a heuristic approach: we may be compelled to return to the problem and revise it, and start afresh.

A production planner often relies on a heuristic approach, i.e., using selected rules, strategies or principles serving to stimulate the investigation in search for a solution. Hendrickson (1998) says:

"Heuristic approaches are also possible to the time/cost trade-off problem. In particular, a simple approach is to first apply critical path scheduling with all activity durations assumed to be at minimum cost (Dij). Next, the planner can examine activities on the critical path and reduce the scheduled duration of activities which have the lowest resulting increase in costs. In essence, the planner develops a list of activities on the critical path ranked in accordance with the unit change in cost for a reduction in the activity duration. The heuristic solution proceeds by shortening activities in the order of their lowest impact on costs. As the duration of activities on the shortest path are shortened, the project duration is also reduced. Eventually, another path becomes critical, and a new list of activities on the critical path must be prepared."

The iterative process is evident both in the ancient method of analysis and production planning methods.

Summary of Main Issues

For all the features contained by the ancient method of analysis, explicitly or implicitly, we can identify current, corresponding ideas and concepts, as summarized in Table 1. Consequently, it is justified to hold the method of analysis as contributing to the establishment of theory of production management. Interestingly, almost without exception, the modern concepts and practices have been forwarded by their originators without any reference to the ancient counterparts.

Table 1. Overview on the method of analysis and corresponding recent developments

Feature	**Method of Analysis**	**Corresponding features in production planning**
1 Problem to Prove/Find	Theoretical and problematic form of analysis	Strategic and detailed planning of project or production
2 Start / End	Starting: we do not know whether it is possible or can be done Ending: something already known	The starting point of analysis is the end point of the schedule.
3 Decomposition	"In the context of geometry, the question is about investigating from which parts… a figure is made up, and which relations exists between those parts…"	Work break down structure
4 Regressive analysis – solution backwards	"…which is sought to be already done, and we inquire from what it results, and again what is the antecedent of the latter, until we on our backward way light upon something already known and being first in order…"	Gantt Charts and CPM networks
5	Auxiliary lines in geometrical	Understanding of higher level

Transformation	analysis	goals
6 Direction of analysis	Backwards for the solution; forwards for the proof	Vee model adapted to design and production, and planning and execution.
7 Strategy of reasoning	The method is heuristic and iterative: we may be compelled to return to the problem and revise it, and start afresh	Heuristic approaches in planning

Discussion

This paper is an initial exploration of how generic and powerful the method of analysis and synthesis can be across situations and contexts. From the discussion presented, it can be concluded that practically all features of the method of analysis can be found in production management. Therefore, in terms of lean processes, the method provides elements for further development and refinement of a better theory of production.

The prevalence of the features of analysis and synthesis in production management arguably derives from three issues. First, analysis and synthesis seem to deliver a detailed theory on what happens in value generation[62]. Let us recapitulate how Shewhart (1931), at the outset of the quality movement, characterised production:

"Looked at broadly there are at a given time certain human wants to be fulfilled through the fabrication of raw materials into finished products of different kinds. These wants are statistical in nature in that the quality of a product in terms of physical characteristics wanted by one individual are not the same for all individuals.

The first step of the engineer in trying to satisfy these wants is therefore that of translating as nearly as possible these wants into the physical characteristics of the

[62] Instead, the method of analysis does not seem to bear on the transformation or flow models of production.

thing manufactured to satisfy these wants. In taking this step intuition and judgement play an important role as well as the broad knowledge of the human element involved in the wants of individuals."

The second step of the engineer is to set up ways and means of obtaining a product which will differ from the arbitrarily set standards for these quality characteristics by no more than may be left to chance.

Shewhart presents here *what* happens in production, but does not touch the issue of *how*. The method of analysis gives an elementary answer to this *how* question.

Second, the applicability of the method of analysis in production management derives from the affinity between designing and planning. If planning is interpreted as design of temporal process, instead of artefacts, we can hypothesise at the outset that the method of analysis is to a similar degree relevant to planning as it is to designing – it has been earlier argued that the method of analysis provides a proto-theory of design (Koskela & Kagioglou, 2006).

Third, as Polya (2004) has argued, the method of analysis can also be seen as a generic method of problem solving, and it is also in this role that various features of this method are used in production management. For example, the method of "5 Why's" (Shingo, 1988) for finding the root cause of a problem equates to regressive analysis.

Thus, all in all, the expectation is that the explicit development and application of the method of analysis in production management can be used to stimulate advances in this field