Cranfield University

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Exploring Whole System Design

Doctor of Philosophy (PhD) Thesis

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Department of Sustainable Systems

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PhD Thesis

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December 2008

This thesis is submitted in partial fulfilment of the requirements for the degree of Doctor of Philosophy

In Loving Memory of My Inspirational Grandad

Sidney Fredrick Coley

(1920 – 2008)

Abstract

The emergence of increasingly complex problems, combined with growing concerns for the environment, is fuelling the demand for more innovative and sustainable products, services and systems. Whole system design is one approach that aims to integrate social, economic and environmental phenomena into a comprehensive design solution. The approach encourages the development of partnerships between actors from a variety of different backgrounds, disciplines and sectors to develop an innovative, sustainable and optimised solution at a whole system level. However, there is limited research concerning the integrative process that actors are required to follow in order to reach such a solution.

The aim of this study was to gain improved knowledge and understanding surrounding the process of whole system design and to identify those factors that influence its success. This was achieved in two phases; firstly a longitudinal case study was undertaken which followed the process of whole system design from beginning to end. 22 design and progress meetings were observed, 18 interviews were carried out and a multitude of relevant documentation was analysed. This resulted in the identification of 10 themes. The second phase of the research aimed to validate initial findings by conducting 5 smaller cases and interviewing 11 individually selected experts. The study ultimately produced 8 confirmed themes, 68 individual findings and 37 factors that enable and inhibit the process of whole system design.

As a result of this study, an improved knowledge and understanding surrounding the process of whole system design has been presented. In particular, findings have been provided concerning: the development of partnerships, the pertinence of human and non-human interaction, the requirement of individual characteristics, enhanced understanding of purpose and process, the necessary alignment of individual and organisational motivation, the necessity of sense making activities, the role of a facilitator and the need for integration, each of these within the context of whole system design. The framework of these findings provides a novel contribution to knowledge within the context of whole system design.

Acknowledgements

This research is a result of access being provided by a number of organisations and people. I would like to thank all the members of the LIFECar Project for their kindness, patience and hospitality whilst being frequently observed and interviewed. Congratulations on the completion of a truly innovative and successful venture!

I would also like to thank those people who took the time to participate in interviews and discussions during the final year of the research. I am particularly grateful to Hugo Spowers and Jules Saunderson for their encouragement and valuable introductions.

Many thanks go to my supervisors, Dr Mark Lemon for his continuous support, guidance and motivating conversation over many cups of tea and Professor Steve Evans for being tirelessly positive and encouraging throughout this journey.

I am hugely grateful for the endless love and support of my wonderful family. My parents Karen and Paul whose infinite encouragement always astounds me, my sister Natalie who has provided me with continuous (and contagious) laughter and faultless optimism and also my inspiring Grandparents; Nellie, Rosemary and Frank, whose interest and support has been exceptional. I would also like to thank my Mother-in-Law, Sue for the time and patience she dedicated to reading my thesis.

I would like to thank a few of my friends for their support and encouragement: Katie and Kim for their loyal friendship over many years, Lou for her constant cheerfulness and enthusiasm even at the most difficult times, Chris for his challenging questions and philosophical conversation and finally all of my fellow researchers in CRME who didn't understand what I was doing but whose support was always available none-the-less.

Finally a huge thank you to Antony, my husband, your unwavering love, patience, encouragement and understanding has been awesome. Thank you for always being able to make me laugh.

Publications

Coley, F., and Lemon, M., 'Exploring the Uncertainty Surrounding the Design and Perceived Benefit of Sustainable Solutions' *Journal of Engineering Design*, Accepted for Publication 2008

Coley, F., and Lemon, M., (2008) 'Supporting Multiple Stakeholders in the Design of more Sustainable and Systemic Solutions: The case of the sustainable sports car' *Design Principles and Practices: An International Journal,* Vol 2, Issue 2, pp. 27 – 34 (International Design Award Runner-Up)

Pollard, S.J.T., Davies, G.J., Coley, F. and Lemon, M. (2008) Better environmental decision-making – recent progress and future trends, *Science of the Total Environment*, Accepted for Publication June 2008

Coley, F., (2007) 'Understanding Stakeholder Integration in the Design of more Holistic and Sustainable Solutions' presented at the *People and Science: Sharing Methodological Insights Conference*, Cranfield University, UK 27-28th February 2007

Coley, F., 'Supporting Multiple Stakeholders in the Design of more Sustainable and Systemic Solutions: The case of the sustainable sports car' presented at: *Design Conference 2008: The Second International Conference on Design Principles and Practices,* University of Miami Conference Centre – Florida, USA 9th – 11th January 2008

Houseman, O., Coley, F. and Roy, R. (2008) 'Comparing the Cognitive Actions of Design Engineers and Cost Estimators' *The Journal of Engineering Design,* Vol. Issue 19, pp. 145 – 158

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Introduction

This chapter introduces the reader to the background, context and need for the research. The novelty of the research and contribution to knowledge are presented and the thesis structure is outlined.

1.1 Background

An increase in environmental awareness initiated by governments over the past century, has led to a dramatic rise in the demand for more environmentally sustainable design across a multitude of contexts. Under the Kyoto Protocol, by 2008-2012 the UK must reduce its baseline emissions of six major greenhouse gases by 12.5 per cent from a baseline target set in 1990. Furthermore, the draft Climate Change Bill commits the UK to reductions in CO2 emissions of at least 26% by 2020 and a long term goal of 60% by 2050 (The Energy Saving Trust, 2008). Additionally, due to a rapid and profound change in contemporary society, the problems that we now face are complex, incorporating multiple aspects, the most pertinent of which are often social, economic and environmental. Subsequently, there is a growing responsibility to replace incremental improvements to existing products with all-encompassing, sustainable and innovative packages of products, services and systems that will provide solutions to consumer needs and requirements.

Mainstream businesses are launching new green initiatives and eco-friendly products each week in an effort to capitalize on society's apparent shift toward a more environmental ethic. Most green business efforts essentially are attempts to improve upon traditional products by somehow making them more environmentally benign, such as by reformulating the product or increasing its energy efficiency (Morson, 2007). However, authors are concerned that environmental considerations are still an add-on option as opposed to being central to the way we do business (Stasinopoulos *et al.*, 2009). There is often little awareness and understanding of the wider, environmental, social and economic impacts of design – in other words, the Sustainable Development aspects (Howarth and Hadfield, 2006). Senge (2006) states that the un-healthiness of the world today is in direct proportion to our inability to see it as a whole. Subsequently, organisations are focusing on sustainability as an objective, but they are largely limiting their efforts to what can be done within the boundary of the firm (Ehrenfeld, 2003). They overlook the fact that every worker arrives at the office or plant from a home within a community within a larger society, and imports the elements of the larger cultural structure. Subsequently, environmentalists want businesses to change their products fundamentally in anticipation of shifting consumer values and thus consumer demand (Morson, 2007).

This fundamental change and required movement towards the development of more sustainable solutions is thought to lie with the way we think about design. Anarow *et al.* (2003) suggest that sustainability cannot be achieved in the absence of whole systems thinking; addressing the problem at a system level. To gain a whole systems perspective companies are increasingly entering into the development of partnerships between multiple organisations, often across disciplines and industrial sectors. This is challenging as it is often uncertain as to how actors from different organisations are to integrate successfully and furthermore the holistic process that they should follow, in order to reach a more sustainable solution, is currently unclear.

This research is therefore necessary to provide improved knowledge and understanding of the integrative and holistic process required to develop more innovative, sustainable and optimised solutions.

1.2 Research Focus

The literature review in Chapter Two suggests that there have been multiple attempts within industry to develop more innovative, sustainable and optimised solutions by adopting a more holistic approach to design. It was uncovered at the beginning of the research, however, that there were, among others, four significant gaps in knowledge. There was no literature addressing:

1. A clear definition of a holistic approach to design,
2. How a whole system view was to be developed,
3. The factors that enable and inhibit the process of whole system design, and
4. The skills, abilities and expertise that actors are required to draw upon to successfully participate in a whole system design process.

The research is concerned with looking at the design process from a whole system perspective, subsequently, the term whole system design has been adopted by the researcher due to a lack of generally shared terminology within the field of holistic approaches to design. Literature surrounding the term holistic design is ambiguous and so, after considering other terminology, whole system design was chosen by the researcher as a term to more accurately represent the approach being investigated. Additionally the focal case study within the research (detailed in chapter 4) adopted the term whole system design and it was subsequently thought appropriate to utilise this term to maintain continuity of terminology.

The focus of the research is concerned with the whole systems approach to design and the process that actors follow in order to reach a more innovative and sustainable solution. The research aims to highlight the qualitative factors that enable and inhibit the process of whole system design to be undertaken. It is not, however, concerned with the benefits and drawbacks of adopting a whole system approach; neither does it address the quality of the final design solution.

It is hoped that the research will further the knowledge and understanding surrounding whole system design both within academia and industry. Furthermore, it is intended that the research will aid actors in the future design of more innovative and sustainable solutions.

1.3 Research Question and Objectives

In view of the need for the research and the gaps in knowledge that have subsequently been identified, a primary research question was established:

What factors enable and inhibit the successful adoption of a whole system approach to design?

In order to address the research question a number of research objectives were set.

- To identify qualitative factors that are generic to adopting a holistic approach to the design of more innovative and sustainable solutions,
- To undertake a case study to enable a better understanding, surrounding the process of whole system design, to be achieved,
- To confirm, modify and validate findings to encompass different whole system design contexts, disciplines and industrial sectors,
- To utilise findings to identify qualitative factors which enable and inhibit the process of whole system design.

1.4 A Summary of the Research Approach

The methodology designed for the current research, detailed in Chapter Three, was guided by the primary research question and the subsequent research objectives. As the focus of the research was to create a rich understanding of the qualitative factors that enable and inhibit the complex process of whole system design, a wholly qualitative research approach was applied. Additionally, as the research was largely inductive in its approach, the research design did not aim to prove or disprove any existing theory or generate hypotheses. A thematic perspective has been adopted for the presentation of emergent knowledge.

Data collection and analysis was conducted in two iterative phases. Phase one entailed the in depth exploration of a case study (detailed in Chapters Four and Five) embedded within the automotive industry; the observation of design and progress meetings, semi-structured interviews with project members, and the analysis of relevant project documentation. This led to the development of 10 themes, detailed in Chapter Five, representing initial enablers and inhibitors which appeared to be common to the whole system design process. Phase two of the research, presented in Chapter Six, saw the modification and validation of the findings across multiple design contexts and resulted in the consolidation of 8 themes. This knowledge was then fed back in an iterative cycle to the original case study to further develop and finalise the findings of the research.
Research findings from both phases of the study were evaluated and a comprehensive set of factors, that were observed to substantially enable and inhibit the process of whole system design, were presented.

1.5 Contribution to Knowledge

The research aims to generate new knowledge through the exploration of how multiple actors adopt a whole system approach to the design of more innovative, optimised, and sustainable solutions. Through the implementation of a qualitative and inductive research design new knowledge is able to be identified directly from the data. The research is novel and demonstrates a contribution to knowledge by:

- Generating new knowledge within the field of sustainable design,
- Adopting a thematic approach to the exploration of the process of whole system design,
- Identifying the qualitative enablers and inhibitors which substantially influence a whole system design process,
- Conducting a study which focuses on the practical implications of the whole system design process; as opposed to addressing the merits of the final design solution.

As a result, this research aims to contribute to knowledge by presenting novel observations, findings and conceptual models through the process of answering the research question and objectives.

1.6 Thesis Structure

Figure 1 presents the structure of the thesis.

	CHAPTER AIMS	ACTIVITIES	OUTCOMES
	INTRODUCTION		
1	To provide an overview of the research and a guide to the thesis structure	Summarised the need for the investigation and decided upon the research focus, design and objectives	- Scene Setting - Thesis Structure - Research Question and Objectives
	LITERATURE REVIEW		
2	To explore the context of the research and to identify and address the gaps in existing knowledge that the research is targeting	Reviewed relevant literature in and around the field, identified gaps in knowledge and validated accuracy of research question and objectives	- Gaps in Knowledge - Validation of research question and objectives
	RESEARCH DESIGN		
3	To consider relevant research approaches and to provide reasoning behind the chosen research design and data collection techniques	Systematically considered research design options. Made decisions regarding research approach and data collection techniques	- Research Methodology
	IMPLEMENTING THE RESEARCH DESIGN		
4	To describe the implementation of the research methodology and to provide detailed examples of how themes were identified	Vignettes detailing the process of implementing the research methodology. Selected process of abstraction for data analysis.	- Detailed documentation following methodology implementation - Process of Abstraction
	CASE STUDY		
5	To present the initial research findings and explore their relevance to the research question	36 months extensive interaction with case study. Observation of 22 design meetings, 18 interviews. Enfolding of literature and synthesis of data	- First Phase Research Findings - 10 Themes
	MODIFICATION AND VALIDATION		
6	To demonstrate how new data was used to elaborate and validate the initial findings	Focus groups and interviews held with 11 experts from various design contexts. Analysis of data and modification and validation of research findings	- Second Phase Research Findings - 8 Modified Themes
	DISCUSSION		
7	To illustrate how the findings have answered the research question and to provide the author's view on the research process and findings	Further analysis of data and generation of deeper understanding of the enablers and inhibitors of WSD. Presentation and discussion of key findings	- How the research findings address the research question - Enabling and Inhibiting Factors - Author's Reflections
	CONCLUSIONS		
8	To summarise the contribution to knowledge , to address the strengths and weaknesses of the study and to make recommendations for future research	Synthesis of key findings into contribution to knowledge. Reflection of research findings and literature to highlight strengths and challenges and future research directions	- Contribution to Knowledge - Strengths and Challenges - Recommendation for Future Research

Figure 1: Thesis Structure

2	CHAPTER AIMS	ACTIVITIES	OUTCOMES
	LITERATURE REVIEW		
	To explore the context of the research and to identify and address the gaps in existing knowledge that the research is targeting	Reviewed relevant literature in and around the field, identified gaps in knowledge and validated accuracy of research question and objectives	- Gaps in Knowledge - Validation of research question and objectives

Literature Review

This chapter grounds the research in current and relevant literature. Gaps in existing knowledge and understanding are identified and addressed as they form a foundation for this investigation.

2.1 Introduction, Purpose and Approach

The aim of this critical review of literature is to ground the research in current and relevant literature and subsequently identify gaps in existing knowledge and understanding. This will provide a foundation for the research question. As the research adopted an inductive approach much of the reading and synthesis occurred during the research activities, therefore literature will also be presented in Chapters Five, Six, and Seven alongside research findings and discussion.

This chapter is presented in three phases. Initially the terminology surrounding holistic approaches to design is explored to determine what, if any, differences exist between the individual approaches. Due to the limited amount of literature surrounding whole system design the second phase of the review calls upon additional approaches to holistic design with the purpose of identifying common qualitative factors within the design process. It is hoped that literature lying outside the field of whole system design might contribute to an improved understanding of the topic. Common qualitative factors are then summarised and explored further to provide a foundation from which the research can grow.

2.1.1 Carrying out a literature search

Typically, a key-word search is used to initiate a search for relevant literature. This can be done as existing research has already contributed to defining, exploring and positioning the topic. As the research surrounding whole system design is scarce this method alone was not adequate to gain a detailed perspective of the subject area. However, through the use of a limited number of key papers referring to whole system design it was possible to identify similar approaches which had been researched using different terminology by following up the appropriate references.

Once a significant number of secondary papers had been identified it was possible to recognise several key journals that regularly published papers around the topic. Journals such as Design Studies, The Journal of Engineering Design, Design Principles and Practices and The Journal of Cleaner Production were monitored frequently throughout the PhD process. It also became clear that relevant research could come from a number of perspectives outside of the field of design: health care (Cameron *et al.*, 2006), environmental psychology (Kuller and Lindsten, 1992), and water management (Collins *et al.*, 2007), for example. This demonstrated the multitude of different paths that the research could potentially take.

During the literature search several objectives were identified in order to begin to answer the research questions. These included: discovering what other researchers had looked at within the current research area, to identify what theoretical and methodological approaches had been utilised; what the results of these studies were, and perhaps most importantly how this informed the current study.

2.2 Background to the Research Field

As contemporary society continues to change, both rapidly and profoundly, so is the demand for new products and services. Incremental changes to current designs are no longer enough for modern day living and so it seems that radical, innovative step-changes are required to fulfil increasing consumer needs. Coinciding with this revelation is the growing concern for the state of the environment, particularly the continued or improved sustainability of our society. Mainstream businesses are launching green initiatives and eco-friendly products in an effort to capitalise on society's apparent shift toward a more environmental ethic. Most green business efforts essentially are attempts to improve upon traditional products by somehow making them more environmentally benign, through, for example, product reformulation or increasing its energy efficiency. However, environmentalists, especially those in the sustainable consumption movement, want businesses to change their products fundamentally in anticipation of shifting consumer values; and thus consumer demand (Morson, 2007). Current technological improvements, although contributing to a potential improvement of the immediate situation, are not adequately addressing the problem as a whole, particularly softer issues such as consumer behaviour and servicing products and economies (Mont, 2006).

The lone ingenious designer, who could do everything by him or herself, is rapidly becoming history (Krippendorff, 2006, pp. 18). Design research suggests that the development of more innovative and sustainable solutions increasingly requires the integration of multiple actors with an expansive array of knowledge and expertise. The importance of cross-disciplinary collaborations and partnerships within industry is escalating, driven by the need to address complex problems more systemically, in a systematic way, and from a multitude of perspectives (Hebel, 2007; Senge, 1990). This is central to what the study is looking at: a design approach which is replicable and consistent in response to increasingly complex problems. Designers, engineers, mechanics, technicians, architects, psychologists, quantitative and qualitative researchers, academics, users and consumers are just some of the stakeholder groups across disciplines that increasingly form these collaborative partnerships.

Subsequently, partnerships are accompanied by numerous expectations and requirements, and also a more extensive network of actors. Some actors, whom were never previously regarded as designers, are becoming heavily involved with the actual process of designing. High levels of multi-disciplinary working not only increase levels of complexity (Mankin *et al.*, 2004) but also create many more issues and concerns to consider and often they can be conflicting (Howarth and Hadfield, 2006). Kemp (2008) agrees and suggests that traditionally, industrial design, graphic design, user-interface design, advertising, and so on, have been separate disciplines, with a product essentially being handed from one to the other in logical sequence. However, delivering the integrated customer experience demanded today requires a more cooperative and, in many ways, more difficult approach.

2.2.1 Exploring the terminology associated with holistic design

Over the last decade, multiple approaches to design have focused on the development of products, services and systems for improved social, economic, and environmental sustainability. It appears, however, that consensus is lacking with regards to the terminology used to describe these approaches and, additionally, the process that the consortium of actors are required to follow. Product Service System (Mont, 2006), Solution Oriented Partnership (Manzini *et al.*, 2004), Whole System Design (Hawken *et al.*, 1999), Highly Customised Solution (Manzini *et al.*, 2004), Eco-Efficient Product Service System (Mejcamp, 2000), Sustainable Product Service System (Heiskanen and Jalas, 2003), Integrated Solutions (Van Der Zwan, 2003), Advanced Industrialisation (Manzini *et al.*, 2004), Strategic Design (Manzini and Vezzoli, 2003), Customer Solutions

(Cornet et al., 2000), and Systemic Innovation (Little, 1987) are just some of the terms that have been coined for projects of a systemic and holistic nature.

As Marxt and Hackiln (2005) emphasise, it is widely accepted in academia and industry that new products or services, which are developed on a regular basis, are one of the main factors for the sustainable success of companies. Although the fact in itself is clear, the terminology used to describe this professional and academic field is manifold. In an attempt to individually distinguish these multiple approaches to the holistic design of more innovative and sustainable solutions; Table 1 presents a number of different terms alongside definitions taken from literature.

Although the definitions within Table 1 appear to focus on individual aspects of the solution and / or the design process, there is a significant overlap of aims and purpose. Subsequently it has been identified that there are relatively few studies within the relevant literature which provide a model or guide as to how actors are to embark on such a messy and complex design process. Very little is available for the phase that bridges concept and detailed design, a phase that Ruder and Sobek (2007) term ‘system-level design’.

Term	**Definition**
PRODUCT SERVICE SYSTEM (Manzini and Vezzoli, 2003)	An innovation strategy, shifting the business focus from designing physical products only, to designing a system of products and services which are jointly capable of fulfilling specific client demands
ECO-EFFICIENT PRODUCT SERVICE SYSTEM (Manzini and Vezzoli, 2003)	When a Product Service System assists re-orient current unsustainable trends in production and in consumption practises
ECO-EFFICIENT SERVICE (Brezet *et al.*, 2001)	Eco-efficient services are systems of products and services which are developed to cause a minimum environmental impact with a maximum added value.
WHOLE SYSTEM DESIGN (Rocky Mountain Institute, 2004)	Whole system design means optimising not just parts but the entire system … it takes ingenuity, intuition, and teamwork. Everything must be considered simultaneously and analysed to reveal mutually advantageous interactions (synergies) as well as undesirable ones
SOLUTION ORIENTED PARTNERSHIP (Manzini, 2003)	A sustainable system of products and services delivered in a highly effective way by a network of local and global partners which is able to address specifically each given user in its given context
INTEGRATED SOLUTION (Wise and Baumgartner,1999 in Van der Zwan, 2003)	Integrated solutions combine products and services into a seamless offering that addresses a pressing customer need
ADVANCED INDUSTRIALISED SOLUTIONS (Manzini, 2003)	Solutions based on collaboration between social players that give rise to highly contextualised services (services that are sensitive and appropriate to the specific characteristics of the contexts in which they are provided), which are also equally effective and efficient (able to offer high quality results while minimising economic and environmental costs)
CUSTOMER SOLUTIONS (Cornet et al., 2000 in Van der Zwan, 2003)	Typically developed as a combination of products, services, and knowledge, a solution is a supplier’s customised response to a customer’s pressing business need. It is an innovative construct built on a foundation of cooperation and mutual trust that revolutionises the customer value proposition.

Table 1: Definitions of multiple design approaches taken from literature

2.3 An Overview of Current Approaches to Holistic Design

The aim of this chapter is to further explore approaches to the holistic design of more innovative and sustainable solutions. More specifically, due to the apparent lack of certainty surrounding the design process actors are required to follow, each approach will be reviewed and compared with reference to the following questions:

- What is the focus of the approach?
- What guidelines are stakeholders given?
- Does the approach result in more sustainable solutions?
- What is the intended outcome of the approach?

In addressing these questions a set of common qualitative factors will be sought and tabulated. It will then be determined whether there is value in developing a generic model of best practice for the design of more innovative and sustainable solutions or, alternatively, whether each approach is unique and subsequently requires actors to adapt to a distinctive design process.

2.3.1 Product service systems

"A Product Service System suggests the need to link hard and soft issues such as technology and sociology, products and services and to view existing environmental problems from a systemic perspective"

(Mont, 2006)

One of the first attempts at utilising a holistic approach to produce more innovative and sustainable solutions and so far the most widely researched approach has been Product Service Systems (PSS) (Baines *et al.*, 2008).

Environmentalist-driven authors have argued that, unless ways can be found to separate economic growth from environmental pressure, mankind would face near-certain disaster (Von Weizacker *et al.*, 1997). Therefore, rather than developing a product to fulfil consumer needs, attention turned to realising final customer needs with a focus on sustainability. Authors suggest that not only would this new perspective address the design of need-fulfilment systems with Factor 4 – 10 sustainability improvement but, in doing so, would present the designer with more freedom to create innovative solutions (Schmidt-Bleek, 1993).

An example of a proposed PSS with a combined solution of products and services was suggested by the ESRC Centre for Business Relationships, Accountability, Sustainability and Society (BRASS, 2006) which argued that in order for the automotive industry to address social, environmental and economic pressures a radically alternative vision must be adopted. The suggestion of micro factory retailing (MFR) was based around the concept of providing personal mobility delivered by means of environmentally optimised vehicles. The cars or modules could be mixed and matched according to customer requirements, but all would be based on low customer cost, high labour input, environmentally and socially optimised technologies, as sustainable as can be achieved (Williams, 2006). Although the case for MFR has its merits it is unclear how this alternate vision is to be adopted. There is little practical guidance as to how radically innovative concepts such as this are to be introduced into the automotive industry. Furthermore traditional working environments and deeply-rooted values and ethics are just some of the issues that may stand in the way of such radical change. Implementing new concepts into old systems appears to be challenging; often new designs do not succeed without re-addressing the system within which it is to live.

A key attribute of PSS according to many authors appears to be the shifting of focus, from designing physical products only to designing a system of products and services, which, through innovative strategies, are capable of fulfilling specific client demands (Manzini and Vezzoli, 2003). Much of the research surrounding PSS has focused on the internal benefits that the approach is thought to provide to business. In a report addressing opportunities for sustainable solutions, conducted by the United Nations Environment Programme (UNEP), it was suggested that PSS is a new concept for business to improve their sustainability performance. The report went on to argue that, as a natural step after efforts to clean up production processes and re-design products, the new approach invites business to shift its focus from selling those products to selling the utility (Manzini and Vezzoli, 2003). However, it has been more recently acknowledged that the ongoing transition towards service development or service economy increasingly requires the development of partnerships and networks (Christenson, 2007). The more we move in the direction of offering industrialised solutions instead of single products or services, the more complex the system of actors required to deliver such offers becomes (Krucken and Meroni, 2006). In fact, to find holistic solutions to the issues of modern society the concept of PSS calls for the development of multidisciplinary approaches that require inputs from a broad range of disciplines, such as economics, management, environmental studies, sociology, psychology, product design and engineering (Mont, 2006). Subsequently it appears that future research surrounding PSS would benefit from focusing on the practical facilitation of cross-disciplinary integration for the development of more sustainable opportunities rather than addressing internal business strategy alone.

Acknowledging that the cohesion of various actors is essential to developing a successful PSS, Morelli (2006) suggests that there are three key stages for a designer to follow:

1) Work on the identification of the actors in the network, on the basis of the defined analytical frameworks;

2) Work on possible PSS scenarios, verifying use cases, sequences of actions and actors' role, defining the requirements for a PSS and the logical and organisational structure of a PSS;
3) Work on representation and management tools to represent a PSS in all its components, i.e. physical elements, logical links and temporal sequences.

Morelli (2003) suggests that, although currently there are no tools in place to aid designers with these steps, other disciplines do in fact utilise methods which could be integrated into the discipline of design, and PSS in particular. There is, however, no current research to suggest this integration has been carried out or even attempted.

Further to the emphasis placed on actor-identification Bijker (1987) highlights the relevance of the extended network of actors. He views relevant actors as not only those social groups that actively participate in the development of the PSS, but those actors that indirectly participate in such a process and even those that may oppose it. The integration of stakeholders into the design process is becoming ever more crucial for the development of a more holistic solution and due to the complexity of actors involved with the development of a PSS, the designer's role is having to change. Designers now need an awareness and understanding of complex and wide ranging issues when applied to a new product, service or system (Howarth and Hadfield, 2006). Designers are increasingly required to have additional skills and expertise in methods, management and organisation. There is a significant gap in the literature, however, regarding what these skills are and how the designer is to obtain them. Furthermore, it needs to be acknowledged that designers cannot have all the knowledge and skills necessary for the design of a more innovative and sustainable solution. Future research must stop focusing on the individual role of the designer and turn towards the facilitation of numerous actors within the process of design.

Although much literature focuses on the benefits of PSS, the definition of specific methodologies to manage some critical aspects of the design process of PSS has rarely been considered in design-related disciplines (Morelli, 2006). Given this, it is no surprise that a sustainable PSS theory with explanatory and predictive power is still largely absent (Tukker and Tischner, 2006). Additionally the transfer of PSS from academia to practice in UK manufacturing firms is still being attempted (Cook *et al.*, 2006). This is necessary not only to move the concept of PSS forwards through an improved evaluation of its practical utility but also to communicate an improved understanding of it to related disciplines.

As previously suggested, a significant aim of a PSS is to develop sustainable solutions (Schmidt-Bleek, 1993) however the success of this aim is questionable and has even been described as a 'myth' (Tukker and Tischner, 2006). The sustainability oriented literature has made relatively few attempts to come to a structured visualization of PSS (Tukkler and Tischner, 2004). Manzinni (2003) suggests that it is generally agreed that PSS does not necessarily lead to sustainable solutions and some PSS approaches could even generate unwanted side-effects. He does however suggest that when a PSS addresses current unsustainable trends in production and consumption practices it is usually referred to as a Sustainable or Eco-Efficient PSS. This further categorisation adds to the complexity and confusion surrounding design approaches and furthermore begs the question: what is the difference in the approach towards a PSS and an Eco-Efficient PSS?

2.3.2 Eco-Efficient Product Service Systems

"An eco-efficient service is a certain product-service mix, which has a higher added value, and a smaller environmental impact compared to a similar product-service mix or a situation in which the activity was not performed at all"

(Zaring et al., 2001)

Van der Zwan (2003) suggests that terms such as eco-efficient PSS, eco-efficient services, sustainable services and systems and eco-services, although with slightly different meanings, simply stress a particular element of the offering.

From a designer's perspective it is suggested that the main difference between a regular PSS and an eco-efficient service can be found in the multiple perspectives that are adopted. The more the boundaries are pushed, the actor network extended and even more potential contexts adopted, the larger the potential for sustainable innovation (Van der Zwan, 2003). While agreeing with this comment; it can be argued that the contribution of multiple perspectives does not differ significantly from any other attempt detailed in this chapter. Consequently it is unclear how a solution produced by this approach would be more sustainable than any other. Manzini and Vezzoli (2003) suggest that the more the notion of whole system optimisation is broadened (beyond a single product life cycle to an interconnected series of product and service life cycles), the greater is the potential for eco-efficiency gains. Additionally, the organisation of stakeholder involvement is more complex and could increase the likelihood of failure. However again, as shown in the following example, through the integration of multiple stakeholders the potential for eco-efficiency gains is greater.

The Allegrini service proposed a new way of supplying detergents for house-keeping as an eco-efficient PSS based on the home-delivery distribution of detergents (Manzini and Vezzoli, 2003). As both a product (the detergent) and a service (home-delivery) the concept focuses on providing:

- added value for the producer by minimising overall packaging costs and postponing the cost of new product manufacture,
- added value for the consumers through an increase in comfort, since the products arrive directly to home and waste disposal efforts are reduced,
- environmental benefits obtained by the optimisation of the distributed process, in terms of both packaging and transportation.

The study does not, however, provide details of how the suggested environmental benefits were measured. Unless significant numbers of consumers were to adopt this service, such benefits may well be negligible. Furthermore it is argued that an environmentally friendly solution is ineffective without successful implementation into the surrounding system; the design of practical implementation of a concept should be as important as the design of the concept itself.

As literature is limited regarding the practical development of an eco-efficient PSS it is difficult to identify how the design process would differ from that of a regular PSS. In a study by Van der Zwan (2003) an attempt to identify several commonalities within the process of designing more holistic and sustainable solutions resulted in the following points:

- The customer need is the starting point of the offer,
- The provider is involved throughout the lifecycle,
- They guarantee a certain level of performance,
- They focus on creating added value.

This top-level representation highlights what little work has been carried out within this area. Furthermore it is still suggested that the environmental implications of introducing eco-efficient services are poorly studied (Van der Zwan, 2003) and that there is so far no conclusive evidence that the use of these services contributes positively to sustainable development (Mont, 1999).

In a review of eco-efficient producer services (EEPS); Bartolomeo *et al.* (2003) investigated three different typologies of eco-efficient services:

- Product-based services,
- Electronic substitution services,
- Information-based services.

The extensive study concluded that there could be no general assumption that services were inherently environmentally superior to products. Furthermore, in cases where improved sustainability was reached, only a minority appeared to have been driven by environmental factors. For most, environmental considerations were only stumbled upon 'by accident' (Bartolomeo *et al.*, 2003). It is suggested that the current shift towards services in industry is unlikely to lead to radical eco-efficiency improvements by its own momentum (Heiskanen and Jalas, 2003). Instead researchers and practitioners are advised to look towards how existing services could be made more sustainable as opposed to developing new ones (Heiskanen and Jalas, 2003).

It has so far been difficult to differentiate between the highlighted approaches, particularly from the perspective of the process that actors are required to follow. One recurring attribute, however, appears to be the intensity of collaboration and integration that is required. The following section investigates this specific collaboration through solution oriented partnerships, another holistic approach to the design of more sustainable solutions.

2.3.3 Solution Oriented Partnerships

"A sustainable system of products and services delivered in a highly effective way by a network of local and global partners which is able to address specifically each given user in its given context"

(Manzini et al., 2004)

Morelli (2006) has defined a Solution Oriented Partnership (SOP) as the partnership that is generated by the convergence of different stakeholders for the generation of the solution within a PSS. He elaborates by suggesting that the glue for such a partnership is attractive design solutions based on a mix of material and immaterial components which satisfy the requirements of each of the stakeholders. The SOP approach is included within this review due to its aim of producing a more sustainable solution through the use of collaboration and partnerships which appears comparable to that of a PSS.

An example of a SOP is La Fiambrera (Lambert *et al.*, 2004) which has been documented as part of the highly customised solution (Hics) project. La Fiambrera was a venture which succeeded in providing lunches to two completely different groups of people that shared provision needs. The system creatively and successfully combined economic business interests and the achievement of social benefits to provide a highly customised solution to fulfil local needs (Lambert *et al.*, 2004). This project is unique as not only does it present evidence of the benefits of the approach but also provides details of the complex integration of multiple stakeholders that was undertaken in order to reach a more sustainable solution.

Introducing yet another term to the sustainable solution mix, Manzini *et al.*,(2004) suggest that SOP's aim: to put forward ideas and useful instruments for the development of solutions, can be described as 'advanced industrialised solutions'. He explains that these solutions are based on collaboration between social players and give rise to highly contextualised services (services that are sensitive and appropriate to the contexts in which they are provided) which are equally effective and efficient (able to offer high quality results while minimising economic and environmental costs).

As the name suggests a SOP rigorously emphasises the development of a collaborative partnership; the process of building a network of partners, capable of effectively working together to design and deliver a solution is fundamental (Burns and Evans, 2004). The integration of multiple actors is again a fundamental attribute to this type of solution.

Jegou and Joore (2004) propose that there are four main objectives that a SOP approach should aim to achieve:

1) Combining stakeholders that would normally not work together like profit and non-profit organisations, multinationals and SME's, global and local players;
2) Industrialised solutions based on a global platform of products, services and knowledge combined with specific local solution elements;
3) Contextualised solutions that are focused on a specific user in a specific context, and can be adapted to fit other related contexts of use;
4) Sustainable solutions that are both profitable for companies and beneficial for society.

These objectives highlight the few subtle differences between a SOP and the approaches that have been reviewed so far. The focus on customisation and the emphasis placed upon local business are new attributes and would require additional skills and abilities of the actors involved.

SOP is a relatively recent classification and has only been applied to a limited number of projects. It is, however, one of the few approaches to specifically document the role of the designer and provide a small amount of guidance as to how actors should approach the process of providing a more innovative and sustainable solution.

Due to the lack of examples it is also difficult to assess the success of the solution from an environmental perspective. The inclusion of local produce and business is a positive step; however, the emphasis put on customisation raises questions of cost and effort to fulfil the needs of individual customers.

2.3.4 Whole System Design

"Whole-systems thinkers see wholes instead of parts, interrelationships and patterns, rather than individual things and static snapshots. They seek solutions that simultaneously address multiple problems"

Anarow et al., 2003

During the 20th century, engineering became more and more specialised as scientific and technological knowledge increased exponentially (Stasinopoulos *et al.*, 2009 pp. 5). Subsequently in the 21st century engineers, scientists and managers prepared themselves to solve complex problems by becoming increasingly specialised and reducing problems to their constituent parts and focusing their attention on each part. As a result, architects design a building, mechanical designers devise its heating system, lighting designers draw up plans for illumination and interior designers plan its internal spaces. This separation of design functions and processes often results in inefficient design, construction delays, oversized heating systems, higher costs and unnecessary environmental impacts (Anarow *et al.*, 2003). Opportunities are often missed to optimize the whole system as the specialist only knows his field in detail and has little interaction with other designers on the project (Stasinopoulos *et al.*, 2009).

A whole system design approach encourages those involved to regard a problem as a whole system and not just to concentrate on one particular component of that system. Additionally, it recognises that a problem is created by every part of the system in which the problem is embedded, and that the problem can and should be addressed at every level. When developing a solution the same forces exist and it should be recognised that interventions within a specific location will impact throughout the system; this requires understanding and management. Anarow *et al.,* (2003) recognise that the approach focuses on interactions between the elements of a system as a way to understand and change the system itself. Whole-systems thinking pays close attention to incentives and feedback loops within a system as ways to change how a system behaves (Senge, 1990). Without this whole system perspective crucial impacts between components could be missed, therefore disrupting the system as a whole.

Hawken *et al.*, (1999, p. 64) are perhaps the first authors to begin to outline a whole system approach from the perspective of the designer. They describe the approach as being a change or shift in design mentality through which designers are required to stop using 'rules of thumb' and to start asking different questions. However, Hawken *et al.*, (1999) do not suggest ways in which designers can stop using rules of thumb and additionally neglect the challenges associated with this such as the modification of life long design practice. The whole system design approach emphasises the intelligent application of existing technologies and the use of cross fertilisation to discover innovative ways of applying these technologies to alternative components of a problem. Hawken *et al.*, (1999, p. 64) advise that the focus of a whole system design should not surround the development of new technologies but rather should address the intelligent application of existing technologies. Ways, in which this concept can be facilitated, however, are not prescribed. Although it is acknowledged that each design context provides a unique set of problems it is thought that research into whole system design would benefit from the identification of methods through which to approach these problems. Currently there is a lack of methodologies aimed at starting off system-level innovations in practice (Van den Bosch *et al.*, 2005)

Authors suggest that understanding the dynamics of a system is integral to the whole system approach (The Rocky Mountain Institute, 2004; Gunderson and Holling, 2002). The Rocky Mountain Institute highlights systems thinking as the method that should be utilised not only to point the way to solutions to particular resource problems, but also to reveal interconnections between problems, which often permits one solution to be leveraged to create many more. An example of where the whole system design approach was used successfully is within Walmart stores. Through the use of a Charrette (Lennertz and Lutzenhiser, 2006) Walmart stores adopted a Whole Building Design approach and subsequently implemented natural day lighting within several of their experimental stores through the use of multiple sky lights. Not only did the implementation result in light saving 300,000 kwh a year but reduced the energy required to cool the building as lights give off heat; provided an increase in sales due to happier customers and reduced staff turnover due to happier staff. A Charrette involves a series of collaborative design and public input cycles for multiple, consecutive days (D'Este Hoare, 2006). An important goal of a Charrette is to bring decision makers and community members together in one place to create a plan that represents a detailed, feasible agreement (Lennertz et al., 2008). Everyone – from city planner to local business owner– becomes aware of the complexities of development and design issues, and everyone works together to arrive at the best possible solution (National Charrette Institute, 2006). While the Charrette was first developed for use by architects and specifically related to building design it is easy to visualise how it could be integrated to many other whole system design solutions and contexts. Additionally, in the context of this thesis, this provides the whole system approach to design with a unique tool through which designers can learn to develop the skills necessary to develop more holistic solutions.

The concept of whole system design is difficult for those involved, including designers, but it is suggested that a combination of ingenuity, intuition, teamwork and simultaneous consideration of all components will result in the teasing apart of the problem to reveal mutually helpful interactions allowing the whole system to be optimized and not just individual parts (Rocky Mountain Institute, 2004). The identification of further tools and techniques would provide substantial guidance and support to actors embarking on the design of more sustainable solutions in the future.

Although, like other holistic approaches to designing more innovative and sustainable solutions, it has been suggested that whole system design could encourage sustainable solutions, the approach does not automatically yield sustainable production and consumption systems. Anarow *et al.* (2003) state however, that sustainability cannot be achieved in the absence of whole systems thinking, a skill that appears to be essential to a designer of more sustainable solutions.

2.4 Identifying Common Factors

Industry is under increasing pressure to produce innovative solutions which fulfil the rapidly growing needs of contemporary society. This pressure is ever-increased by the requirement to adopt a more sustainable approach to the design and manufacture of products and services. The first phase of this critical review of literature has demonstrated the confusion surrounding the multiple approaches to the design of more sustainable solutions, due to the numerous definitions and interpretations currently being used. Key approaches have been discussed including PSS, eco-efficient PSS, SOP and whole system design, with the aim of reviewing each against the questions highlighted in Section 2.3. Table 2 provides a direct comparison of the reviewed approaches against the pre-selected questions.

	PSS	Eco-efficient PSS	SOP	WSD
What is the focus of the approach?	Added value, fulfilment of customer requirements,	Added Customer and Producer Value, sustainable solutions for wider contexts	Highly customised solutions, highly focused on both the solution and the design	Identification of relationships between components of a system
What guidelines are stakeholders given?	Change in focus, inclusion of multiple perspectives	Pushing the boundaries, extending the actor network	Stakeholder involvement, Emphasis on Collaboration, Network of Partners	Change / shift in design mentality, Systemic thinking, The use of Charrettes
Does the approach result in more sustainable solutions?	Unclear	Unclear	Unclear, positive use of local produce and business	Unclear, positive use of systemic thinking
What is the intended outcome of the approach?	Products and / or services	Products and / or services	Products and / or services, partnership between local business and globalisation	Products and / or services

Table 2: A comparison of holistic design approaches

From the table it is clear that there are many similarities between the design approaches, subsequently it is difficult to say whether each approach is individually unique. The common attributes that are shared by the approaches are highlighted in Table 3 which is presented later on in the chapter. Possibly the most obvious characteristic is that ultimately each approach aims to produce a more sustainable solution in the form of a product and / or service. It remains unclear how successful each approach is at producing significantly more environmentally sustainable results. This lack of clarity is due to a limitation in the number of examples that exist and a gap in research and/or the literature regarding the analysis of examples that do exist. Future research would benefit from quantifiable studies exploring and comparing the sustainable quality of the results from these design approaches. It has been suggested, however, that there does not seem to be any way to measure the environmental benefits of services in general and, even in specific cases, calculations are complex and surrounded by many uncertainties (Heiskanen and Jalas, 2003). The positive attention and awareness being created by such projects is definitely a step forward for industry. Further utilisation of holistic approaches to design should place even greater emphasis on environmental concerns and again designers would benefit from tools, techniques and methods to aid them with this challenge.

The focus of this study is concerned with the process by which actors undertake a whole system approach to design as opposed to addressing the outcome of that process. The decision to utilise the term 'Whole System Design' further illustrates the need for the current study as although the approach emphasises the 'process' there is a gap in knowledge regarding how that process is to be carried out. It is clear that authors still recognise the role of the designer as crucial to the holistic design, development and production of more innovative and sustainable solutions. It is also clear, however, that the integration of actors from multiple disciplines is necessary to enable a more holistic and subsequently sustainable solution to be reached. Few studies have been carried out into the facilitation and implementation of the integrative process associated with this type of design approach. It is currently unclear what skills, abilities and experiences actors are required to draw upon and furthermore, tools, techniques and methods to aid the process are extremely limited. Due to this substantial lack of literature and subsequent knowledge it is difficult to define what is meant by the term Whole System Design. For the purpose of clarity within the thesis the following definition, provided by the Rocky Mountain Institute, has been adopted:

"Whole system design means optimising not just parts but the entire system … it takes ingenuity, intuition, and teamwork. Everything must be considered simultaneously and analysed to reveal mutually advantageous interactions (synergies) as well as undesirable ones"

(Rocky Mountain Institute, 2006)

Further clarity surrounding this definition shall be provided through the exploration of whole system design throughout the study.

This gap which has been identified through the review of available literature has subsequently informed the primary research question:

What factors enable and inhibit the successful adoption of a whole system approach to design?

The following phase of the literature review utilises the comparison of holistic approaches to design to identify those factors that are generic to this type of approach.

2.5 Exploring Common Factors

The previous section highlighted some of the similarities between holistic approaches to design. These similarities are now explored further and factors, generic to the process which actors are required to follow, are investigated. This literature will provide an initial insight into the factors that enable and inhibit the process of whole system design. These will act as a foundation on which to base the practical research.

Table 3 presents several attributes that have been identified as generic to the approaches investigated within the review. It is necessary to investigate these attributes further within the study to provide designers with knowledge surrounding trans-disciplinary skills, to be practised across various contexts. Trans-disciplinary skills are those that exist 'across' disciplines and are therefore generic to all disciplines as opposed to inter-disciplinary skills which exist 'between' disciplines. Trans-disciplinary skills are those that are relevant to whole system design and are evident in the table. It is thought that, by grouping and emphasising different aspects, a model of enabling and inhibiting factors would have the potential to be defined by and help to define multiple design problems. Furthermore it is argued that the development of such a tool should help to address the confusion surrounding the vast array of terminology currently utilised to define design approaches.

Attribute	**Description**	**Literature**
Development of Partnerships	Collaboration is required between disciplines, organisations and expertise	Christenson, 2007, Mont, 2006, Van der Zwan, 2003
The use of multiple perspectives	The development of an expansive network to provide multiple resources, knowledge and perspectives	Christenson, 2007, Krucken and Meroni, 2006, Morelli, 2006, Bijker, 1987
The Integration of Multiple Disciplines	The sharing of knowledge across and between disciplines for successful integration	Mont, 2006, Jegou and Joore, 2004, RMI, 2004, Van der Zwan, 2003, Hawken *et al.*, 1999
Change in focus	Designers are required to adopt a change in design thinking and to start seeing the system as a whole	BRASS 2006, Anarow *et al.*,, 2003, Hawken *et al.*, 1999, Senge, 1990

Table 3: Generic attributes across design approaches

Utilising Table 3 the following section of the literature review highlights and further explores some of the factors that have been recognised as generic to holistic design.

2.5.1 Development of Partnerships

The development and utilisation of partnerships between organisations has been highlighted as a key factor to adopting a holistic approach to design.

Subsequently the process of developing and maintaining these partnerships is thought to require intensive collaboration between actors. Collaboration is an activity where expertise, ideas, resources, and responsibilities are shared between a team of people in order to achieve a more successful solution than if attempted by an individual or single discipline. Katzenbach and Smith (1993) support this and suggest that in any situation requiring the real time combination of multiple skills, experiences and judgements, a team inevitably gets better results than a collection of individuals operating within combined job roles and responsibilities. Design teams are of major importance in any organisational context because, with increasing complexity, groups of individuals work together in order to accomplish problems they cannot solve on their own (Stempfle and Badke-Schaub, 2002). Emphasis is particularly put on the importance of multi-disciplinary collaboration for the achievement of innovation and / or creativity; to create innovative artefacts, design participants must increasingly explore technical and scientific information from a variety of disciplines (Sonnenwald, 1996). Fischer (2005) agrees suggesting that an idea or product that deserves the label 'creative' arises from the synergy of many sources and not only from the mind of a single person. Montuori (1997) presents a detailed argument supporting multi disciplinary creativity as opposed to individual input through a review of literature.

It is convincing that the cross fertilisation of multiple perspectives, disciplines, ideas, backgrounds, technologies, and actors can aid the production of a more successfully innovative solution. The process of collaboration required to reach such a solution, however, is not so obvious.

Although there has been a vast amount of research conducted surrounding the benefits and process of effective collaboration this has never been explored within the context of a whole system design. It is currently unclear how the process of collaboration is to be modified to allow for a design team to develop a combined holistic perspective and ultimate solution. One suggestion is, that to enable a holistic perspective to be formed, actors must first develop shared understanding.

Shared Understanding

A shared understanding is a similarity in the individual perceptions of actors about either how the design content is conceptualised (content) or how the transactive memory system works (process) (Kleinsmann, 2006). Team effectiveness will improve if team members have an adequate shared understanding of the team's objectives, processes, and situation (Dong, 2005). It appears that effective collaboration is dependant not only on how actors visualise the end goal but additionally the process required to reach that goal. Creating this shared understanding is difficult, however, as actors from different disciplines have different backgrounds, interests and perspectives on the new design (Kleinsmann and Valkenburg, 2008). Additionally, within the current research, actors are likely to come from very different companies and organisations and so may have individual motivations and requirements of the project.

This, and subsequent literature regarding multi-disciplinary design, will be referred to throughout the thesis as data is collected.

2.5.2 The Use of Multiple Perspectives

The structure, management and functioning of a project team is not only determined by internal considerations and choices but is also strongly influenced by a range of volatile, external, environmental factors (Mullins, 2002). This is particularly relevant to whole system design in which taking external environmental influences into consideration could result in the success or failure of the ultimate solution. Literature emphasises the importance of networks to support collaborative design and to provide multiple perspectives. The productivity of a team depends, to a large extent, on the ability of its members to tap into an appropriate network of information and knowledge flows (Leenders *et al.*, 2003). Extensive inter-personal networks improve design outcomes, especially in projects with high levels of uncertainty (Sonnenwald, 1996). Windahl

(2006) agrees suggesting that, not only inter-personal, but inter-firm relationships are important for innovation and value creation. Additionally he proposes that the ability to manage, use and exploit inter-organisational relationships is likely to increase of the development of integrated solutions.

External Social Networks

Granovetter (1973) argues that the ability to draw upon different social networks is fundamental to enlarging the knowledge base of a system (Family, community, organisation etc) and thereby it's adaptive capability. Similarly studies have shown that inter-organisational relationships that are embedded in a network provide access to new technologies, resources and learning opportunities that help enhance competitive position (Dyer and Singh, 1998; Nohria and Eccles, 1992). Networks are dynamic and multi-dimensional (Putnam 2000) as when working in collaborative partnerships; organisations are often knitted together by ties of a complex and diverse nature. Ties can differ according to whether they are based on friendship, work, or advice; and whether what flows through them are resources, information, knowledge or affection; whether they are face to face, electronic etc. (Marouf, 2007). A useful network theory to enable the visualisation of networks surrounding project teams has been developed by Granovetter (1973, 1983) entitled: the strength of weak ties. The argument asserts that our acquaintances (weak ties) are less likely to be socially involved with one another than are our close friends (strong ties). The importance of weak ties within groups of actors is emphasised as individuals with few weak ties will be deprived of information from distant parts of the social system and will be confined to the provincial news and views of their close friends (Granovetter, 1983). The macroscopic side of this communications argument is that social systems lacking in weak ties will be fragmented and incoherent. It is proposed that a large number of strong ties within a project team could be detrimental as the tendency to develop cliques with similar views would be common. Blau (1980) conducted a case study in a children's psychiatric hospital where there was a particularly large, structured network of weak ties. Within the children's centre, in comparison to other departments within the hospital, she found an unusually high morale level, low staff turnover and an absence of cliques between the staff. Blau (1980) puts these findings down to the institution’s intolerance of close dyadic ties and concludes that extensive weak networks can remain viable only when close ties are prohibited.

Granovetter (1983) highlights the need for both weak and strong ties within both a social context and within a project team; weak ties provide people with access to information resources beyond those available in their own social circle; but strong ties have greater motivation to be of assistance and are typically more easily available. This finding is particularly relevant to the development of partnerships where it may be common for project members to already have developed strong ties particularly if several members come from the same organisation or company. It is unclear however what the ratio of strong to weak ties should ideally be to encourage success.

It is proposed by Levine and Moreland (1990) that many researchers seem to assume that groups relate to one another in a social vacuum. Most studies focus on just two groups, each completely separate from the other. Yet nearly all groups are bound together in some way, because they share members, have developed 'weak ties' or are embedded within the same social network. Also, other groups or individuals often intervene in inter-group relationships when they believe their own outcomes can be affected. As a result, inter-group relations are complex, involving many actors related to one another in a variety of ways. This is significant advice and it is important within the current research that the group being observed is not limited to the actors involved. The researcher must be aware of the extended network of weak ties and aim to identify the effect, seemingly external, actors are having on the project team and holistically upon the final design solution.

Internal Social Networks

The presence of strong and weak or bridging and bonding ties internally within an organisation are also paramount to successful communication and knowledge sharing. Interaction enables people to build communities, to commit themselves to each other, and to knit the social fabric. A sense of belonging and the concrete experience of social networks (and the relationships of trust and tolerance that can be involved) can, it is argued, bring great benefits to people (Smith, 2006). The development of partnerships relies substantially on social interactions and therefore needs to be explored as a potentially key attribute to the facilitation of a whole system design.

The concept of social networks is often described as having social capital. Social capital refers to the institutions, relationships and norms that shape the quality and quantity of a society's social interactions. Social capital is not just the sum of the institutions which underpin a society – it is the glue that holds it together (Halpern, 2005). The application of social capital to organisational life is relatively new, however it is suggested that when harnessed within an organisation it can generate substantial economic returns (Cohen and Prusak, 2001). In particular the benefits claimed include:

- Better knowledge sharing due to established trust relationships, common frames of reference, and shared goals;
- Greater coherence of action due to organisational stability and shared understanding.

As design teams are social systems, to get work done requires the structuring of individuals and the activities (Senior, 2002). Claver-Cortes et al., (2007) suggest that organisational design or structure is one of the most influential elements as far as the implementation of a knowledge management process is concerned (Claver-Cortes et al., 2007). Focusing on the formal hierarchical structure as a coordinating mechanism, while ignoring the informal lateral relations seems to inhibit the sharing of private noncodified (tacit) knowledge. Yet this is the type of knowledge that most researchers and practitioners believe is the most valuable knowledge in terms of its uniqueness and its importance for innovation in the emergent knowledge economy (Marouf, 2007). No matter how adequate the organisational structure might be, employees may not feel motivated to transfer the knowledge acquired (Claver-Cortes *et al.*, 2007).

Moenaert et al., (2000) suggest that the degree of transparency within a network is important. Transparency is defined as the degree to which the communication network is sufficiently clear and accessible, in order to let everyone understand the inputs and progress made. They propose that limited transparency implies that members of a network have problems identifying the relevant persons to transfer information to or to obtain information from. This concept appears to be particularly relevant to multi-disciplinary teams in which actors posses highly specific expertise. It is essential that relevant knowledge is identified to enable a holistic perspective to be developed.

2.5.3 The Integration of Multiple Disciplines

Within a design team consisting of actors from multiple backgrounds, disciplines, and much unique expertise it is reasonable to assume that the capture, sharing and assimilation of knowledge between the group has the potential to be extremely complex. Scarbrough *et al.*, (2004) suggest that the synthesis of specialised knowledge into situation-specific systemic knowledge is essential to successful integration and the development of more innovative solutions.

Knowledge Boundaries

Knowledge boundaries are highlighted as both a source of, and a barrier to, innovation within collaborative design projects (Carlile, 2002). These knowledge boundaries are not only a critical challenge, but also a perceptual necessity as it is at these boundaries that crucial differences between specialisations occur. Learning about differences in expertise is not always enough to deal with every knowledge boundary, however, in some cases by making one's knowledge explicit the potential conflicts and costs associated in working across a boundary are made more explicit (Carlile, 2002). To overcome and take advantage of these knowledge boundaries, some authors think it necessary to introduce formal interventions to the project team. Okhuysen and Eisenhardt, (2002) found that knowledge integration within groups with dispersed specialised knowledge could be increased by small, common sense interventions such as time management and encouraging the questioning of other group members. They suggest that although individuals bring certain resources to the group, they might not use these resources effectively unless they are encouraged to do so. Lu and Cai, (2001) agree suggesting that effective information sharing mechanisms accelerate the process of achieving a shared reality.

Boundary Objects

Another common technique for the encouragement of knowledge integration within cross-disciplinary partnerships is the utilisation of boundary objects. These serve to communicate and coordinate the perspectives of various constituencies. They serve multiple constituencies in situations where each constituency has only partial knowledge and partial control over the interpretation of the object. Boundary objects perform a brokering role involving translation, coordination and alignment among the perspective of specific communities of practice (Fischer, 2005). Boundary objects that are common to integrative design projects could include CAD and working drawings, models, materials, and costs. These are used, not only to portray information from one area of expertise to another, but also to support the development of a common vision across the project team. In an observation of a workshop of designers from various disciplines it was identified that, whilst gaps in ways of thinking and talking were very apparent in more formal sessions, they were much less obvious when it came to handling and discussing objects in the exercise (Ingram *et al.,* 2007). It must be acknowledged however that the use of boundary objects is not always helpful and in some cases can even be disruptive. If the boundary object is familiar to one group but not another, data can still be open to misinterpretation.

Boundary Spanning Roles

In addition to boundary objects, Sonnenwald (1996) suggests that a type of role that appears to be particularly important to knowledge exploration and integration in design is the boundary spanning role. In a study of four cases: Architecture, Expert Systems, Telecommunications, and Engineering, observations were carried out with the aim of developing a model that characterises boundary spanning roles in the design process. A boundary spanning role within the study was defined as 'communication and information processing behaviour between two or more networks or groups' and is said to be typically represented by team members who have a particularly high level of communication and interaction with other actors inside and / or outside their project team. Sonnenwald (1996) found that when boundary spanning roles do not emerge in design situations and / or when the goals of a role are not met, problematic situations develop during the design process. Although the importance of this role is highlighted it appears that much of the available literature has been based around intra-organisational projects, additionally in Sonnenwald's study it is unclear how compatible the four observed disciplines were.

As presented, much literature highlights knowledge transfer and integration as crucial to the development of multi-disciplinary partnerships and subsequently whole system design. It is still unclear, however, where the boundaries between specialties and the requirement to obtain knowledge from other specialties is to be drawn. Postrel (2002) asks: 'When does it make sense, from the point of view of a cooperative team, for actors to focus entirely on their own specialties, and when is it efficient for them to develop a common understanding about one another's capabilities?'. For designers entering this uncertain area of design; the extent of the role of boundary spanning is still uncertain, this will be explored further within the research.

2.5.4 Change in Focus: Systems theory and systemic thinking

Much of the literature highlighted the need for a shift in focus or design thinking as necessary for adopting a holistic approach to design. Systems theory is an interdisciplinary field of science and the study of the nature of complex systems in nature, society, and science. It can be argued that it is also cross disciplinary; there are generic skills that are associated with systems thinking that are not specific to any discipline. More specifically, it is a framework by which one can analyse and/or describe any group of objects that work in concert to produce some result (Bale, 1995). This precedes the suggestion that a system as a whole has properties that are not founded in one of its parts but in the way they relate together. For example the human body behaves differently from an accumulation of water and minerals (Rosner, 1995). A systems perspective assumes that a system is coupled with its environment or context as a duality i.e. it is not possible to think of a system without its environment or context (Collins *et al.*, 2007). As demonstrated in Figure 2, the environment of a system is made up of those things that are not part of the system; they exist outside the system boundary, but can affect the system. A system boundary is a subjective notion which divides the system from its environment but doesn't necessarily have to correspond to any real life limit. Choosing where to draw a system boundary therefore requires a substantial amount of judgement and it could in fact be argued that there is no such thing as a system, merely a way of bounding a process or problem.

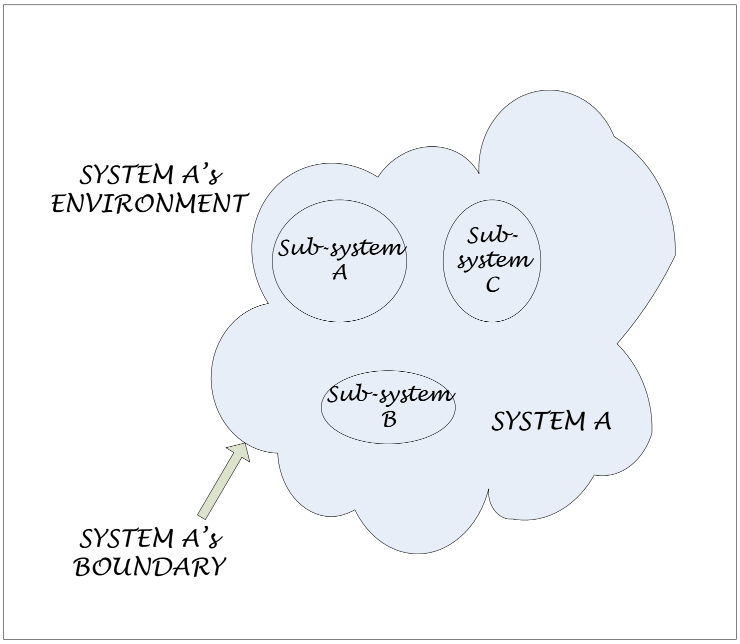


Figure 2: Representation of a System

Systems theory respects complexity and makes it manageable by taking a broader perspective (The Open University, 2008) rather than simplifying it. This is often a difficult concept to grasp as, designers, and to a larger extent engineers, are traditionally trained to think in a linear way. A complex problem is typically broken down into its component parts before being able to systematically solve the problem piece by piece. While this is powerful for some problems, not all components of a problem can be looked at independently. This is one of the reasons why the development of more sustainable solutions is said to require a shift in design mentality (Hawken, 1999 pp. 65). Waddell (2005) expands upon this and suggests that we need to create new processes, social norms and etiquettes for letting go of habits and traditions that are self-destructive. The reason that habitual thinking is insufficient to deal with systems is because it tends to see simple sequences of cause and effect that are limited to time and space, rather than a combination of factors that mutually influence each other (O'Connor and McDermott, 1997). Subsequently adopting a change in mindset is difficult as it entails changing individual and organisational behaviours that we are accustomed to and like, and challenging basic assumptions which can be very uncomfortable. Some traditions or old ways of thinking, which Waddell (2005) suggests are already dying, are depicted in Table 4.

What is Dying	What is Developing
Atomistic (reductionist) as the approach	Whole systems thinking
Linear mechanical mental models	Circular and biological mental models
Inter-national structures	Glocal
Negotiations as deep change	Collaboration for deep change
Hierarchy as dominant	Hierarchy embedded in networks
Power as brute force	Power as knowledge, education, information

Table 4: Dying and Developing Traditions (after Waddell, 2005)

Seiffert and Loch (2005) suggest that the most important property of systems is that they are made up of several parts that are not isolated, but closely interlinked, forming a complex structure. Systemic or systems thinking, then, facilitates the improved understanding of these complex systems and enables the identification and utilisation of interrelationships and linkages as opposed to things. Systems' thinking encourages a view of the whole and for seeing interrelationships rather than static 'snapshots' (Senge, 1990). Global warming, ozone depletion, the international drug trade and more recently the crash within the British economy are all examples of what Senge (1990) terms 'systemic breakdowns' - problems that have no simple local cause. He therefore proposes that systems thinking is needed more than ever to start to manage the overwhelming complexity that is growing around us.

The concept of feedback is fundamental to systems thinking and involves thinking in loops as opposed to straight lines. The parts of a system are connected directly or indirectly and as such changes in one part will affect change elsewhere which in turn will affect the original (Senge, 1990). There are two types of feedback loop:

1) Reinforcing (positive) - when the changes in the whole system amplify the original change,
2) Balancing - when the changes in the whole system oppose and dampen the effect.

Understanding the relationships between parts of a system and consequently, the impact that design decisions are going to have, appears to be a focal part of designing holistically.

Even when adopting the suggestions made by systems thinkers one person's view of a system can be a very partial view of a situation. Subsequently bringing together actors with individual interests in that situation creates a better understanding (Collins et al., 2007). This suggestion is compliant with the literature already presented within this chapter and adds to the evidence that the development of partnerships and systems thinking could be required for the successful facilitation of a whole system design. There is, however, a substantial gap in literature connecting studies surrounding the development of partnerships, systems thinking and the process of whole system design.

This section has discussed several attributes that were identified as being common to the design approaches reviewed within section 2.3. Due to the lack of literature surrounding whole system design this has informed the research by providing insight into a number of factors that are likely to be observed within the study. The literature suggests that although a substantial amount of research has been conducted surrounding these attributes there is a significant gap within the context of whole system design. Therefore, this supports the need for the study and the development of the research question.

2.6 How the Literature Informed the Research Question

The requirement for more innovative, sustainable and optimised solutions to the complex problems we are increasingly faced with has been presented. Authors are concerned that if a radically different approach, not only to the way in which we design but also to the way in which we think, is not adopted then it will no longer be possible to live in a way that is sustainable for future generations.

Studies have shown that companies, organisations and academics across industrial sectors are slowly adopting holistic approaches to design. However these cases appear to be infrequently documented and analysed. The main downfall to holistic design approaches is that, although academics would like the approaches to be taken up by industry, they struggle to find the much needed demonstration projects and pilots to generate sufficient knowledge and experience (Van der Zwan, 2003). An exploration and critical review of the documentation that does surround these approaches has been carried out. The review has recognized that there is no guide or support for actors who wish to adopt a whole system approach to design in the future. Furthermore there is a clear gap in knowledge surrounding what enables and prevents a whole system design from being carried out successfully.

The review of literature has been synthesised to highlight, among others, the four gaps in current knowledge that this study is dedicated to addressing:

- A clear definition of a holistic approach to design,
- How a whole system view was to be developed,
- The factors that enable and inhibit the process of whole system design, and
- The skills, abilities and expertise that actors are required to draw upon to successfully participate in a whole system design process.

In turn these have subsequently informed the primary research question of:

What factors enable and inhibit the successful adoption of a whole system approach to design?

It is intended that addressing this question will provide the design research community, and other communities utilising this and similar design approaches, with new knowledge and insight concerning the process of whole system design.

2.7 Chapter Summary

This chapter has presented a critical review of literature in the fields that were found to be of relevance to the general research area. The need for more innovative, sustainable and optimised solutions was made clear. However, it was discovered that much uncertainty exists surrounding the holistic and integrative design process required to reach these solutions. In particular, the terminology that is currently being utilised to describe holistic approaches to design is vast.

As there is a limited amount of available literature surrounding whole system design, other approaches were explored to gain a better understanding of the research topic. This literature was synthesised to reveal attributes that were common to each approach.

The final section of the review explored these commonalities further but more specifically within the context of implementing a whole system design. This has provided the researcher with a foundation which can now be developed when undertaking actual observations of a design team. This literature shall be referred to and expanded upon when findings of the research are discussed in Chapters Five, Six and Seven.

Based on a review of literature, several gaps in current knowledge have been identified and the research question has been validated. The following chapter goes on to describe the research design through which the research question and objectives shall be answered.

3	CHAPTER AIMS	ACTIVITIES	OUTCOMES
	RESEARCH DESIGN		
	To consider relevant research approaches and to provide reasoning behind the chosen research design and data collection techniques	Systematically considered research design options. Made decisions regarding research approach and data collection techniques	- Research Methodology - Research Methodology Model

Research Design

This chapter considers relevant research approaches and provides reasoning behind the chosen research design and data collection techniques.

3.1 Introduction and Purpose

Based on the research questions and objectives informed by the literature review conducted in Chapter Two, this chapter describes the methodological considerations and choices made to meet those objectives. Available approaches to the research are discussed and the chosen methodology is presented. The methodological techniques employed by the researcher have been detailed along with the rationale behind decisions and any subsequent limitations explored.

3.2 Designing a Research Methodology

Before commencing the research it is important to select and justify a structured and rationalised approach. This will validate the research further and provide guidance to the process. Additionally, documenting the research methodology and justifying the reasoning behind its selection enhances the understanding of others and therefore its repeatability.

Robson (2002) suggests that, when carrying out research, there is a tendency for researchers to assume the there is no alternative to their favoured approach. Although the methods and techniques applied are determined by the research question to some extent, there will still be multiple ways of designing the research. The following sections will illustrate different alternatives and reasoning for the approach chosen; outlined in Figure 3.

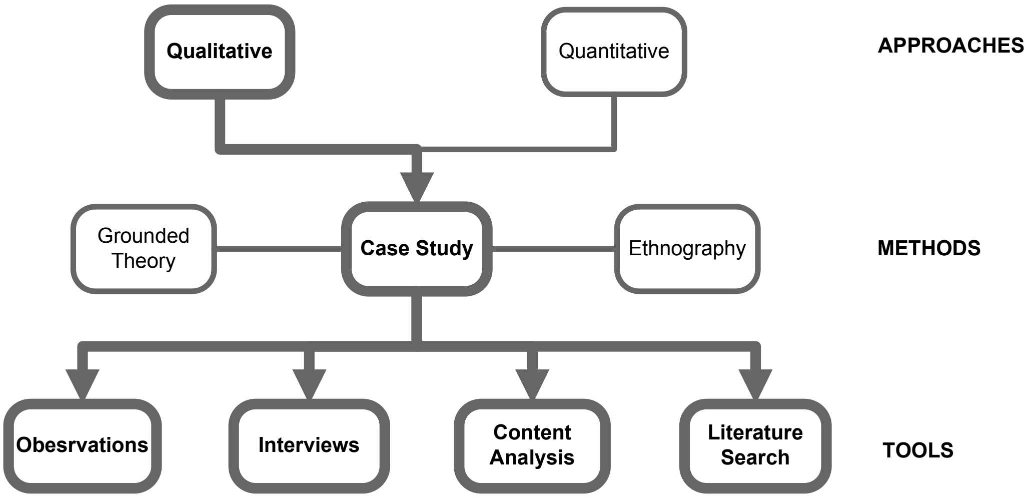


Figure 3: Methodology Choices

3.3 Research Approach

Approaches to research are generally termed as being either quantitative or qualitative. Robson (2002) likens quantified research to a process in which the design of the study is fixed before the main stage of data collection takes place. Quantitative research generally assumes that everything in the social world can be described or measured with a numerical system (McQueen and Knussen, 2002). This type of research has great statistical advantages, since it allows large amounts of data to be collected and analysed in a logical and replicable way. It is most commonly used in laboratory situations in which the environment and surrounding conditions can be closely monitored and controlled, therefore producing very specific results.

Qualitative research is often based around social and behavioural studies in which specific outcomes cannot be expected, and so exact ways in which to measure data are undetermined. For this reason Robson (2002) likens qualitative research to a flexible design, typically anticipating that the design will emerge and develop during data collection. Originating from anthropology, interpretivism, and psychoanalysis it is an investigative approach commonly using tools and techniques such as observations, interviews, and surveys. This is an advantage to a qualitative approach, since the researcher personally interacts with the study and so gains a more personal understanding of the subject area.

As shown in Table 5, Burns (2000) has identified and effectively compared key research methods used in both approaches.

Following an investigation into the benefits of both qualitative and quantitative approaches to research it has been decided that a qualitative approach shall be adopted within the current study. This has been decided upon as the study largely involves the observation, identification and analysis of individual and group behaviour. Consequently data is likely to be emergent and complex as opposed to structured, and therefore a qualitative approach will provide the research with the flexibility to make changes within the research design as and when necessary.

Qualitative	Quantitative
Assumptions	
Reality socially constructed	Facts and data have an objective reality
Variables complex and interwoven; difficult to measure	Variables can be measured and identified
Events viewed from informant's perspective	Events viewed from outsider's perspective
Dynamic quality to life	Static reality to life
Purpose	
Interpretation	Prediction
Contextualisation	Generalisation
Understanding the perspectives of others	Casual explanation
Method	
Data collection using participant observation, unstructured interviews	Testing and measuring
Concludes with hypothesis and grounded theory	Commences with hypothesis and theory
Emergence and portrayal	Manipulation and control
Inductive and naturalistic	Deductive and experimental
Data analysis by themes from informants descriptions	Statistical analysis
Data reported in language of informant	Statistical reporting
Descriptive write-up	Abstract impersonal write-up
Role of researcher	
Researcher as instrument	Researcher applies formal instruments
Personal involvement	Detachment
Empathic understanding	Objective

Table 5: Comparison of Qualitative and Quantitative Research Strategies (Burns, 2000, p. 391)

3.4 Research Methods

Within qualitative research, Robson (2002) identified three influential design traditions: grounded theory, ethnography and case study. Some of the key features of these traditions are compared in Table 6 in order to give an evaluation of some of the approaches available.

Robson (2002) recommends that it is beneficial for the researcher to stay within one tradition initially with the aim of becoming comfortable with it, to learn from it and to keep the study concise and straightforward. He acknowledges however that, as the study progresses, features from other research traditions might be useful and in fact characteristics of a flexible design include the use of multiple data-collection techniques.

	Grounded Theory	**Ethnography**	**Case Study**
Focus	Developing a theory grounded in data from the field	Describing and interpreting a cultural and social group	Developing an in-depth analysis of a single case or multiple cases
Discipline origin	Sociology	Cultural anthropology, sociology	Political science, sociology, evaluation, urban studies, many other social sciences
Data collection	Typically interviews with 20-30 individuals to 'saturate' categories and detail a theory	Primarily observation and interviews during extended time in the field	Multiple sources-documents, archival records, interviews, observations, physical artefacts
Data analysis	Open coding, axial coding, selective coding, conditional matrix	Description analysis, interpretation	Description, themes, assertions
Narrative form	Theory or theoretical model	Description of the cultural behaviour of the group	In-depth study of the 'case' or 'cases'

Table 6: Comparing Research Traditions in Qualitative Research (Robson, 2002)

The current research will be conducted through the use of one primary case study with the aim of investigating the case in both depth and breadth and therefore taking a holistic and exploratory approach. As Huberman and Miles (2002) suggest, the case study is a research strategy which focuses on understanding the dynamics present within single settings through the utilisation of a combination of data collection methods. By selecting and investigating a specific case study will allow the researcher more time to interact with those involved than if sharing time between several. This shall direct the research and provide a more realistic, focused view compared to utilising ethnography or grounded theory approaches.

Strauss and Corbin (1998) suggest, however, that by utilising a grounded theory approach the resulting theory is likely to offer insight, enhance understanding, and provide a meaningful guide to action. As, upon commencing the current research, the author had no preconceived theory or hypothesis in mind, insights from the tradition of grounded theory will provide substantial guidance. This can also be referred to as an inductive approach.

3.5 Research Tools

Due to the nature of the research a number of data-collection techniques, which are presented in Table 7, shall be utilised. This approach will not only ensure the collection of data from multiple sources and perspectives but will substantially reduce bias and increase validity. Reliability, validity and triangulation of data is discussed further in Section 3.6. The data collection methods, outlined below, are expanded upon in subsequent sections.

Data Collection Method	**Source**
Case Studies	The LIFECar Project
Observations	Project Meetings
Interviews	Project Members
Documentation Search	Project Agendas, Minutes, Press Releases, Reports
Literature Search	Journal and Conference Papers, Articles, Theses and Books will be used to support and add to case study findings

Table 7: Data Collection Methods and Sources

3.5.1 Case study techniques and limitations

The case study method is useful for research that involves an empirical investigation of a particular contemporary phenomenon within its real life context using multiple sources of evidence (Robson, 2002). Gill and Johnson (1997) support this statement, arguing that the case study is relevant if there is a need to combine research with practice in the real world. Voss *et al.*, (2002) argue that the case study method is good not only at investigating 'how-and-why' questions, but is also particularly suitable for developing new theory and testing, and refining it.

As with many qualitative research techniques, the case study is subject to much criticism concerning subjectivity, validity and verification. Diamond (1996) suggests that the case study suffers from a crippling drawback because it does not apply scientific methods and therefore encourages a bias towards verification. Flyvbjerg (2001) denies that this is the case and in fact states that, on the contrary, experience indicates that the case study contains a greater bias toward falsification of preconceived notions than toward verification. Embarking upon a case study early on in the research will further confront this criticism as pre-existing interpretations and expectations will be limited through restricted exposure to existing literature. Perceptions and opinions will develop over time through personal observation which is accompanied in parallel by relevant literature.

Yin (1994) states that the case study is an appropriate technique for business and management research; it is also capable of standing up to academic scrutiny, and so it is no longer considered weak when compared to techniques used for quantitative research. He supports these arguments by addressing the main concerns expressed over the case study method, namely the lack of rigour and the lack of a basis for scientific generalisation. The case study will be more rigorous if all evidence is reported fairly and without bias, while the problem of scientific generalisation is largely resolved as a result of the investigator's goal being to expand and generalise theories rather than to enumerate frequencies. Yin (1994) suggests that case studies are the preferred strategy for qualitative research when 'how' or 'why' questions are being posed, when the investigator has little control over events, and when the focus is on a contemporary phenomenon within some real-life context. Additionally when there is uncertainty and concern over validity then triangulated data is often a more effective response than experimental designs that attempt to remove that uncertainty.

Due to the lack of literature surrounding the context of the current research, identified in Chapter Two, it is important that the researcher spends as much time as possible immersed within the case study. Additionally any data is potentially crucial to the study and therefore comprehensive and accurate documentation of meetings, documents and even informal discussions with project members must be undertaken.

Due to this wealth of data resulting from first hand observation and experience; case studies often contain a substantial element of narrative. Flyvbjerg (2001) suggests that good narratives typically approach the complexities and contradictions of real life and so, accordingly, may be difficult or impossible to summarise in neat scientific formulae, general propositions, and theories. Additionally he suggests that through summarising case studies, crucial information could be lost. Flyvbjerg concludes that often it is not desirable to summarise and generalise case studies and that good studies should be read in their entirety. Law (2004) agrees and suggests that simple clear descriptions don't work if what they are describing is not itself very coherent. If the world is complex and messy, then at least some of the time we are going to have to give up on simplicities (Law, 2004). This will be taken into account and although resulting themes and observed phenomena will be defined, the underlying complex data will be documented and remain accessible for reasons of validity and reliability.

The main limitation when carrying out individual case studies is time: a) time that the researcher has access to the various projects and b) time the researcher has available to devote to each individual study. This limitation can be partially overcome by becoming involved with the case study as early as possible during the research. It is also essential that correspondence is maintained and good relationships are developed so that in the event of further queries later on in the process contact can be made quickly and further access can be easily arranged.

TYPE OF SELECTION	**PURPOSE**
A. RANDOM SELECTION	To avoid systematic biases in the sample. The sample's size is decisive for generalisation
1. Random Sample	To achieve a representation sample which allows for generalisation of the entire population
2. Stratified Sample	To generalise for specially selected sub-groups within the population
B. INFORMATION-ORIENTED SELECTION	To maximise the utility of information from small samples and single cases. Cases are selected on the basis of expectations about their information content
1. Extreme / Deviant Cases	To obtain information on unusual cases, which can be especially problematic or especially good in a more closely defined sense
2. Maximum Variation Cases	To obtain information about the significance of various circumstances for case process and outcome; e.g. three to four cases which are very different on one dimension: size, form of organisation, location, budget, etc.
3. Critical Cases	To achieve information which permits logical deductions of the type, "if this is (not) valid for this case, then it applies to all (no) cases"
4. Paradigmatic Cases	To develop a metaphor or establish a school for the domain which the case concerns

Table 8: Strategies for the selection of samples and cases (Flyvbjerg, 2001)

Gaining access to companies for the purpose of validation of the study could also be a problem and limit the number of interviews available. Flyvbjerg (2001) suggests, however, that often it is more important to clarify the deeper causes behind a given problem and its consequences than to describe the symptoms of the problem and how frequently they occur. Random samples emphasising representativeness will seldom be able to produce this kind of insight; it is more appropriate to select a few cases chosen for their validity (Flyvbjerg, 2001). Table 8 summarises various forms of sampling, through which cases can be specifically and carefully selected.

The initial phase of the research will be based around one focal case study: The LIFECar project. The project is already underway therefore addressing limitations surrounding sampling, access and time restraints. During the second phase of the research, interviews and focus groups are to be undertaken with the aim of modifying and validating the initial findings gained from the case study. Participants will be chosen on the basis of their expertise and experience of whole system design projects and therefore an information orientated sample selection will be utilised.

3.5.2 Observation techniques and limitations

The actions and behaviour of people are central aspects within this study and much qualitative research. A natural and obvious technique is to watch what participants do, to record this in some way and then to describe, analyse and interpret what has been observed (Robson, 2002). Table 9 highlights the different types of observations and what role the researcher is to play in each.

TECHNIQUE	FOCUS	RESEARCHER ROLE
Naturalistic Observation	Behaviour in its natural environment	The researcher does not attempt to interfere with what is being observed
Controlled Observation	Unlike natural observation the emphasis is not on the setting but on the natural occurrence of the event	The researcher attempts to structure or influence the behaviour or response to be observed
Participant Observation	Processes occurring in particular groups	The researcher becomes a part of the 'thing' that is being observed

Table 9: Different types of observational study (after Robson, 2002)

Gross and McIlveen (1998) suggest that the best type of observational research is that in which those that are being observed are not aware of this. Although the current research requires the observation of behaviour in its natural environment i.e. during project meetings, it would not be possible or indeed ethical, for the project members to be unaware of the observation taking place. The researcher will attend all project meetings and will therefore be regarded as a member of the project team; in this respect the researcher will be carrying out a participant observation. It is has been decided, however, that the researcher will not take an active role in any of the meetings and will remain impartial so as to limit the influence she has on team members' behaviour.

The way in which the data is to be recorded is one of the key issues concerning observations. It is important that data is captured adequately to provide accurate analysis, although it is also important for the participant not to be disturbed. Coolican (1999) suggests that records of behaviour can be made using any or a mixture of the following devices:

- Film or video recording,
- Still camera,
- Audio tape (to record spoken observations),

- Hand written notes, ratings or coding on the spot.

The observations of meetings will be recorded using a digital audio recorder. This will provide the researcher with reliable records that can be easily accessed and will not be too intrusive to those who are being recorded. The researcher will take detailed notes to accompany the recording; they will act as a guide to important discussions and conversation. Any parts of the meeting which are seen as particularly important will be transcribed and analysed in more depth.

When conducting participant observations the research is prone to two types of bias:

- Participant Bias,
- Observer Bias.

If you are a known observer, the observed are already well aware of being observed (Lofland and Lofland, 1995). Subsequently there is a risk that they will start to behave differently. This could be for many reasons, such as they want to influence, consciously or unconsciously, the observations being made or the results being derived. This could be particularly apparent if that person was trying to impress a colleague or manager. Being aware of these potential reasons for bias and underlying relationships between participants is beneficial.

In the current research, as the researcher is to be present in meetings for up to three years, the project members will become very familiar with being observed. Additionally the researcher will build up a level of trust with the participants and therefore they should feel comfortable around her. Any abnormal behaviour should be easy to identify given the number of observations that will take place and additionally the one-to-one interviews with each participant should provide further evidence of 'typical' behaviour.

As the researcher is to be observing and interacting with the team for a substantial amount of time there is a risk of observer bias. This can occur when the observer gets too close to the participants being observed, and can no longer maintain a critical and external perspective. As the researcher is taking a passive approach to the observations, the interaction with the participants will be kept to a minimum. The researcher must develop her own inter-personal skills to enable a level of trust to be obtained with the participants whilst still remaining critical and avoiding bias.

As Montuori and Purser (1997) highlight, any observed system is always described by an observing system. The observing system makes certain choices about what to define as a system and its environment. The researcher must therefore make a conscious effort to document and justify any decisions that are made throughout the research process. This will further validate the findings and enhance the repeatability process.

3.5.3 Interviewing techniques and limitations

Interviewing as a research method is widely used in social research, although there are many different types that the researcher should be aware of (Robson, 2002). Interviewing typically involves receiving answers from the participants and choice of technique usually depends upon the depth of knowledge required. Three typical styles of interviewing are:

1) Fully structured interviewing: often common to quantitative research, since objectives can be predetermined and produce data that is relatively easy to analyse using tested statistical methods,
2) Semi-structured interviewing: has predetermined questions but the order can be modified based upon the interviewer's perception of what seems most appropriate. Additional questions can also be posed which further explore the response to the predetermined questions. Semi-structured and

unstructured interviews are widely used in flexible, qualitative designs (Robson, 2002),

3) Unstructured interviewing: often viewed as a rich form of descriptive data, since open-ended questioning encourages free expression on the part of the interviewee and no predetermined set of expectations on the part of the researcher (McQueen and Knussen, 2002).

As the current research is qualitative in its approach, semi-structured and unstructured interviewing techniques will be adopted. Occasionally discussions with team members may be opportunistic and not planned in advance; therefore it is important that the researcher has the ability to perform unstructured interviews to take advantage of these unforeseen situations.

Huberman and Miles (2002) emphasise that the interview is a social situation and inherently involves a relationship between the interviewer and the informant. Understanding the nature of that situation and relationship, how it affects what goes on in the interview, and how the informant's actions and views could differ in other situations is crucial to the validity of accounts based on interviews. It is intended that, through attendance at frequent meetings and informal discussions, the researcher will build up trust and relationships with individual project members and, in doing so, be able to intuitively gauge the best way of approaching interview situations.

Undertaking interviews is an important part of the study. Unstructured interviews will be used with project team members during the initial phases of the research to explore the research domain and gain information about the case study. These will become more structured as themes emerge. The later stages of the research will entail semi-structured interviews with additional participants with the aim of validating and expanding upon initial findings. This stage will be unfamiliar to the researcher, as access to additional actors will have to be sought, and therefore will be accompanied by additional challenges. To overcome any problems, additional interviews should be carried out as early as possible once the initial data has been collected. This will familiarise the researcher with the process of conducting one-off interviews with another set of participants. Each interview throughout the research process will be recorded with an audio recorder and transcribed for further analysis.

Interviewing poses some special problems for internal generalisability and reliability because the researcher is usually in the presence of the informant only briefly, and must necessarily draw inferences from what happened during that brief period (Huberman and Miles, 2002). In the case of the current research this issue can be overcome, as not only will the researcher be conducting individual interviews with project members but she will also have the opportunity to observe individuals frequently within a project team situation, therefore verifying the interview results. The researcher will also have the opportunity to re-interview participants for clarification, expansion and validation as and when necessary.

Interviewing can be time consuming. Robson (2002) suggests that an interview lasting less than 30 minutes is unlikely to be valuable whereas an interview lasting longer than 60 minutes might be making unreasonable demands on busy interviewees and could have the effect of reducing the number of persons willing to participate. He suggests specifying the length of time the interview will take to the participant prior to commencing and that, in the case of an unstructured interview, it is the researcher's professional responsibility to terminate the interview on schedule. However, in the case of the current research it is the nature of the relationship between the researcher and the participant and also the context of the interview that will occasionally determine appropriate timings.

3.5.4 Content analysis techniques and limitations

Many common scientific methods of inquiry prevent the researcher from addressing what matters most in every day social life. According to Krippendorff (2004) these matters are: human communication; how people coordinate their lives; the commitments they make to each other; the concepts of society they aspire to; what they know and why they act. It is suggested that content analysis is a powerful and unobtrusive method that can be used to make sense of what is mediated between people and in turn to address these, often neglected, issues. Krippendorff (2004) suggests that Content Analysis is potentially one of the most important research techniques in the social sciences

The method of content analysis has been recognised for over 50 years. Weber, (1995) defines content analysis as a research methodology that utilises a set of procedures to make valid inferences. He suggested that these inferences are about:

a) The sender(s) of the message,
b) The message itself,
c) The audience of the message.

Krippendorff (2004) agrees, although he emphasises that the inferences made must be replicable and valid. Furthermore he suggests that one of the most significant factors is the context in which the inferences gained are to be used.

For the methodology of content analysis to be useful within the current research it is necessary to understand what types of content can actually be analysed by utilising this approach. Neuendorf (2002) suggests that previously authors have related the methodology of content analysis to textual matters only, for example written and transcribed words. He goes on to comment that this form of study is unnecessarily limiting and that the methodology can in fact be conducted on written text, transcribed speech, verbal interactions, visual images, characterisations, non-verbal behaviours, sound events or any other message type. Krippendorf (2004) agrees and suggests that in content analysis works of art, images, maps, sounds, symbols, and even numerical records may be included as data, provided they speak to someone about the phenomena outside of what can be sensed or observed.

Although content analysis remains an underutilised research method, it has great potential for studying beliefs, organisations, attitudes, and human relations (Woodrum, 1984). Woodrum (1984) goes on to suggest that there are many advantages of content analysis contributing to its potential for social science:

- The logic and skills the technique requires: summarising interviews, coding open-ended questionnaires, and conducting verbal evaluations, are well known to research designers, therefore making the technique readily employable;
- Content analysis is an unusually safe methodology. If the researcher determines that information was missed or incorrectly coded, it is feasible to return to the original text for confirmation. This is not typically possible in experimental research;
- Content analysis has the advantage of facilitating empirical study without disrupting the research subjects. A technique that reacts with research subjects can distort original measurements, preclude subsequent measurements, or be unethical.

As with much qualitative research, content analysis is subjective and can be prone to researcher bias. Measures can be taken to overcome this limitation, however, due to the presence of documentation; findings can be repeatedly validated by external mediators. Any coding that is undertaken will be confirmed by at least two researchers and subsequently arbitrated and validated.

Woodrum (1984) suggests that since the contents of messages themselves are analysed rather than the characteristics of individuals or groups, the significance and interpretation of these findings are often uncertain. It will be possible, however, when observing the project team, to confirm the meaning of project documentation. Additionally it is hoped that, due to the relationship built up between the researcher and project members, interpretation of documentation, such as project emails, meeting minutes, and transcribed interviews will be confirmed repeatedly with the relevant project members.

As with all qualitative approaches, triangulation of data collection techniques and theory is superior to any single procedure or type of information (Denzin, 1970). Therefore, when supported by other forms of data collection, it appears that the utilisation of content analysis within the current research will be beneficial so long as limitations are acknowledged and overcome.

3.6 Quality of Research

The trustworthiness of findings from flexible, qualitative research has been the subject of much debate (Robson, 2002). It is argued however that many social sciences have put aside the old doubts and mistrusts of qualitative inquiry and that the research community now generally recognises that rationales and supporting criteria for various enquiries will differ (Marshall, 2006). Never-the-less it is maintained by many authors that the credibility of any research is significantly dependent upon the validity, reliability and generalisation of research findings and the way in which supporting evidence is presented (Yin, 2003, Huberman and Miles, 2002, and Robson, 2002).

3.6.1 Validity, reliability and generalisation

The validity of a qualitative piece of research can be interpreted as the extent to which an account accurately represents the social phenomena to which it refers (Silverman, 2001). Many challenges concerning the validity of research findings are related to the biases of the researcher him/herself. Marshall (2006) asks how we can be sure that the findings reflect the participants and the enquiry itself rather than a fabrication from the researcher's biases or prejudices?. Authors suggest several tactics to enhance the accuracy of the researcher's account of social phenomena. Triangulation of data, that is, the use of multiple sources of evidence (Yin, 2003) is a method that is argued to reduce the threat of researcher and respondent bias (Robson, 2002) and therefore increase the validity of research findings. Additionally the researcher is encouraged to establish a comprehensive chain of evidence early on within the research process (Yin, 2003). Marshall (2006) suggests two phases of evidence:

1) By keeping thorough notes, logs, journals, recording methodological design decisions and the rationale behind them, researchers allow others to inspect procedures, protocols and decisions;
2) By keeping collected data in well organised retrievable form, researchers can make them easily available if the findings are challenged or if another researcher wants to re-analyse the data.

The reliability of research findings is the demonstration that the operations of a study, such as the data-collection procedures, can be repeated with the same results (Yin, 2003). This relates to the concern that the tools or instruments used produce consistent results. Robson (2002) suggests that common pitfalls in qualitative data collection and transcription can include equipment failure, environmental distractions and interruptions, and transcription errors. Within the data analysis phase of the research Silverman (2001) suggests that reliability refers to the degree of consistency with which instances are assigned to the same category by different observers or by the same observer on different occasions. Comprehensive documentation of the procedure followed during the analysis can help to ensure that others can repeat the case study research (Yin, 2003). Yin (2003) also suggests that performing a reliability check to confirm that an auditor can produce the same results when following the same procedures also provides evidence of reliability.

Generalisation, also known as external validity, deals with the problem of knowing whether a study's findings are generalisable beyond the immediate case study (Yin, 2003). This does not imply that the findings from one study are going to be applicable to a sample of additional settings as is achievable from a statistical survey (Robson, 2002). Rather it implies that the findings from one study may help in understanding other cases or situations. Yin (2003) suggests that it is useful for the researcher to identify other cases to which the results are generalisable. When carrying out this investigation it is essential to utilise replication logic, ensuring that research design and application is repeated in each case.

3.6.2 Methodological considerations

Based on the criteria for research quality identified within Section 3.6.1 Table 10 demonstrates how they have been sought within the current research.

	Criteria for Research Quality	Suggested Tactics	Considerations within the Study
Validity	Establishing correct operational measures for the concepts being studied	- Using multiple sources of evidence - Establishing a chain of evidence	- Triangulation of multiple data sources: literature, interviews, observations and documentation - Documentation of methodological design decisions and rationale - Well organised data and transparent linkages to themes
Reliability	Demonstrating that the operations of a study can be repeated with the same results	- Consistency of tools and instruments - Documentation of procedure to ensure replication - Reliability check	- Concurrent audio recording and note taking during all interviews and observations - Accuracy check of transcriptions - Utilisation of another researcher to check data analysis - Documentation of all methods used and challenges met
Generalisation	Establishing the domain to which a study's findings can be generalised	- The utilisation of replication logic in additional cases	- Replication of interview questions during case study phase - Identification of 5 additional cases and subsequent semi-structured interviews

Table 10: Tactics for achieving enhanced research quality

During the case study triangulation of data collection was achieved through carrying out observations, undertaking interviews with actors, collating relevant documentation and reviewing relevant literature. Once relevant data had been identified from one source of data its significance was then confirmed through the use of the other data sources. Documentation of this process is provided in chapter 4 through the use of actual scenarios and primary data.

Reliability is critical when using thematic analysis (Boyatis, 1998). Within the current research this has been addressed in three phases. Initially, once several interviews had been transcribed, the researcher confirmed the accuracy of the transcripts by:

a) listening again to the audio tape and concurrently re-reading the transcript,
b) by comparing a transcript to that of an independent researcher who had been present in the same interview.

These activities provided evidence that the transcriptions utilised within the research were accurate.

Once the data had been analysed and the themes confirmed, coding consistency was achieved by asking other researchers to code a sample of the data to see whether the same themes could be identified. Additionally during the case study actors were presented with themes as they emerged and were asked questions surrounding these themes to validate or deny their existence.

3.7 Research Design Summary

Following the development of the research question and objectives, presented in chapters one and two, this chapter has identified the approaches that could be and are to be followed in order to fulfill these objectives. The decision to adopt a qualitative approach to the research through the use of a case study method has been discussed and justified.

The triangulation technique of using multiple methods of data collection has been selected to substantially reduce bias whilst increasing validity. In the event of being unable to use one source of data there will be additional methods to rely on, each one as significant as the other. As shown in the research methodology model in Figure 4, the methodology chosen will follow an iterative process to continuously validate findings as they emerge. This will be carried out through:

- continuous involvement with the case study via observations, interviews and content analysis;
- consultation of current literature to structure, question and validate findings;
- interviews with additional participants to modify and validate findings through a number of alternative contexts.

Following the delineation of the research design Chapter Four will provide details of the intended case study and the implementation of the research design.

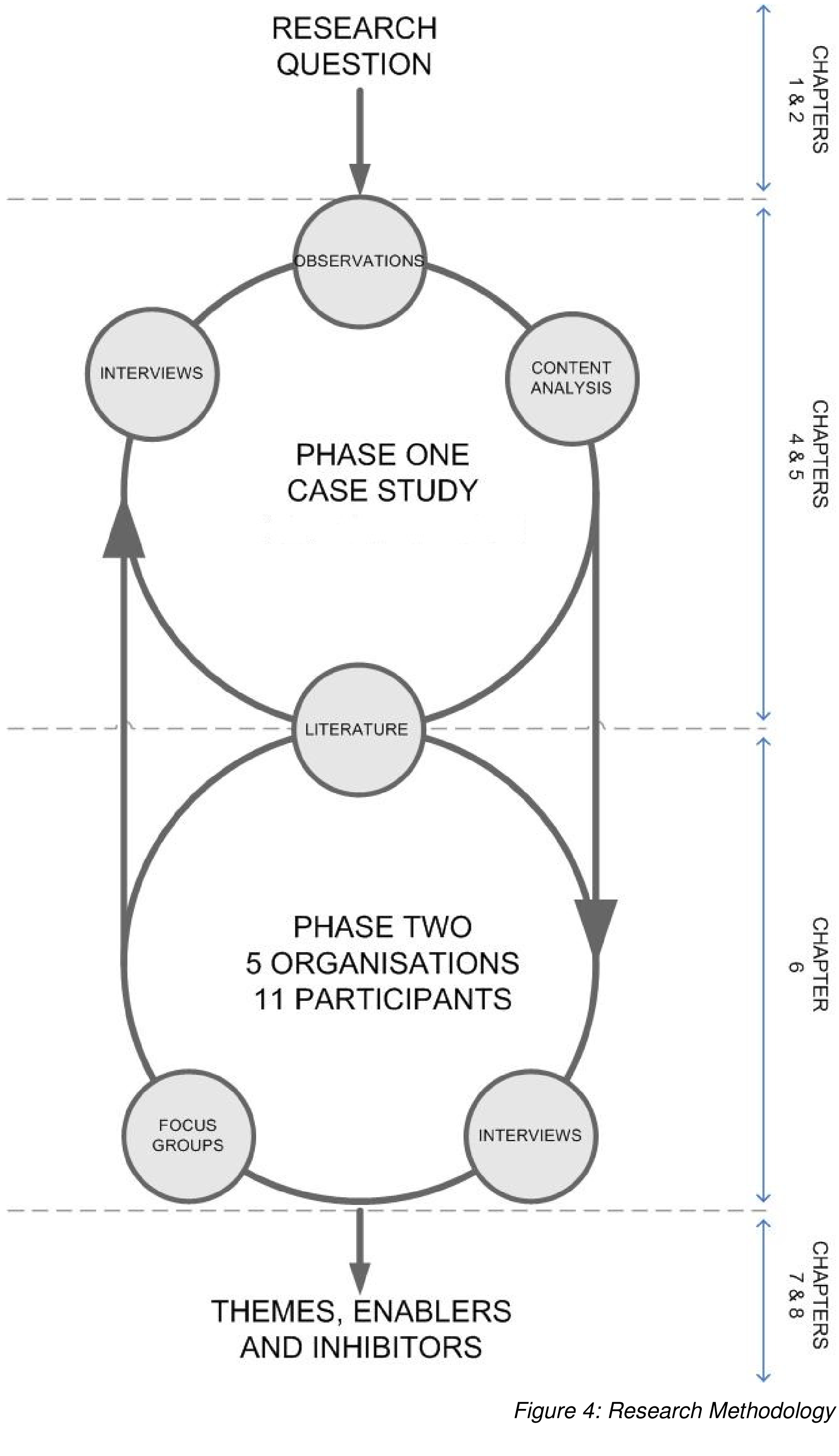


Figure 4: Research Methodology Model

4

IMPLEMENTING THE RESEARCH DESIGN

To describe the implementation of the research methodology and to provide detailed examples of how themes were identified	Vignettes detailing the process of implementing the research methodology. Selected process of abstraction for data analysis.	- Detailed documentation following methodology implementation - Process of Abstraction

Implementing the Research Design

This chapter provides details of the primary case study and how subsequent data is to be analysed. The implementation of the chosen research design is discussed and challenges encountered and resulting modifications are presented.

4.1 Introduction and Purpose

The previous chapter discussed the available approaches, methods, tools and techniques for conducting the current research. It was decided that a case study methodology would be utilised involving the observation of design meetings, the conducting of semi-structured interviews with key members of the case study, and the implementation of content analysis techniques on primary and secondary data. This chapter introduces the LIFECar project; the case study that is to be undertaken, its main aims and objectives and the key partners involved.

The second part of this chapter goes on to discuss the implementation of the chosen methodology within the context of the case study. The flexibility and dynamics of the methodology are demonstrated through the use of examples from the case study and the challenges faced are discussed.

4.2 The LIFECar Project

The Lightweight Integrated Fuel Efficient Car (LIFECar) Project was initiated as a venture to design and manufacture a zero emission sustainable sports car. The project aimed to demonstrate that significant gains in fuel efficiency could be achieved with readily available technology (Spowers, 2008). The project is based around hydrogen as the fuel source because the only emission is pure water (Morgan Motor Company, 2008). Through the use of a whole system approach to the design of the car it was thought that relationships between the different components of the systems architecture could be utilised to optimise the system as a whole.

The project is co-funded by the Technology Strategy Board, a government body which promotes and invests in technological innovation in the UK, and involves the collaboration of six industrial partners.

4.2.1 The Partners

The LIFECar project involves the collaboration of six high profile partners. Each partner is from a unique background and therefore is assumed to be able to bring a novel perspective to the design problem and subsequently the solution. All partners play an equal part in the project and from the outset it was decided that there would be no lead partner.

Partner A

Partner A is a large science and technology solutions provider, producing fuel cells for the aerospace, energy, aviation and defence industries. The company has been designing and developing fuel cells for the past 20 years.

Partner B

Partner B is a small but well known manufacturer of traditional British motor cars. The company has been designing and developing their range of cars for nearly

100 years. The family run company is known for using traditional manufacturing techniques to produce high quality cars.

Partner C

Partner C is a large international industrial gas and engineering company with around 49,000 employees working in more than 70 companies world wide. The company has gained particular expertise in the industrial production and handling of hydrogen.

Partner D

Partner D is a small independent design firm specialising in the design, development and commercialisation of fuel-efficient cars. The firm has 15 years experience in producing one-off racing and concept cars.

Partner E

Partner E is a small university based group who specialise in conducting research in the field of sustainable energy. They have particular experience of providing technical expertise for the development of electrically powered transport.

Partner F

Partner F is another small university-based group specialising in all aspects of road based vehicles. They have particular experience in evaluating new technologies and automotive product engineering processes.

4.2.2 The suitability of the LIFECar Project as a case study

The LIFECar project has adopted a whole system approach to design in the hope of achieving a more innovative, efficient and sustainable solution. As identified in Chapter Two, there is a significant gap in knowledge concerning the process of whole system design and consequently the focus of this study is to provide a better understanding of the whole system design process.

Additionally the project consists of six industrial partners each providing between two and three actors to work on the project. This provides the researcher with a broad perspective and a significant number of actors from which to gain knowledge and data. Chapter Three recognised that it was important for the researcher to develop a professional but trusting relationship with actors to avoid participant bias. The number of actors within the project is manageable and consequently the researcher has had the time to get to know and speak extensively with each one.

The LIFECar project is not only an endeavour in the integration of technologies but is also a social venture in the complex integration of multiple actors (Vaughn *et al*.,, 2008). As such, LIFECar is an ideal case study for doctoral research focusing on qualitative and social aspects of the process of whole system design.

4.3 A Dynamic Methodology

To ensure that the methodology for working with such complexity is flexible and dynamic it is important that the researcher has a variety of tools and techniques available. As documented in Chapter Three, a combination of observations, interviews, informal discussions, search and analysis of documentation and a review of relevant literature was identified and utilised to collect as much reliable data as possible.

This section explores the practicalities of implementing the chosen methodology and documents situations where adaptation and flexibility was demanded both of the researcher herself and the tools and techniques available.

4.3.1 The observation of design meetings

The researcher's involvement with the case study has necessitated the regular attendance at, and observation of, design meetings. It is frequently difficult to obtain continuous access to industrial projects and therefore having the unique opportunity to witness decisions being made and opinions being formed can provide the researcher with an extremely rich source of data. You do not ask people about their views, feelings or attitudes; you watch what they do and listen to what they say (Robson, 2002). Robson (2002) is implying that when directly asked, participants may not provide full answers. Observations of natural behaviour are essential therefore in gaining evidence of sub-conscious and tacit knowledge use. Every meeting was voice recorded and as relevant themes and issues emerged they were noted and subsequently written up for further exploration.

Observation is, however, neither an easy nor trouble free option (Robson, 2002) and one of the first challenges to be encountered was the physical recording of data. As Lofland and Lofland (1995) state, the observed are already well aware of being observed and therefore you need not increase any existing anxieties by continuously and openly writing down what you see and hear. In the first few meetings it was apparent that the team members were aware of the researcher picking the note book up off the conference table and jotting notes as one actor commented:

"I am very intrigued by the notes you take during the meetings; what are the diagrams that you draw?"

[Fuel Cell Project Manager]

This was particularly awkward if note-taking followed conflict between the team members or if one member had said something controversial, although, as the meetings became more frequent the team members were noticeably more at ease with the researcher's presence. The researcher did make her note-taking a lot less conspicuous by writing with the note book on her knee and only jotting down key words at suitable moments within the meeting. Lofland and Lofland (1995) suggest that jotted notes such as little phrases, key words and quotes should be used to jog the memory when later writing up the field notes in full.

Another of the many obstacles encountered when carrying out observations is deciding how to fairly and validly represent opinions and findings. In particular, narratives, of which case studies contain a substantial amount, may be difficult or impossible to summarise in neat scientific formulae, general propositions, and theories (Flyvbjerg, 2001). It is proposed, however, that formal generalisation is overvalued as a source of scientific development, whereas 'the power of the good example' is underestimated (Flyvbjerg, 2001). If a narrative is well-written and read in its entirety then the proof and validity should appear in the example. Below is a short narrative taken from the observations of a LIFECar project meeting:

Towards the end of the meeting Tom highlighted the topics of the following meeting which had been arranged by him in order to reach some decisions as a team so that he could move on with his part of the work. It was revealed that only two members had actually responded to the proposed technical meeting. Stuart suggested that if key members from companies A and C were not going to attend then the meeting should be postponed or cancelled. Tom was silent for the remainder of the meeting and left the room quickly at the end.

Figure 5: Example of a Narrative

This short narrative provides an example of the complexities present within an integrated design team. The observation that only two project members responded to the meeting request could indicate a lack of commitment. The meeting was however a week away at this point so it could, instead, represent a weakness in communication. The episode appeared to be very disappointing and possibly de-motivating for Tom who expressed his frustration by a) not commenting for the remainder of the meeting and b) leaving the meeting room hastily. On the other hand he may have just had another appointment to get to.

The example demonstrates the subjectivity involved in observation as results often rely on the opinion of the observer. This highlights the requirement for the researcher to immerse herself in the project, therefore developing a more informed understanding of the project members and the surrounding issues. Giddens (2006) suggests that generating descriptions of social activity involves “mutual knowledge” shared by observer and participants whose action constitutes and reconstitutes the social world.

As well as intuition playing a large part in qualitative research so should the practise of triangulation. As highlighted in Section 3.5 the triangulation strategy can reduce threats to validity through the use of more than one data collection technique (Robson, 2002). Within the current research it is particularly useful as it can be utilised to confirm the existence of the views and opinions of both the team members and the researcher.

Following the episode presented in Figure 6 the researcher undertook an interview with Tom. During the interview a number of issues, observed in Figure 5, were explored further. Extracts from the interview can be seen in Figure 6.

The extract from the interview confirmed the researcher’s suspicions that communication and commitment appeared to be an issue. Further exploration of these topics, however, will need to be carried out to uncover whether this is a common and re-occurring theme amongst the team or if it only relates to Tom. This exploration will take the form of further observations of design meetings and interviews with other project members.

Researcher: What do you think the biggest challenges have been so far?

Tom: So far probably non-technical, communication things like that … I think its communication and commitment that are the biggest problems

Researcher: What do you think the biggest restraints with regards to collaboration are?

Tom: Oh gosh! I think the biggest problems we've got at the moment are probably non-technical … communication, commitment, location... those would probably be my top three because I think ultimately we've got a group of people that if they did work together well they could produce something … its just a question of getting the time, location and commitment to get them to work well together

Researcher: How frequently would you say that you interacted with other members of the team?

Tom: (Laughs) Does one way interaction count?

Figure 6: Example Interview Extract

4.3.2 Carrying out interviews

As demonstrated in the previous section, interviews can be used to successfully provide a reliable source of data particularly when used in triangulation with additional data-collection techniques. As the research is qualitative in its approach semi-structured and unstructured interviewing techniques have been adopted. Occasionally discussions with team members may be opportunistic and not planned in advance; therefore it is important that the researcher has the ability to perform unstructured interviews to take advantage of these unforeseen situations.

Huberman and Miles (2002) emphasise that the interview is a social situation and inherently involves a relationship between the interviewer and the informant. It is important to recognise that access to interviewees does not only concern physical and logistical access but social access too. Understanding the nature of that situation and relationship, how it affects what goes on in the interview, and how the informant's actions and views could differ in other situations is crucial to the validity of accounts based on interviews. Through the attendance of design meetings and informal discussions, the researcher will build up trust and relationships with individual project members and in doing so be able to intuitively gauge the best way of approaching interview situations.

When undertaking an informal interview it is important to make the interviewee comfortable whilst still attempting to obtain as much information as possible. Often, however much preparation is done prior to the interview; it depends upon the interviewee as to the actual format the interview follows. Within the current research it was intended that each team member was to be interviewed in an unstructured way, only referring to the questions prepared as a tool to guide the discussions. This approach was decided upon, as not only was it thought that more information would be obtained this way, but it would also provide an informal way of getting to know each team member. Unfortunately, as detailed in Figure 7, the very first interview did not go as planned and is an example of how social access, mentally connecting with the interviewee, can substantially affect the structure of an interview.

Participant one was very quiet and, although attempting to put him at ease, it was clear to detect that he was very nervous, possibly about the type of questions he was going to be asked. His response to each question was short and to the point even answering 'no comment' several times. This made it very difficult to have open discussions around topic areas and the interview developed into a highly structured format of strict questions and answers. Consequently the interview only lasted for 20 minutes and it was felt that not much had been gained.

Upon reaching the final question and informing the team member that there were no more questions to be answered, the relief he felt was visible as he sank back into his chair. The fifteen minute informal 'chat' that followed the interview was substantially more useful than the answers to the questions themselves.

Figure 7: Reflecting upon Interview One

Due to the infinite types of personality that a researcher could potentially meet, it is impossible to plan an ideal format; it is, however, possible to be better prepared. The actor in interview one was asked to attend ‘an interview’ rather than an informal discussion; this could have made him nervous. Additionally a Dictaphone was placed in the centre of the table which could have made him uneasy, and the environment, which was quiet, could have been intimidating, tense or possibly too intimate.

Following the experience of the first interview, several changes were made regarding how the team members were approached with the aim of making them feel more comfortable:

- They were asked to attend an informal discussion rather than an interview;
- A rough outline of the topics to be discussed was emailed prior to the meeting;
- Team members were asked to meet in informal environments.

Additionally, although a Dictaphone is useful in ensuring information is captured accurately, the researcher used her own judgement as to whether the team member would feel uneasy being recorded.

When Alan was approached he was more than happy to discuss the project and asked if Simon, another team member, could also join in. This appeared to be an excellent way of ensuring the comfort of team members whilst also capturing twice the information in one session.

To encourage further comfort it was proposed that Alan suggest a location for the discussion to take place. The discussion was held in a restaurant over lunch which provided the team members with an environment in which they very openly discussed the project. Although conversation was rich the informal and loud environment made it difficult to ask specific questions. Additionally the environment also meant that recording the conversation using the Dictaphone was impossible and note-taking at a dinner table was awkward. As the two team members were good friends, the conversation often strayed from the intended topic.

The situation resulted in the researcher having to take retrospective notes on the train on the way home which may have resulted in a loss of valuable data.

Figure 8: Reflecting upon Interview Two

With the researcher feeling better prepared, the interview process continued with participant two as documented in Figure 8.

Although not ideal, interview two was successful in the sense that it gave the researcher the opportunity to further develop the relationship and trust with the team members. Being in a comfortable environment with familiar faces resulted in the team members providing a lot more detailed and sometimes sensitive data that otherwise may not have been uncovered. Future preparation for carrying out interviews subsequently involved one team member at a time and an informal environment that the interviewer was familiar with.

As more themes and issues were identified during observations of design meetings it was possible to adapt interview questions in order to explore these further. Initial interviews consisted of more general questions with the aim of developing a better understanding surrounding both the project and the project members; however, this format didn’t restrict subsequent interviews.

Small additions to the methodology such as this are representational of a dynamic and continuously emerging process. It also shows how a methodology can, like a design, be continuously developed in creative ways. This ultimately makes the data collection and analysis process more animated for the researcher but also more interesting for the participants.

4.4 Identifying Themes

Law (2004) describes the world as messy and is himself interested in the politics of mess, the process of knowing mess and, in particular, methodologies for knowing mess. He suggests that simplicity, often found within many social science methods, will not help us to understand this mess but rather, in practice, research needs to be messy and heterogeneous. Consequently, to enable the identification and extraction of relevant data from this 'messy' social environment, it has been necessary for the researcher to immerse herself within the project. Whilst interacting with the project and its members, no inquiries can be excluded no matter where or when they occur, no matter how vast or trivial their scope (Flyvbjerg, 2001). This was particularly relevant to the current research; as the LIFECar project had already commenced, the researcher was expected to 'hit the ground running'. Every piece of information gathered from the very first design meeting was potentially crucial data and had to be included and considered.

4.4.1 Thematic Analysis

Thematic analysis is a method for identifying, analysing and reporting patterns (themes) within data (Braun and Clarke, 2006). As the research has adopted an inductive approach, thematic analysis has been chosen to represent this as patterns and themes can be identified from the raw data. Additionally it is proposed that by using this method the data can be analysed without being simplified; allowing the underlying complexity to remain accessible.

There are several computer software packages that facilitate the process of thematic analysis such as NVivo. NVivo allows the researcher to code the data and will then group it electronically presenting it in groups or a hierarchy of groups and sub-groups. Following an introductory course to NVivo the researcher decided that, in the case of the current study, processing and analysing the data by hand would provide more accurate and sensitive results.

Braun and Clarke (2006) suggest several steps that should be followed when using thematic analysis:

Phase	**Description of the Process**
1. Familiarising yourself with your data	Transcribing data (if necessary), reading and re-reading the data, noting down initial ideas
2. Generating initial codes	Coding interesting features of the data in a systematic fashion across the entire data set, collating data relevant to each code
3. Searching for themes	Collating codes into potential themes, gathering all data relevant to each potential theme
4. Reviewing themes	Checking if the themes work in relation to the coded extracts (phase 1) and the entire data set (phase 2), generating a thematic 'map' of the analysis
5. Defining and naming themes	Ongoing analysis to refine the specifics of each theme, and the overall story the analysis tells, generating clear definitions and names for each theme
6. Producing the report	The final opportunity for analysis. Selection of vivid compelling extract examples, final analysis of selected extracts, relating back of the analysis to the research question and literature, producing a scholarly report of the analysis.

Table 11: Phases of thematic analysis (Braun and Clarke, 2006)

4.4.2 Defining themes and sub-themes

A theme captures something important about the data in relation to the research question, and represents some level of patterned response or meaning within the data set (Braun and Clarke, 2006). Within the current research a theme has been defined as a set of behaviours, actions, and / or thoughts that have been displayed by those participants being observed and are perceived by the researcher as common to the process of whole system design. Ideally, there will be a number of instances of the theme across the data set, but more instances do not necessarily mean the theme itself is more crucial (Braun and Clarke, 2006). Researcher judgment is needed to determine what a theme is. However, as detailed in Section 3.5 themes will be coded by more than one researcher to ensure validity and reliability.

Sub-themes are essentially themes-within-a-theme. They can be useful for giving structure to a particularly large and complex theme, and also for demonstrating the hierarchy of meaning within the data (Braun and Clarke, 2006). Jim talking to Alan is an example of data under the theme of communication. Having identified that Jim talks to Alan every other day, this data can now be used to create a sub-theme 'frequency of communication'. Sub-themes are only formed once sufficient data has been collected and patterns within that data have been recognised.

4.4.3 A process of abstraction

In order to identify common themes, understand their relevance and the resulting enabling and inhibiting factors of a whole system design, a three stage process of abstraction was developed and followed as represented in Figure 9.

The model presents an example of one theme: communication, and its subsequent sub-themes and underlying data. The first stage in the model represents the complexity and 'messiness' of the raw data. This not only consists of the thoughts, opinions and actions of project members but also the organisational structure, geographical location, and physical environments and contexts which can affect these. This stage is rich in information and provides the researcher with the opportunity to immerse herself within the project, to really get to know the project members and to fully understand the reasoning and motivations behind the project. The second stage in the model represents the identification of patterns in the data resulting from the immersion. As patterns re-appeared again and again they formed a list of sub-themes.

The following stage involved the identification of the relationships between the sub-themes. Once connections between sub-themes had been explored in detail they could then be formalised into a list of key themes. The process is iterative as firstly it is important to ensure no attributes have been missed and secondly for validation that the themes continue to be evident and relevant.

Highlighting these key themes can then inform the enabling and inhibiting factors of whole system design therefore beginning to address the research question and objectives.

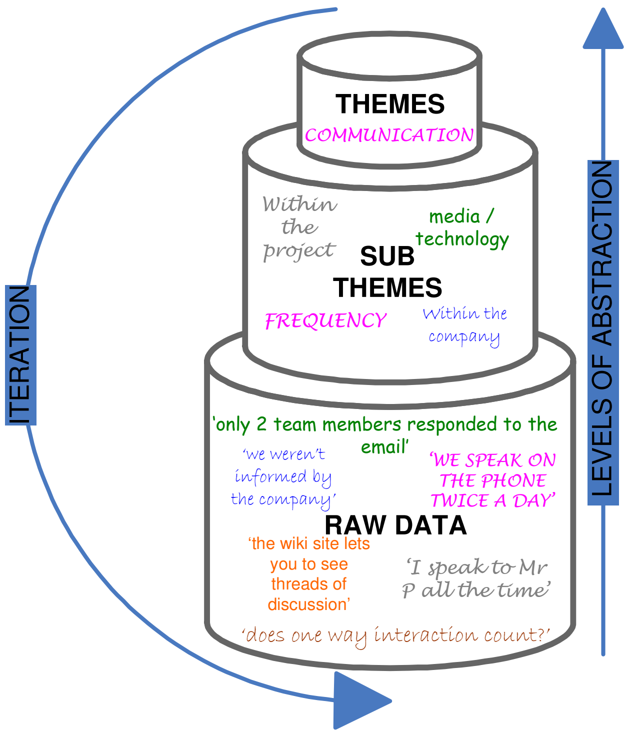


Figure 9: Process of Abstraction

4.4.4 Identifying Themes

Thematic analysis is a long and complex process for the analysis of qualitative data. Subsequently this section provides in-depth detail surrounding how this process was carried out and how themes were identified.

Initially as the author had no previous experience of Whole System Design projects, data resulting from the observations of design meetings was messy and complex. Potentially, any information could be relevant to how Whole System Design is carried out and therefore the notes taken by the author during these meetings were long and detailed. Following each meeting, before writing the notes up formally (as shown in Appendix 4), the author re-read the notes and highlighted any information that she thought could be relevant in terms of process, behaviour, organisation, location etc. As more and more meetings were observed patterns occurred within the data and it was possible to define codes to which data could be assigned. Figure 10 provides an example of a page of notes taken from a design meeting. The figure demonstrates how the author has highlighted certain points from the meetings and assigned them to codes. A formal record of the data and resulting codes was kept after each meeting. Appendix 4 demonstrates how notes were formally written up and codes recorded. However, the author also took specific points from the notes taken and wrote them on to post-it notes which over time formed a map of ideas. This was an informal way for the author to visualise the data and to begin to make sense of it through the development of groups and patterns.

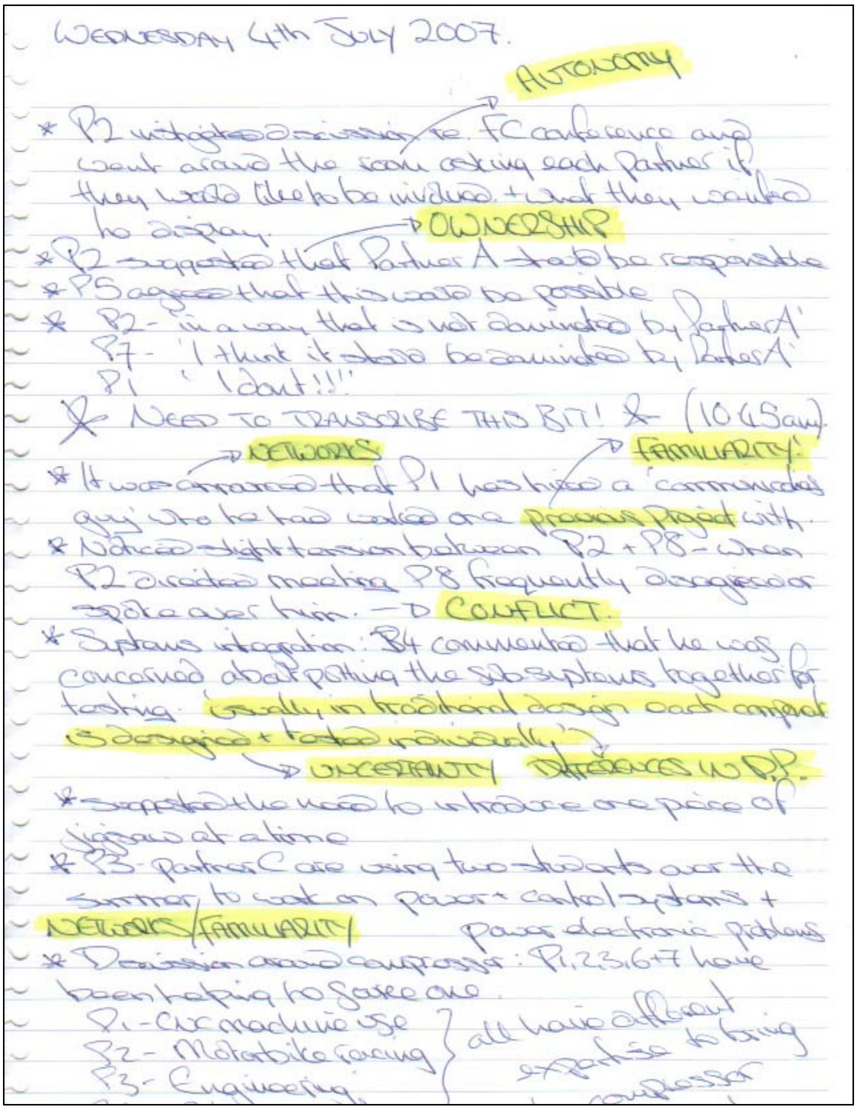


Figure 10: Notes from Observation of Design Meeting

At the same time data was being identified from interviews, project documentation and literature and relevant parts of the data were identified and coded in the same way.

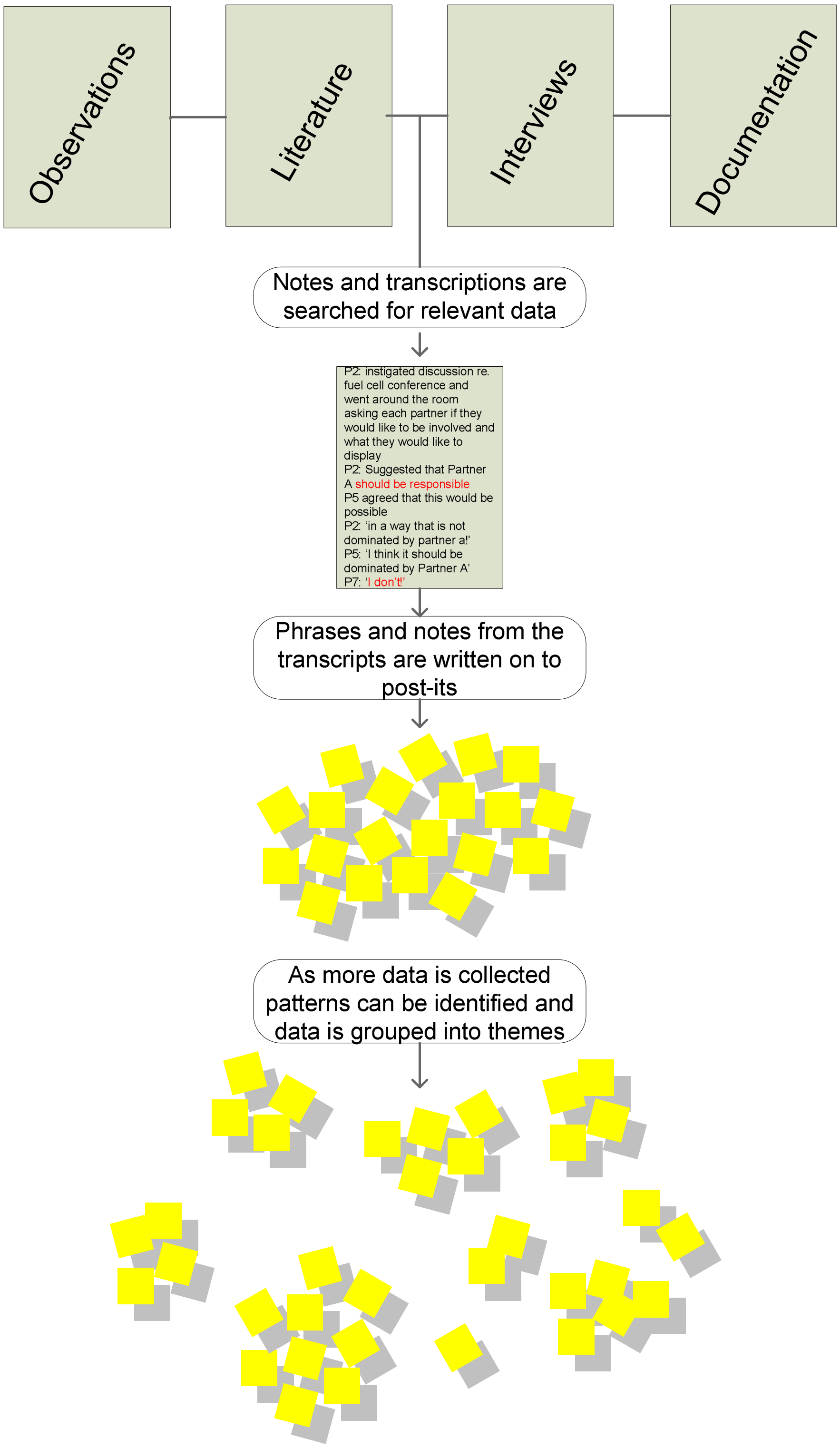


Figure 11: Identifying Themes

As more and more data was collected and analysed groups the wall of post-its became bigger and the groups of themes were added to, modified and confirmed. After approximately 18 months of observing meetings, carrying out interviews, searching through relevant documentation and analysing the resulting data, 10 themes had been identified. At this time it was realised that the data being collected was now adding to and confirming existing themes rather than contributing to any new ones.

4.5 Summary

This chapter has introduced the primary case study, it's aims and objectives and the project partners. Due to the complexity involved in the whole system design process the methodology that is being undertaken needs to be sufficiently dynamic and flexible to work with this complexity. The chapter has detailed examples of when and how certain areas of the methodology have had to be adapted and additionally where tools and techniques have been implemented. In particular the issue of social access was identified and discussed.

The process of abstraction which has been followed by the author has been detailed and the subjectivity involved has been discussed. The process of thematic analysis has been described and through use of diagrams and the appendix the identification of themes has been detailed. The 10 themes which have resulted from the primary case study are presented and discussed in Chapter Four.

	CHAPTER AIMS	ACTIVITIES	OUTCOMES
	CASE STUDY		
5	To present the initial research findings and explore their relevance to the research question	36 months extensive interaction with case study. Observation of 22 design meetings, 18 interviews. Enfolding of literature and synthesis of data	- First Phase Research Findings - 10 Themes

Case Study

This chapter presents the first stages of the research and the initial findings based on the case study. Data is presented in themes which have emerged through analysis; these are discussed in relation to the process of whole system design.

5.1 Introduction and Purpose

The aim of the first phase of the research was twofold. Firstly it was important for the researcher to gain a good understanding of the case study. As the research is inductive any information gained from the project was potentially crucial to the study from day one. Secondly this stage of the research sought to gain a broad view of whole system design utilising the multiple perspectives of actors. As explained in Chapter Three, the use of design meeting observations, interviews with project members and the analysis of relevant project documentation was used to meet these initial objectives.

As the case study lasted for 36 months the methodological approach adopted by the researcher was sufficiently flexible to enable accurate and relevant data to be collected. As themes began to emerge from the case study, the interviews with project members were adapted to include these findings and gain feedback.

Additionally, within the final stages of the research, data gained from carrying out interviews with actors from different design disciplines, detailed in Chapter Six, was fed back into the case study to enable a more holistic understanding to be formed. The researcher followed an iterative process as was demonstrated in Figure 5 in Chapter Three.

This chapter presents and discusses the initial 10 themes that were identified from interaction with the case study during the first phase of the research.

5.2 Data Analysis and Presentation Format

Over 36 months 22 observations of design and progress meetings took place; the meetings typically lasted for a day and resulted in over 120 hours of audio data. Additionally, 18 interviews were undertaken lasting between 1 and 2 hours resulting in 150 pages of transcribed data. Approximately 300 group emails, 25 sets of meeting agendas and minutes and numerous press articles were also analysed.

The insights gained from the observations, interviews and project documentation were recorded and analysed which lead to the identification of themes; the process of which was described in Chapter Four. The following ten themes which were identified and are presented and discussed within this chapter are:

1. Group Composition
2. Communication
3. Individual Characteristics
4. Commitment
5. Motivation
6. Identity
7. Sense Making
8. Managing Uncertainty

9. Collaboration
10. Ownership

The themes are presented in the following format:

- Theme Heading,
- A discussion around the theme using relevant literature, data and quotations taken directly from the observations, interviews and project documentation,
- Key findings and implications for the process of whole system design surmised from each theme.

Key findings are highlighted within the text, referenced finding 1: [F1], finding 2: [F2] etc, and are then collated at the end of each theme.

5.3 Findings from the First Phase of Research

This section presents the findings from the case study. Within the discussion surrounding the themes the project members are frequently referred to as 'actors'. This term incorporates anyone who participated in the LIFECar project. Each direct quote is followed by the title of the person who gave it. These titles have been directly extracted from the interviews, during which each actor was asked to provide their title in relation to the project. Figure 12 provides a graphical representation of the primary actors involved in the case study:

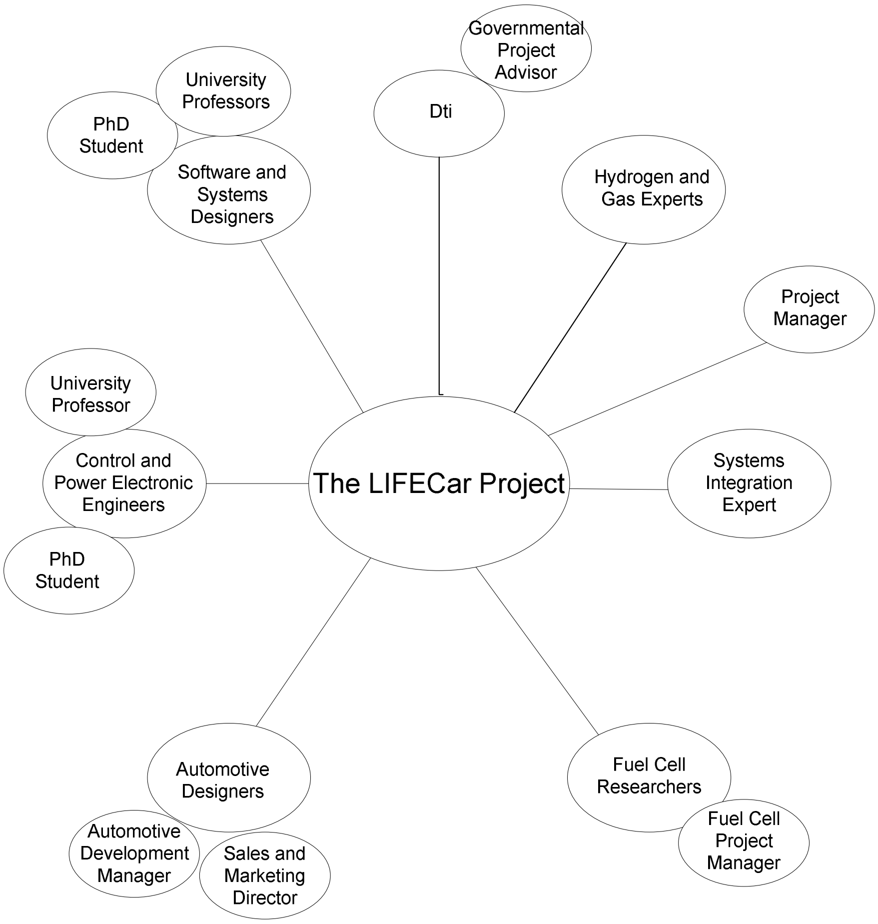


Figure 12: Map of Actors

5.3.1 Theme 1 - Group Composition

There are obvious potential advantages associated with bringing together experts from different domains as a means of transferring knowledge and skills between partners (Coley and Lemon, 2008). As highlighted in Chapter Two, one of the key principles of successfully undertaking a whole system design is the integration of multiple perspectives combined with complementary expertise, experience, ability and competence. Consequently it is reasonable that the characteristics of the actors who ideally possess those qualities and additionally the composition of the group of actors as a whole is a critical attribute to the success of a whole system design. This was highlighted in an interview with a design engineer:

"The profiles of the people are very different but I think that's crucial to it; the profile of the individuals and their profile together".

[Design Engineer]

However, selecting and enticing actors with suitable competencies to effectively provide adequate insight into a complex design problem is not straightforward, as the design engineer continued:

"Can they work together? What's the politics of the environment that they are in? Do you have a big problem with these people? Do they have the depth of knowledge? Do they have enough experience to actually deliver a package which is solid? And often you don't find that they do".

[Design Engineer]

There has been a wealth of research carried out into the 'correct' or 'ideal' composition for a successful and even innovative team (BELBIN, 2007; Myres, 1998). However, there are no hard and fast rules as to how to go about recruiting a successful design team and, furthermore, as to how to ensure that an adequate number of perspectives have been consulted for a whole system solution to be reached.

The LIFECar project emerged out of a series of friendships and a network of people with similar interests and ambitions **[F1]**. This is supported by the data as the statement below is a typical response from actors when they were asked how they became involved with the project:

"I wanted to get involved in vehicles that had electric motors, that were electrically driven, and I met Alan and he was involved with the Hydrogen project which needed electric motors and that was how I originally got involved"

[Control and Power Electronics Engineer]

This finding is in keeping with both Granovetter's theory of strong and weak ties and the concept of bridging and bonding social capital which were discussed in Chapter Two. The formation of the original LIFECar project group is a good example of how both strong and weak ties are required for both the development and sustainability of a successful partnership **[F2].** Figure 13 depicts how the partnership was formed through a series of:

- Strong ties: already formed friendships, employees of companies,
- Weak ties: relationships formed via chance meetings or through another actor, company, organisation,
- Similar interests,
- Conferences and seminars.

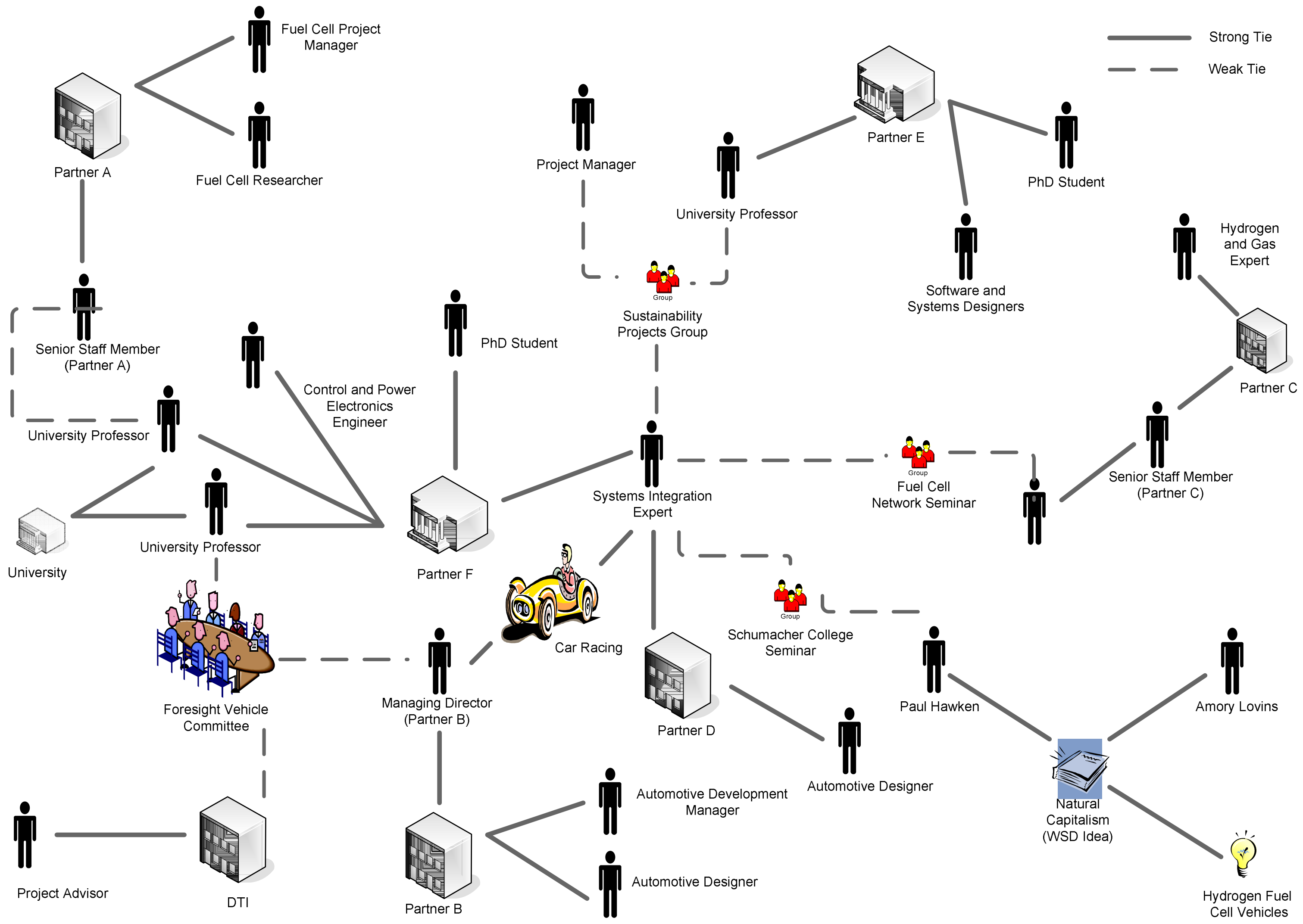


Figure 13: LIFECar Emergence

Through the network map it is possible to see how partnerships such as the LIFECar project can be initiated through personal contacts and shows the importance of a wide spanning network. Often the link between different partners was originally established through a weak tie. This map also portrays the importance of conferences and seminars for the development of cross-disciplinary, industrial projects.

The funding process that many university and industrial collaborative projects have to go through was observed to significantly affect the emergence of the LIFECar Project. When an organisation, such as the Department for Trade and Industry (Dti), release a call for proposals of funding there is often a limited amount of time to prepare and submit the proposal report. Due to this, pressure is put on key actors to construct a consortium who are willing to take part in the research project. It is understandable, therefore, that actors will call upon friends and acquaintances with whom they are already familiar to form that consortium. As the figure demonstrates many of the actors already shared ties with either people or places, this provides the team with familiarity and consequently a feeling of confidence and trust from the outset.

It is not enough, however, to rely on existing contacts to provide a whole system perspective and consequently, as in the LIFECar project, it is likely that additional members will need to be recruited to expand the breadth of expertise required. As previously discussed in Chapter Two the productivity of a team depends, to a large extent, on the ability of its members to tap into an appropriate network of information and knowledge-flows (Leenders *et al.*, 2003). It was observed that, once key partners were involved, the recruitment of additional project members tended to be handled internally by recruiting additional team members from the supporting companies. Although this was a convenient and easy way of obtaining required expertise, it does indicate a degree of inflexibility within the team, as knowledge was being sought through ease of accessibility as opposed to quality and relevance **[F3]**. However, seeking expertise from additional external companies would have added to the already complex composition of actors as was represented in Figure 12.

Consistency of group members

Even once a partnership of actors and organisations has been formed it takes a lot of time and commitment for that group of people to successfully develop into a productive team. Whereas a group is a collection of people, a team is a group which, as a whole, agrees on its purpose, then works towards it. Not knowing the difference, managers might think all they need is to assemble a skilful, multifunctional group - it takes more than that (Shalley *et al.*, 2004). It appeared to take the LIFECar members a long time to form a team and it is thought that this was largely due to the inconsistency of meeting attendance by the team members **[F4]**.

Early project meetings consisted of several actors representing each partner or company and often these actors would change from meeting to meeting. In one of the first meetings four managers and only one technician turned up to represent just one company, seating themselves in a row at the back of the meeting room. This was understandably interpreted as slightly defensive behaviour by some of the other partners. The pattern of attendance was often dependent upon the geographical location of a meeting **[F5]**. On one occasion six members representing one company attended a project meeting when it was conveniently located at the company's headquarters. Additionally the large-scale re-structuring of staff within two of the companies meant that key members of the project team were replaced on several occasions. This proved to be unsettling for many actors as it was unclear which members were permanent and consequently which members were able to talk to about which part of the design **[F6]**. As Bamford (2006) suggests, maintaining continuity can be difficult; a partnership has to have reached a degree of maturity to cope with key personnel changes without significantly affecting the partnership, either for better or worse. As key personnel changes took place within the initial stages of the project, it is thought that this had a detrimental effect on the partnership and the design process as a whole.

A role that can be found in most groups at one time or another is that of ‘newcomer’ (Levine and Moreland, 1990). Levine and Moreland (1990) suggest that newcomers are expected to be anxious, passive, dependent, and conforming, and those who play this role more effectively are more likely to be accepted by old timers. The role of the newcomer was observed several times throughout the project; however it was also observed that this role does not always arrive hand in hand with passive behaviour. On one occasion the ideas and enthusiasm of one newcomer were positively embraced and comments such as the one below were common.

“I think the main difference has been Alan coming in on the ‘Partner B’ side.”

[PhD Student]

Newcomers to the team have, however, also caused tension. Occasionally a company manager or director attended project meetings. Due to the cross-disciplinary understanding that had been painstakingly developed throughout the team, the requirement to explain details to an actor who attended a one-off meeting was understandably frustrating **[F7]**. On one occasion, and at a particularly critical time in the project, a regular team member was replaced by a senior level partner from the same company. This was frustrating as the senior member was unable to answer many of the questions put to him as the meeting extract below indicates:

Systems Integration Expert: "Is there anything you can do other than adding more plates in? Will we not end up with a weight increase anyway?"

Senior Level Partner: "Erm …" [silence]

Systems Integration Expert: "I mean even at the 1 kw stage if you can see there is a problem, the solution, is it not going to be to put in a cleaning plate every third cell rather than every fourth?"

Senior Level Partner: "possibly… again I'd have to talk that through with Rich and Terry, I mean from a common sense point of view that seems to be the case"

Systems Designer: "How much time have you got for Rich to spend with the car and on the track?"

Senior Level Partner: "off hand today I don't know…"

Figure 14: Design Meeting Extract demonstrating the need for Team Member Consistency

Over time it was observed that group members did become a lot more consistent in their attendance of meetings and subsequently stronger relationships were able to be formed **[F8]**. Unavoidably this meant that towards the later stages of the project when a key member had to leave and was replaced, it had a substantial impact upon the group. It is normal for the people in a partnership to change over the life of the partnership, but it can also be disturbing as intelligence is lost (Bamford, 2006). This was effectively avoided in most cases however as the departing actor spent time inducting and educating the replacement actor.

Key Findings and Implications from Theme 1

[F1] The group emerged out of a series of friendships and via a social network. This meant that many of the actors already had similar interests, motivations, ambitions and ethics;

[F2] The group consisted of a network of strong and weak ties. This enabled easier access to resources and expertise and therefore allowed a more holistic vision to be developed;

[F3] New members of the team were recruited internally via existing partners. Expertise and knowledge was often sought through ease of access as opposed to quality and relevance;

[F4] Initially group members were very inconsistent, with one company often being represented in meetings by several different people. This slowed down progress and delayed the group from forming a cohesive team and shared understanding;

[F5] Team members were geographically dispersed. This meant that it was often difficult for actors to attend regular meetings and to meet face-to-face. Additionally it limited the group meetings to one every quarter which delayed the cohesion of the team;

[F6] Large scale re-structuring took place within two of the participating companies. Key members of the project team were replaced on several occasions. This proved to be unsettling for many actors as it was unclear which members were permanent and subsequently which members were able to talk to about which part of the design;

[F7] Some team members only attended the occasional meeting. This was frustrating both because time had to be spent updating that team member on progress, and also because a cross-disciplinary understanding had already been developed by regular team members.

[F8] Over time group members became a lot more consistent in their attendance of meetings. This enabled strong relationships to be formed and knowledge regarding sub-systems to be shared more efficiently;

5.3.2 Theme 2 - Communication

For any collaborative project to be successful, effective communication is essential. Design communication is central to design development; the effectiveness of design communication becomes critical for designers in sharing design information, in decision making, and coordinating design tasks (Chiu, 2002). This is even more essential between actors from multiple disciplines, industrial sectors and backgrounds. Sonnenwald (1993) suggests that actors with different perspectives need to interact so that they can come to a working understanding of how the solution being developed will co-exist with, and ideally support, patterns of work activities, social groups and personal beliefs.

It appears that communication within a whole system design is even more crucial particularly regarding the effective communication of information between the individual sub-systems of the design. It was not surprising then that concerns regarding communication between different parts of the design were raised early on in the project:

"We need to get the fuel cell to communicate with the motors"

[Control and Power Electronics engineer]

As different members of the team are working on different parts of the design the communication between team members is essential to ensure the successful integration of the final design solution. However, it appeared that, although understanding the collaborative nature of the project, some team members were unaware of the importance and need to communicate information, particularly when making design decisions **[F1]**. This was inferred through comments such as those below:

"generally people's work, people's sub-systems, are fairly separated so it's questionable just how much communication is required for everyone, do you know what I mean like I'm not that interested to know every single detail of what's happening with the hydrogen filling station or the fuel cell although it has relevance to the whole project.

[PhD Student]

"I can't be going to all the meetings because a lot of the stuff isn't relevant"

[Automotive Designer]

"we will do our own; if you draw a box around the re-fuelling system we will do our own kind of HAZOP check as we go through the process. That doesn't necessarily need to involve anyone else in the room"

[Hydrogen and Gas Expert]

As a result of this it was observed that some design decisions were made by one partner and not shared with another as shown in the brief discussion in Figure 15. This often meant that a partner was left working on a part using the wrong dimensions for example. It is clear that the significance of sharing all decisions on a regular basis was not completely understood by all actors.

Control and Power Electronics Engineer: "The ultra caps are 60 x 170 so 60 caps can fit in the transition tunnel"

Systems Designer: "I think you'll find that those dimensions have changed slightly"

Figure 15: Project Meeting Extract demonstrating the need for frequent communication

In a whole system design it is clear that frequent and consistent communication is required for a successfully integrated design.

Communication Frequency

Quarterly progress meetings were held consistently throughout the 3 year project and during the final 12 months these became more frequent and were increased to one every month or two months **[F2]**. It was felt that quarterly meetings did delay the initial integration of the team and consequently productive and successful collaboration did not take place for 9 – 12 months. It was, however, observed that due to the hectic schedule of team members it would have been unrealistic to insist on additional meetings. The design meetings were successful overall and attended by most members; additionally, communication was enthusiastic and constant **[F3]**. This was a great advantage within the project compared to a study conducted by Newell and Swan (2000). The study by Newell and Swan (2000) found that although the team being observed did have fairly regular face-to-face meetings, these were never as frequent as originally intended because of the difficulties of actually finding dates on which all the members could attend. The communication between quarterly meetings however was not so consistent to begin with, as suggested in the following interview extract **[F4]**:

"I've got to admit I would like to have more meetings and whatever with 'Partner D' but more with Phil really but he's so busy. But I know with now the racing season drawing to a close I will probably be able to maybe speak a bit more and maybe visit him or whatever 'cause I need to just talk, just to go over some of the things that he's designed and how I'm integrating them"

[Software and Systems Designer]

After probing the designer further about the frequency of communication between himself and the other project members he replied:

"does one way interaction count? (laughs), I don't I suppose I have any contact with Partner B really, I think I tried once but it just didn't work out and Partner A, about as much … this is going to sound strange, but I tend to speak to people

who speak to me, which sounds obvious, so for example I don't communicate much with Roger because its always one way because he has got a very high teaching load etc so I generally talk to Jerry rather than Rodger because Jerry's more available."

Understandably the team member then went on to say:

"I think its communication and commitment that are the biggest problems"

As the project got underway, communication between team members did get more frequent and intermittent design meetings began to take place between individual partners as described below. This noticeably increased the rate of progress throughout the project.

"A lot of it (communication) happens outside of the regular meetings and the more informal side of meetings, but that's working well. Alan's come to visit quite a few times and we talk on the phone and email regularly so there's just been generally a lot of communication."

[Control and Power Electronics Engineer]

Type

Communication comes in many different forms. Probably the most common forms of interaction within a design team are individuals communicating:

- Verbal statements that others can hear,
- Sketches that others can see,
- Drawings that others can see ,
- Text that others can see,
- Calculations that others can see,
- Tabulated data that others can see,
- Non-verbal signs of their emotional state.

(Johnson, 2005)

When asked what the most frequent type of communication used throughout the group was, most participants listed (in order of frequency):

- Email,
- Telephone,
- Face-to-Face Project meetings.

Although email was utilised a lot during the project, Levine and Moreland (1990) suggest that there is little evidence that electronic communication improves group productivity and that electronic mail seems to affect the work group by:

- Reducing overall communication,
- Equalising participation,
- Weakening status systems,
- Emphasising informational rather than normative influence,
- Encouraging certain forms of deviance.

Within a highly dispersed design team, however, communication in any form is very important and the use of emails did not appear to have had any detrimental effects upon the project team. Within a whole system design it appears that a flatter hierarchy encourages equality, joint ownership and overall integration therefore the suggested weakening of status systems and allowing team members to communicate on level ground appears to be beneficial. This was displayed during design meetings when participation was consistently equal; there were not many occasions when an actor would overpower another or dictate actions **[F5]**.

Communication during project meetings was enthusiastic and it was easy to identify that information was being combined within meetings to produce a synthesis that could not be achieved by individual designers (Johnson, 2005). However, information-flows between actors can become complex and maintaining a level of discussion in which everyone could partake was often difficult **[F6]**. Within the LIFECar project concerns were often raised suggesting that meeting discussions must focus on fulfilling the needs of the whole system as opposed to concentrating on sub-system details.

"I think partners need to be reminded at the beginning of every meeting that discussions are to be kept at a whole system level".

[Systems Integration Expert]

It was observed that when discussions were maintained at a whole system level more actors within the team were seen to participate. However, it was clear to see frustration and boredom emerge when conversations reached detailed sub-system levels; members began to have their own individual conversations in groups of two or three; they left the room frequently or walked about or they sat in frustrated silence doodling and showing signs of boredom. Although smaller expert group-discussions are essential to the design process, when held within large group meetings there is a risk of other partners becoming withdrawn from the meeting and demotivated. As one actor explained:

"in the big meetings there's 3 people who are actually having a discussion and the way it goes normally is that there's a discussion which happens obviously in front of quite a lot of people but then quite often everyone's collaring each other saying 'that thing we're doing you know…' it doesn't need discussing in front of everybody but it just needs to be sorted out and its better when they're face to face, people actually agree what they're going to do"

[Fuel Cell Researcher]

This observation is supported by literature which suggests that, the spaces in which creative and innovative activities take place are an important part of the innovation process (Moultrie et al., 2007). Providing space for universal communication, which allows for break-out groups to participate in more detailed level conversation, may provide a solution to maintaining comfort and motivation during project meetings.

Integrating multiple actors with many different perspectives is essential for the co-evolution of innovative solutions. Consequently it is understandable that team members are going to send the discussion in completely unexpected directions. This is good when new aspects of problems and opportunities are discussed, and sometimes it is bad, as when people embark on long digressions which ultimately contribute little to the matter in hand (Johnson, 2005). This was an ongoing problem throughout the project and despite attempts to manage discussions, a solution to the problem was never completely realised. It is suggested that holding more frequent meetings or conference calls between specific members of the group or alternatively allowing an allocated time within / or at the end of a group-meeting for these types of discussion to take place could have been a solution, as one actor suggested:

"the only way of getting through with it is to have more technical focused conferences or meetings. You don't need that much project management and stuff, only every so often, but you do need more technical, because it is all technical in the end so we need to improve that interaction"

[Fuel Cell Project Manager]

Company and Project Communication

Since the sub-systems of the design are so intrinsically linked, actors needed detailed knowledge from the content of each others' designs. Subsequently the interdependency between the actors was strong and therefore communication between actors also needed to be strong. Communication between supporting companies and the project team, however, appeared to be flawed and caused disruption to the progress of the project on several occasions **[F7]**. The following is a statement taken from a meeting in which the Fuel Cell Senior Level Partner was responding to a question about the delay of the Fuel Cell:

"well it's a communication issue because if we look at the delays we've had through the two cell development phase … they have been longer and we've known about those problems for quite some time; the problem is, that hasn't been properly communicated"

[Fuel Cell Senior Level Partner]

It was revealed that although Partner A had been aware of the Fuel Cell delivery delay for quite some time, they had failed to communicate this to the rest of the group. Consequently the group were working towards a substantially unrealistic deadline. This breakdown in communication resulted in a significant delay of the final design solution.

Upon discussing this issue further it was uncovered that the source of the problem was found in yet another breakdown in communication but this time internally between members of the same company. As represented in the quote below, the Senior Level Partner working on the project had also been kept in the dark about the critical delay

"I wasn't aware of this delivery issue until Monday this week"

[Senior Level Partner]

Much of the lack of communication within the company had resulted from the repeated restructuring of staff and the subsequent replacement of company and team members which was discussed in Section 5.3.1. This is another example of how the relationship and subsequent communication between supporting companies, the project team and the team members ultimately and detrimentally affects the design process. Figure 16 represents the communication between the individual actors, the project team and the supporting companies; through this model it is possible to observe the complexity of these relationships.

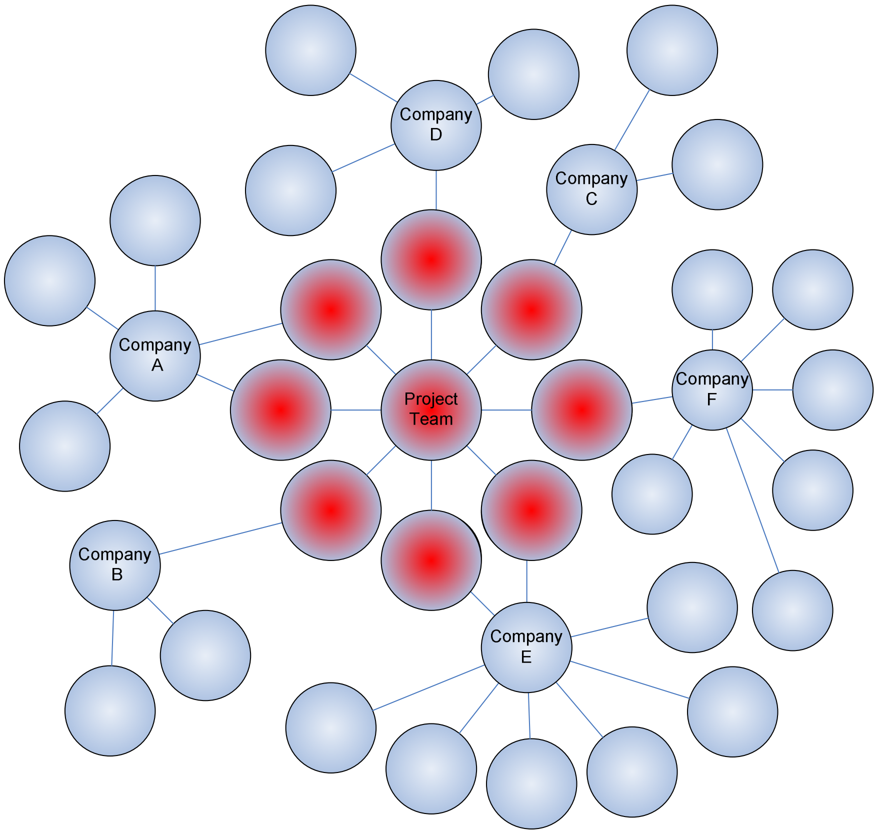


Figure 16: Model of Actor Communication

Key Findings and Implications from Theme 2

[F1] It appeared that some team members were unaware of the importance and need to communicate information, particularly when making design decisions. This meant that frequently decisions made by one partner were not communicated with the rest of the team. This often resulted in a partner working on part of the design using the wrong dimensions for example;

[F2] Quarterly progress meetings were held consistently throughout the 3 year project, with these becoming more frequent during the final 12 months, increasing in frequency to one every month or two months. This gave the actors the opportunity to have regular face-to-face discussions, such that:

[F3] Communication during project meetings was enthusiastic and constant;

[F4] Outside of team-meetings, team-members often neglected to communicate frequently and consistently with the whole team. This potentially prevented an understanding of how components of the design impacted upon each other. Additionally opportunities for optimisation between components of the design could have been overlooked and this put the realisation of a fully integrated design at risk;

[F5] During project meetings communication was equal and it was rare that one actor dominated the meeting or overpowered other actors. This meant that actors were more comfortable in expressing ideas and opinions and encouraged a sense of equality between the team members;

[F6] During meetings it was often difficult to maintain a system-level discussion that was relevant to everyone. Discussions often advanced into a sub-system level which meant that not all actors were able to join in. This caused some actors to lose motivation and concentration during some parts of the meeting;

[F7] Communication between some companies and the project team was not sufficient. On one occasion the delay of an integral part of the design was not communicated to the project team. Subsequently the team were working towards a substantially unrealistic deadline. Lack of communication between a company and the project team caused severe delay, disruption to the project team and ultimately the delay of the final design solution.

5.3.3 Theme 3 - Individual Characteristics

Theme one discussed in Section 5.3.1 highlighted that successful whole system design requires the integration of multiple perspectives combined with complementary expertise, experience, ability and competence. Subsequently the mix of people within a project team can have a substantial effect on the success of the project as a whole. The individual characteristics of those people, however, have been observed to be equally as important.

It is assumed that a designer will bring individual expertise and experience to a design problem or context. Often the nature of the design problem will dictate the type and amount of expertise and experience that are required. Through interviewing LIFECar team members it was apparent that there was an abundance of technical expertise and experience **[F1]**. It is acknowledged, however, that possessing these characteristics is not always accompanied by the ability to utilise and apply them appropriately;

"you must have the right level of skill but equally … at the beginning you have to have people who are equally able, not only have you got the specification, you have to have people who can structure the progression of this idea to hardware in a way that they can limit the damage. So they have enough experience to identify where the risks are, where the true novelty is"

[Design Engineer]

It has been suggested that the characteristic or skill that is required of actors within particularly innovative projects is 'receptivity' **[F2]**. Receptivity, in the context of innovation and technology transfer can be defined as the extent to which there exists not only a willingness (or disposition) but also an ability (or capability) in different constituencies (individuals, communities, organisations, agencies, etc.) to absorb, accept and utilise innovation options (Jeffrey and Seaton, 2004). Observations made from the current research have confirmed the need for 'receptivity'. It has been observed, however, that in order to successfully contribute to a whole system design, actors need to not only posses relevant levels of expertise, experience and the competence to use those effectively but also that a large degree of enthusiasm and eagerness to further their learning is required **[F3]**. A whole system design requires actors not only to excel within their own area of expertise but, also to develop a good understanding of surrounding disciplines and sectors. This is largely to ensure that the effects from design decisions on surrounding sub-systems are thoroughly understood and accounted for and that interrelationships and potential for innovation is identified. As Anarow *et al.*, (2003) highlight, whole-systems thinkers see wholes instead of parts, interrelationships and patterns, rather than individual things and static snapshots. They seek solutions that simultaneously address multiple problems. Many actors agreed that additional learning was required to enable linkages between sub-systems to be recognised, as is highlighted in the following quote:

"I think that you've got to have an appreciation for whatever you are bringing into the car has many different faces where it interacts. It acts in many different directions and many different fields electrical, mechanical, gravitational, lots of different ways"

[Fuel Cell Project Manager]

The ability to regard the system as a whole and to identify relationships between sub-systems can be referred to as thinking systemically, as introduced in Section 2.5.4. Systemic thinking appears to be a unique skill but is necessary to the process of whole system design **[F4]**. Adopting a different approach to thinking and problem solving unavoidably takes a significant amount of extra effort. Therefore the enthusiasm and eagerness to learn across boundaries in order to develop a more systemic way of thinking is an essential characteristic. As one of the designers working on the collaborative and holistic development of the Xbox 360 highlighted:

"The truly brilliant 'designers' are not specialists. They blur boundaries very, very effectively and can speak to the idea of design in a 360-degree realm successfully. This isn't to say that specialisation is dead, but even as a specialist, if you can't decipher the other design dialects, you'll never achieve truly transcendent ideas" (Kemp, 2006)

Within the case study it was unclear as to whether every member of the team possessed the ability to think systemically.

Additionally, within a whole system design, the type of expertise and perspective that is required of those actors involved is often not empirical or initially obvious. For example an end user may be able to provide knowledge and expertise to a design context which would have otherwise been missed by professional designers.

Key Findings and Implications from Theme 3

[F1] There was a high level of technical expertise and experience within the team. This enabled the sub-systems of the solution to be designed and manufactured competently and efficiently;

[F2] The characteristic of 'Receptivity' is necessary within the process of whole system design. Actors must possess relevant expertise and experience, however, the ability to apply those skills accurately within multiple design contexts is paramount.

[F3] Actors need to possess an enthusiasm and willingness to learn from other sub-systems, disciplines and sectors. This willingness, observed within the project, enabled a shared understanding and vision of the whole system to be developed;

[F4] It was unclear as to whether every member of the team possessed the ability to think systemically. This prevented some team members from consistently seeing the solution as a whole and could have meant that links between sub-systems were not taken advantage of.

5.3.4 Theme 4 - Commitment

A characteristic which has been observed to be a pertinent requirement of those working on a whole system design is commitment to both the project and to the project team. Studies frequently relate effective commitment to the extent to which people experience a sense of identification and involvement with an organisation (de Gilder, 2003). People are willing to spend considerable effort on things that are important to them, so the value dimension for truly personal meaningful activities is more important than the effort dimension (Fischer, 2005).

From the beginning of the project it was noticeable that the issue of team member commitment was a concern. Comments such as that below were frequently made during initial interviews.

"There are a lot of people working sort of semi part-time on it, so my concern is what do six or seven people working semi part-time expect to achieve as compared to the likes of Ford, Honda, Toyota and everyone else. We'll have to wait and see I suppose"

[Software and Systems Designer]

As identified and discussed further in Section 5.3.9 partners who were unable to fulfil their responsibilities were observed to cause conflict as other members had to take on extra tasks **[F1]**. This is thought to be particularly challenging to the process of whole system design as frequently a part of the design cannot move forward without data created by another partner.

"Roger is just so busy that he cannot carry out the tasks required of him. He is creating a bottle-neck"

[Systems Designer]

Through carrying out interviews with the team members it appears that effective commitment does not necessarily depend on the level of interest, value or enthusiasm for the project. The key obstacle that challenges members' commitment to the project is clearly the amount of time they are willing or able to provide. This willingness and ability is frequently determined by the workload they have aside from the project.

Time

Out of the sixteen primary members working on the LIFECar project only two were appointed to work on the project full time **[F2]**. This was extremely frustrating at the beginning of the project, as shown through the interview extracts below, as the two actors were understandably working a lot more quickly than anyone else. As a result the two actors were eventually assigned additional work.

"everyone is sort of working part time ..'[Systems Designer]

"I think ultimately we've got a group of people that if they did work together well they could produce something … its just a question of getting the time, location and commitment to get them to work well together"

[Systems Integration Expert]

Throughout the project the issue of individual commitment was a frequently discussed topic and the amount of time some actors were dedicating to the project was noticeably less than others as the comments below demonstrate.

"He hasn't been coming to the meetings" [PhD Student]

“Rodger has a very high teaching load,” [Systems Designer]

“Alan is trying to build up his business, doing other projects” [Systems Designer]

Additionally it was apparent that some partners were not aware of the level of commitment and collaboration that was required of them as the following comments, taken directly from design meetings, demonstrate **[F3]**:

“We are putting a lot of effort into it and there has been a lot of unscheduled collaboration and things that we didn’t have costed into this thing at the start”

[Fuel Cell Project Manager]

“Have I got this right we are all giving up some of our own time to do this?”

[Fuel Cell Senior Level Partner]

Partners were all observed to bring individual expectations and understanding of requirements to the project and subsequently this may have led to a misunderstanding of the level of commitment that was required. The difference in partner expectations and requirements is explored further in Section 5.3.7.

It was observed that the amount of time the group members were able to spend on the project was often dictated by the company that they were working for. As shown within the next section, this became a topic of conflict for the group and had to be resolved.

Personnel

The number of personnel that a company was able to allocate to the project varied between partners and appeared to depend substantially on the size of the company **[F4]**. As the supporting companies that were involved in the project varied so much in size this noticeably had an impact upon the team.

“This is only a small part of what they (Partner A) are doing, Partner B are also a step back but are still involved” [Systems Designer]

In particular it appeared that other projects, which members had been assigned to, were frequently taking up substantial amounts of time and personnel. This is demonstrated in the extracts below.

“Well, it’s like everything. You’re funded to do the research but once you’re here you get sucked into doing other things. So I would guess probably about 60% of my time is LIFECar and 40% is teaching … applying for other grants that sort of thing. [Software and Systems Designer]

“We have another hybrid car which we are working on at the moment. It’s a little Ford Focus with a new battery in it. We are testing sort of this new battery management system, so I am overseeing that one. There is someone else that’s actually involved in doing the work but I am overseeing that project.”

[Systems Designer]

As this became such an issue at one stage in the project, actors suggested that they should approach the senior members of one partner in particular in order to secure more of the project member’s time.

“I would really like the opportunity for someone from this group to go along and talk to someone at as senior level as possible within Partner A and say this is what this project is all about. Do a brief presentation and say this is this project and we’re just letting you know how its going because, between ourselves, I could envisage a time in the Autumn when things aren’t going as well as we thought and when the project budget for Richard has run out and we’ll be in a sticky situation then, more than sticky. And if we can’t rely on someone at a senior level saying ‘ok we need to release some of Richard’s time to fix this’, then we’ll be in real trouble. And I think the way to pre-empt that is to get them brought in and to be really excited about the project sooner rather than later”

[Project Manager]

Again this reflects on the complex relationship between supporting companies, the project team and individual project members which is explored further in Section 5.3.6.

It has been observed that within a whole system design process the level of commitment required from partners is significantly high. This is primarily due to the intense collaboration and integration that is required to obtain a successful outcome. To achieve a high level of commitment from all actors it is recommended that partners should be briefed early on in the project planning phase regarding the commitment of time and personnel.

Key Findings and Implications from Theme 4

[F1] Actors were occasionally unable to fulfil their responsibilities due to a lack of time and other commitments. This often created a bottle neck and other actors had to take on extra tasks to enable the project to move forward;

[F2] Some actors worked full time on the project whilst other actors worked part time. This meant that those working full time were constantly waiting for work from other members of the team before they could continue. This caused a sense of frustration;

[F3] It was apparent that some partners were not aware of the level of commitment that was required of them. This caused friction between partners and made carrying out a whole system design difficult as significant levels of commitment are required;

[F4] The number of personnel that a company was able to allocate to the project varied between partners. This meant that some partners had substantially larger workloads than others.

5.3.5 Theme 5 - Motivation

It was observed that high levels of commitment from actors were often unobtainable without significant motivation towards the project. Motivation is defined as:

1. The psychological feature that arouses an organism to action toward a desired goal; the reason for the action; that which gives purpose and direction to behaviour,
2. the condition of being motivated,
3. the act of motivating; providing incentive.

(Dictionary.com, 2008)

It is acknowledged that not only do actors need to possess the motivation to succeed in both their own personal goals and those of the project but also need to feel valued as a project member in order to maintain that motivation. As described below, motivation is often a personal unquantifiable feeling as opposed to a monetary incentive for example.

"What you want is creativity, this thinking and these excellent solutions; you don't get by paying people in your team. There has to be more I think more personal, it's got to matter and I think there are big issues in how you do that to get your really excellent work I think money is not enough. Having fun, feeling you're clever and contributing your part of the total is really exciting" [Design Engineer]

This comment is supported by the results of an employee motivation survey, conducted by GoalManager, in which salary came 5th in the list of factors that motivate people to stay in their job. Much more important were social aspects of work such as people, work environment and relationship with management. The complete results of the survey are presented in Table 12.

What do you like about your current job? What are the things that keep you there?	
People and Work Environment	66%
The management cares about me / Good relationship with management	33%
Challenging and Exciting Job	33%
Flexibility	24%
Salary	19%
Autonomy and Creative Freedom with Job	16%
Training and Learning Opportunities	13%
I like the Product / Technology	9%
Teamwork	8%
Percentages are based on multiple responses to each question and thus will not add up to 100%	

Table 12: Employee Motivation Survey (Goalmanager, 2000)

As motivation plays such a large part in business management theory and best practice literature (see Maslow, 2000) it is understandable that the concept of motivation was addressed early on in the LIFECar project. Within the initial project meeting all members were asked, by the project manager, why they wanted to take part in the project. The answers given fell into four categories and are presented in Table 13:

MOTIVATION	EXAMPLES
Environmental Concerns	'I like the environmental focus'
Technical Application	'it is good to be participating in a real product project'
Disciplinary Recognition for Innovation	'we want to push the boundaries in fuel efficiency and fuel cell application'
Company Benefit	'our current collaboration with BMW is working well, something similar is desirable with Partner A'

Table 13: Partner Motivations

These answers were not unexpected as they fell neatly within the overall aims and goals of the project **[F1]**. However, when asked the same question again; this time by the researcher during one-to-one interviews, the answers that were given were very different; as represented in the extracts in Figure 17 :

"Well the project is a means to an end really. I wanted to get back into academia and so this project was a means to getting back into academia and having a full time lectureship at the end of it." [Systems Designer]

***"before my 4th year (university) project I started thinking more and more about electric cars and why they don't exist and what needs to be done to make them work, so I just got interested and so did my 4th year project in that area and that's how I got involved"* [PhD Student]**

"It's a good CV thing isn't it; saying you've worked on the design of a fuel cell car" [Automotive Designer]

***"I wanted to get involved in vehicles that had electric motors, were electrically driven"* [Control and Power Electronics Engineer]**

"I was brought in to try and give it a theme and the design on it really. To try and take it from a bunch of ideas into a whole vehicle I suppose ..." [Automotive Designer]

***"looking to develop the fuel cell for this type of application... and find exploitation routes for that ... to look at how we pull this forward to end up with a real product"* [Fuel Cell Researcher]**

"Quite openly there would have been no point in us signing up to the programme if we couldn't bring in some IP (Intellectual Property) because we would have been developing a product that had no clear rights to exploitation" [Fuel Cell Project Manager]

Figure 17: Individual Motivations

This data shows a difference between the motivations that individuals were willing to share with the project team and those more personal motivations that were shared only with the researcher **[F2]**. The reason for this difference could be due to the surrounding environment in which the question was originally asked. It was the first meeting and so the group were unfamiliar with each other, additionally each member is likely to have wanted to appear enthusiastic and to have needs and motivations that were in keeping with others. This is supported by Maslow's hierarchy of needs in which social acceptance and security features highly (Maslow, 1998). Throughout the project it was apparent that individuals held two sets of motivations: those which coincided with the overall motivations and goals of the team, and those which were personal. However, as partners grew to know each other these personal motivations became more transparent.

“everybody comes with their ulterior motives and their background plans”

[Fuel Cell Researcher]

Kleinsmann (2007) suggests that due to the fact that actors in a design team have different responsibilities, the interests of the different actors may be in conflict. Additionally, they may lack a shared understanding of which design factors are most important because of the different interests and their knowledge bases (Kleinsmann and Valkenburg, 2005). Consequently tradeoffs in parts of the design may have to be made which ultimately compromise the motivations and interests of particular group members. An example of this appeared early on in the project when designing the physical lay-out of the car; where each part was going to be located.

“there were two different parties that wanted to go in two different directions really. One side wanted to stay within the boundaries of what we have already got whereas the other partner wanted to do monumental changes which just weren’t … well I don’t know .. I still believe which weren’t within the brief of the project” [Automotive Designer]

Two partners had different ideas about the layout of the car which meant that ultimately the goals of one partner, which involved designing the layout of the car from scratch, had to be compromised **[F3]**.

It has been observed that the more closely the group worked together as a team the more tightly knitted individual goals and motivations became. It is thought that this was due to the development of an identity as a team rather than a group of individuals working alongside one another. Consequently, for successful identification with the overall purpose, aims and goals of the project, an alignment needs to be found between the individual motivations of the actors and the overarching motivations of the project. This does not suggest that the motivations of all actors should be generic but that individual motivations should complement and not deter from system level goals and overall project motivations **[F4]**. Referring back to Section 5.3.2 it has been observed that maintaining system level conversations within team meetings aids the development of common goals and motivations and additionally the development of a team identity. The following section goes on to explore the idea of identity further.

Key Findings and Implications from Theme 5

[F1] Partners were motivated by similar overarching aims and goals. This contributed to the successful development of a common purpose amongst actors;

[F2] Partners often held individual and personal aims and goals. These did not appear to detract from the joint aims and goals of the project and in fact lent themselves to a more deeply routed motivation to succeed. This meant that an alignment between shared and personal goals was achieved;

[F3] Due to conflicting goals, compromises within the design had to be agreed upon by partners. This meant that not all individual goals could be achieved. This, however, led to compromises being made between partners. This was essential for the successful development of a final solution.

[F4] An alignment between individual motivations and the overarching motivations of the project needs to be found. Doing this encourages a sense of identity between the project team.

5.3.6 Theme 6 - Identity

Most designers have a degree of autonomy in how they work, and how they interact with other designers; thus they can be viewed as autonomous agents in multi-agent systems (Johnson, 2005). That said, however, it is important for actors to integrate with each other, the first step of which is identifying with both the purpose of the project and the other people working on that project. Within the LIFECar project it took a substantial amount of time for the team members to form an identity and to develop from a group of people into a team **[F1]**.

"at the beginning, the first year or so, there were a lot of hiccups and some of the partners really hadn't bought in to the whole project and were not really spending much effort on it".

[Power Electronics Engineer]

Once the project group had formed into a team, however, it was possible to observe a degree of identity and solidarity between the actors. It appeared that the team was no longer a group of actors representing a number of different organisations but that they had become autonomous **[F2]**.

"Recently, I would say in the last 6 months or so, I think there has been substantial progress and things are really working well and people are talking to each other."

[PhD Student]

In some instances it was observed that, rather than behaving as a member of an organisation, the priorities and allegiance of team members had shifted slightly. Shalley *et al.*, (2004) suggests that this sense of identity is good and that team members and employees alike need to feel that they have some autonomy over either how their time is allocated or in the determination of how their work is to be done. The team's autonomy did however appear to create a strong division, at times, between the project team and the supporting companies. In the extract below, taken from a design meeting, the project manager is communicating his concern that one of the supporting companies are not providing Richard with enough support:

"I'll tell you the bit that bothers me about it, what I want to get off my chest. As I said in my email to Mic (a director within Partner A), I think we, those of us who work with him, have a good working relationship with Rich, he's a more than competent bloke but I am not sure that he is getting the support he needs and the fact that Alan (a team member from a substantially smaller company) has to offer to design the end plates for him; for an organisation the size of yours, that strikes me as … frankly it's a bit odd!" [Project Manager]

This extract supports the observation that the team did form an identity. Members of the team were willing to represent and speak on behalf of a team member in front of his own company **[F3]**. This also provides an example of how difficult the relationship between individual actor, the project team and the supporting companies continued to be throughout the project. There was often a lot of tension and push-and-pull, particularly between the project team and the individual companies, and often team members got caught up in the middle of this.

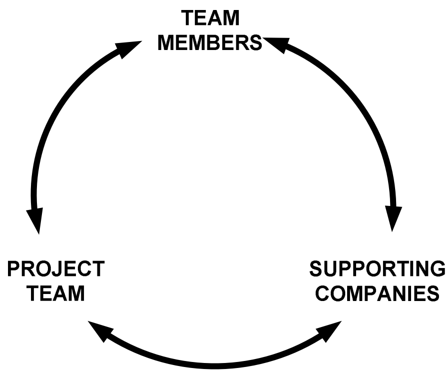


Figure 18: The relationship between team members, the project team and supporting companies

It has been observed that this relationship played a significant part within the project and can substantially affect the whole system design process overall.

The gained autonomy and identity of the team also appeared to further affect the behaviour of actors when confronted by new or occasional team members. On one specific occasion a senior member of one company attended part of a meeting to explain the late delivery of the fuel cell. There was instant animosity towards him and subsequently the group were reluctant to give away information about the progress of their own parts of the project despite being directly asked on several occasions as shown in Figure 19:

"My question is; where is everyone else against the delivery plan?"

"I am really keen to look at the overall project; where everyone else is, where this slots in, in terms of integration and testing and see if that makes any sense"

"So I'd really like to look at this point about how it ties in with everyone else's deliveries. I'd really like to get, on a board or a Gantt or whatever, exactly how that ties together, where everyone else is, and understand how much of this time is actually critical. Because six weeks difference could obviously make all the difference or on the other hand, depending upon where everyone else is, it might not be that relevant, I don't know"

Figure 19: Meeting extract demonstrating hostile behaviour

Although no-one was willing to provide an answer to these questions, upon the departure of the occasional team member actors freely discussed their own progress and openly admitted where they were expecting delays and falling behind schedule.

Developing shared goals and purpose is only the initial stage of becoming a fully integrated team. The following sections begin to address how a team is to make sense of the individual expectations and requirements possessed by each stakeholder so that ultimately a fully integrated and holistic solution can be reached.

Key Findings and Implications from Theme 6

[F1] There were a lot of problems during the first year of the project which de-motivated the group. This initially prevented the group from forming an identity and meant that becoming a 'team' as opposed to a group of people was difficult.

[F2] Actors began to identify with the project purpose and the other actors within the project. This substantially aided the integration of partners, facilitated successful collaboration and allowed the team to develop a sense of autonomy;

[F3] Forming an identity gave the project team a voice through which to communicate. This allowed the team to speak with supporting companies as an autonomous consortium;

5.3.7 Theme 7 - Sense Making

There are obvious potential advantages associated with bringing together experts from different domains as a means of transferring knowledge and skills between partners (Coley and Lemon, 2008). The integration of individual perspectives, ideas and knowledge is essential to developing a whole system perspective **[F1]**. However, the use of collaborative design teams such as these adds an additional dimension to the project which if not properly recognised and managed will be detrimental to the overall ability of the team to meet its objectives. Partners from different organisations bring different agendas, goals, points of view, and even different cultures to the consortium, making these types of collaborations far more complex and challenging, than if they were from the same organisation (Mankin *et al.*, 2004). Additionally, due to the fact that actors within the design team have different responsibilities, the interests of the different actors may be in conflict. The consortium may lack a shared understanding of which design factors are most important because of the different interests and their knowledge bases (Kleinsmann et al., 2007). These factors, alongside others, make the process of developing a combined design solution challenging. To facilitate the forward movement of multi-disciplinary design projects potential psychological, cultural, and geographical distances must be overcome (Mankin *et al.*, 2004).

Expectations, Requirements and Perspectives

Gaining an appreciation into the expectations, requirements and perspectives of the different actors is difficult. It has been observed that due to the Funding Call process undertaken by the LIFECar project, often stipulated by the funding body, there is insufficient time to fully explore each partner's requirements and expectations of the project **[F2]**. The highly competitive nature of the grant application process further compounds this deficiency in the project, since partners are often reluctant to commit resources to the application process. Ironically, it is at this stage however, that some of the key objectives and deliverables for the programme (against which the success of the project may be judged) may be defined. The net result of this process is that partners may have different (uncommunicated) needs and requirements for the project and importantly different expectations of the other partners **[F3]**. This is demonstrated in the following comment:

"we didn't actually know, well we thought we knew, but it actually turned out that we didn't know exactly what it was that we were going to be supplying and by then we were already signed up"

[Fuel Cell Researcher]

Furthermore, It is common for participants to come to the design situation with pre-existing patterns of work activities, specialised languages, and different expectations of perceptions of quality and success with different organisational priorities and constraints (Sonnenwald, 1996). It has been suggested that in order to manage the introduction to this new and uncertain environment a substantial amount of time is taken up with the clarification of ideas at the beginning of the project (Olson et al., 1992). It appears that to obtain a common understanding of the problem at hand, all team members need to explore the design context from their own perspective before merging this view with those of other members **[F4]**. This activity is necessary for members to identify differences between this context and their usual practice so that they can be addressed and integrated. As one actor explained:

"*you don't have to know everything, not by any stretch of the imagination. What you have got to do is that you've got to know what it is that you have got to learn"*

[Systems Integration Expert]

When the design context is not explored effectively preconceptions of individuals may cause project members to make design decisions that have a negative impact on other disciplines and on the solution as a whole.

Integrating Knowledge

Despite the need for individual exploration it is acknowledged that integration has been identified in many studies as an important ingredient in innovation and as such can be viewed as the synthesis of specialised knowledge into situation-specific systemic knowledge (Scarbrough et al., 2004). Consequently, individual requirements and expectations need to be aligned and it is suggested that team effectiveness will improve if team members have an adequate shared understanding of the team's objectives, processes, and situation (Dong, 2005). Developing a shared understanding unavoidably requires the sharing of both discipline and context specific knowledge. (Kleinsmann 2006) argues that this is commonly challenging as actors often have difficulties with sharing knowledge; this is because actors involved in a design process have their own knowledge, operating procedures and methods for executing their part of the design process.

This is even more apparent within a whole system design process as it is a novel approach and therefore new and uncertain for those involved. Below is an extract taken from an interview; the team member was describing the design process that he was familiar with, which is noticeably different from the whole system design approach:

"So you have stage gates, you meet those stage gates and you make a decision, irrespective if it's the right one or not you have to move forward"

[Software and Systems Designer]

A whole system design process is not as linear as a stage gate system; it is an organic and emergent process and therefore it is often not possible to identify or enforce rigid stage gates. It was observed that decisions could not be made until much later on in the process and so actors had to work around this, making temporary assumptions and allowing for uncertainty, as is being suggested in the extract below **[F5]**:

"What one needs to do is to recognise where some of the interfaces are between the different players. So for instance if there is a particular value such as the power of the fuel cell or the upper coupling of the motor, that people have to recognise what the impact of not knowing what that number is exactly or to know

what the bounds are. So for instance the fuel cell; that impacts quite a large number of range of components and different things"

[Power Electronics Engineer]

Additionally other partners were not familiar with working in such a collaborative and integrative design process:

"I've never really worked on a collaborative project before so it's all very new to me really"

[PhD Student]

"I think that we have put a lot more effort into collaboration than was originally expected!"

[Fuel Cell Researcher]

A recurrent observation of design meetings was the lack of knowledge sharing **[F6]**. This was not only in the form of verbal information between actors but also included the sharing of data, files, drawings and even the formalisation of design decisions. The following extract captures one team member asking for a decision to be made so that he can move his own part of the design forward:

"Can I say that I think you should set a date for deciding which one (capacitor) you are going to use… because we've got to re-design the tunnel because that's where we are going to put them all so we really need to get that modelled. And obviously not just the capacitors but what goes round them and how they are linked"

[Automotive Designer]

In particular it appeared that one actor was not willing to share drawings of his part of the design until they were complete and he was entirely happy with them. The actor appeared to distance himself from the group, possibly as he lived furthest away and therefore attending meetings was inconvenient as was identified in Section 5.3.1. This was observed to cause friction between the actor and the group and resulted in work being halted and even work being duplicated. Finally the actor left the team altogether.

Additionally, actors in a design team differ in both the ways in which they view the design and also in how they communicate about the design they are making (Kleinsmann, 2006). Furthermore the course of the process of integrating knowledge and creating shared understanding between the actors influences the quality of communication (Kleinsmann and Valkenburg, 2008). It is therefore argued that to enable the integration of ideas and understanding through effective communication between partners, a common language needs to be identified in order to effectively share knowledge.

Common Language

Johnson (2005) suggests that designers build the multi-level language necessary to represent what they are designing. In doing this they use many vernacular terms, often giving them specialised meanings in the particular context. Within a whole system design this appears to be a complex process as actors are required not only to identify terminology for the component parts of a problem but also to maintain a visualisation of the problem as a whole. Therefore Johnson (2005) argues that when analysing a system the designer has to abstract a vocabulary to represent the system between the uninformative highest level term, 'the system', and the intricate component parts.

Designers contemplate what might be called 'could-be systems', things that don't currently exist, but that could exist. Thus the designer is contemplating things that, if they did exist, would be sets of components assembled under appropriate relations to form a whole. However, the precise set of components is generally unknown in systems that are multiple assemblies of assemblies. Thus the best the designer can do is contemplate the abstract whole and hypothesise a set of unspecified component parts (Johnson, 2005).

This phenomenon was identified early on in the LIFECar design process. Team members developed a unique system-level terminology to describe the requirements of the design. The term ‘fun to drive’, for example, was identified immediately as a requirement of the car and subsequently became part of a formal vocabulary that was frequently utilised. It was not until many months later, however, that team members began to question what the term actually meant and attempts were made to identify the components of the solution that would actually make up the ‘fun to drive’ requirement.

Even when a common language is shared between a design team the meaning of the same words may still differ when used by actors from different disciplines (Kleinsmann *et al.*, 2007). In addition, actors in a design team may use different representations of the design, which may lead to further complications.

“I think particularly in design you can tell people something which means something to you but the interpretation of the person has to be biased by their experience so you think you have now told them the meaning of life in a particular situation; they’ve taken it away, they’ve interpreted it on the basis of their knowledge and in fact you haven’t got even close to that fact and that approach going forward. And when you go and talk to people later and you look at what they’re doing you say ‘no! This is not what we talked about!’.

[Design Engineer]

As identified in Chapter Two; effective boundary spanning is one method that can support the development of both a common language and a shared understanding of a whole system design. Actors were observed to initially utilise discipline-specific terminology which was difficult for other actors to comprehend **[F7]**. As team members became more familiar with sub-systems across the design so too did they become familiar with the terminology that was being used to describe that sub-system. Subsequently it became apparent that it was no longer the use of a common language that was important but the ability to understand the terminology that was being used to communicate different parts of the design **[F8]**. As one actor explained:

"you don't have to be a technical expert in every area but what I do think is important is that you've got to be able to explain, with clarity, your own area otherwise it makes everyone else's understanding of your area more difficult. You need to be able to talk clearly about the impact and why your area is so important". [Fuel Cell Project Manager]

This clarity of explanation led to a good understanding of unique terminology and language that was utilised throughout the project. This in turn led to the gradual development of a shared mental model and architecture.

Shared Mental Models

It was observed that often in the context of highly complex system design; the sharing of knowledge between disciplines is not adequate. Windahl and Lakemond (2006) suggest that the development of innovative solutions necessarily involves high interaction and blurred boundaries between the actors. This isn't to say that specialisation is dead, but even as a specialist, if you can't decipher the other design dialects you'll never achieve truly transcendent ideas (Kemp, 2008). This is at the heart of sense making activities as Weick (p. 108, 2005) explains; sense making is about contextual rationality, it is built out of vague questions, muddy answers and negotiated agreements that attempt to reduce confusion. It is suggested that as a way of coping with the complexity of their environment (Boos, 2007) and managing the uncertainty of the design, teams develop shared mental models. Shared or team mental models are characterised as knowledge or belief structures that are shared by members of a team, which enable them to form accurate explanations and expectations about the task, and to coordinate their actions and adapt their behaviours to the demands of the task and other team members (Badke-Schaub et al., 2007). Research has been carried out into many areas of design in order to understand, in different domains, the complex cognitive actions and behaviours of designers (Coley et al., 2007). However, the process of how mental models are developed and how they influence what the team members do and think is still poorly understood, especially for design teams (Badke-Schaub et al., 2007). Most research on team mental models has focused on operating complex technical systems rather than designing them.

Shared Architecture

Actors within a partnership have different interests and requirements and therefore each places emphasis upon different aspects of the system **[F9]**. Subsequently, even following the successful development of a shared mental model, each actor views the system from a different perspective. For complex tasks like designing a car or just a part of it, it is obvious that there is not one shared mental model of all the team members (Badke-Schaub et al., 2007). Thus, especially in heterogeneous, multidisciplinary teams in which distinct team roles require unique knowledge, mental models need to be distributed throughout the team (Cooke et al., 2000). It is apparent, therefore, that although a shared mental model of the system is necessary, each view of the model is needed to appear slightly different depending upon which partner is looking at it and from which perspective.

Due to the sharing and integration of knowledge and the spanning of disciplinary boundaries each team member should have the ability to view and understand the shared model from multiple perspectives **[F10]**. Furthermore, the representation of the movement of knowledge around the team should enable team members to easily identify who knows what. It has been identified however that too much overlapping in teams with distinct roles may be inefficient and create a redundancy of effort, and that too much distributed knowledge may undermine the ability of the team to work together as a coordinated whole (Badke-Schaub et al., 2007). This re-emphasises the need to establish a balance between discipline-specific expertise, and cross-disciplinary working. Commonly held mental models are thought to provide a set of organised knowledge of the task and the team from which predictions about team member behaviour can be drawn and relied on (Badke-Schaub et al., 2007). It is thought by the author, however, that within the context of a whole system design, in which the final design solution is unique and uncertain, a shared mental model provides more than this. The process of abstraction and integration not only provides team members with a shared model of knowledge but that it also enables actors to develop and visualise a mental representation of the end goal. Knowledge about the relationships and interfaces between different disciplines and subsequent sub-systems creates a joint architecture through which components can be developed in alignment with the whole system **[F11]**.

Key Findings and Implications from Theme 7

[F1] Actors from different organisations were accompanied by unique perspectives, ideas and knowledge. This is essential to develop a whole systems perspective ;

[F2] Due to the Funding Call process, stipulated by the funding body and discussed in Section 5.3.1, there was insufficient time to fully explore each partner's requirements and expectations of the project. This led to a confusion surrounding roles and responsibilities;

[F3] Partners from different organisations were accompanied by unique needs, expectations, ways of working and requirements. This makes the design process far more complex than if actors were from the same organisation. Additionally, collaboration and integration are difficult as these differences can be conflicting and therefore need to be addressed;

[F4] Actors spent a significant amount of time at the beginning of the project exploring the design context from their own perspective. This enabled them to effectively communicate and merge their ideas with other actors later on in the process;

[F5] The whole system design process is different from a traditional design process. Partners found whole system design uncertain as frequently they could not make decisions surrounding their own part of the design until other design decisions had been made in other parts of the system. Actors were observed to spend time identifying differences between the emergent and organic whole system design process and their usual, more structured, practice. This enabled these differences to be addressed and the new design process to be adopted;

[F6] Some partners were reluctant to share their designs until they were complete. This was trying for other actors as their own part of the design was delayed as a consequence;

[F7] Partners communicated initially using their own terminology. This was difficult as other partners were not able to fully comprehend what they were explaining;

[F8] Over time partners established a common language in which to communicate their ideas between the team. This was established due to an understanding of the terminology used within each of the sub-systems. Subsequently communication was much more efficient which substantially enabled progress;

[F9] Actors within the design team had different responsibilities and interests. The interests of the different actors may be in conflict, which may lead to the lack of a shared understanding as to which design factors are most important;

[F10] Disciplinary boundaries were blurred and actors gained a good understanding of other sub-systems. This allowed an overall shared understanding of the final design solution and the process required to get there, to be developed;

[F11] Knowledge about the relationships and interfaces between different disciplines and subsequent sub-systems creates a joint architecture through which components can be developed in alignment with the whole system.

5.3.8 Theme 8 - Managing Uncertainty

As introduced briefly within the previous section, the design process has been observed to be both unique and uncertain, due to the innovative and complex nature of designing a holistic and sustainable solution. There are initially a multitude of ideas, opinions and expectations but little certainty of what the final design solution is going to look like **[F1]**. At the beginning of the LIFECar project, for example, it was decided that the final design solution was to be a sustainable sports car but there was no suggestion of what the car was going to look like, how fast it would go or even what fuel it would use.

Two of the most challenging aspects of developing a holistic and sustainable solution appear to be: firstly, as previously highlighted, making sense of the complexity that is brought to the design process by the multiple actors; and secondly, learning to manage the level of uncertainty. For many actors the feeling of uncertainty is uncomfortable.

Figure 20 captures a discussion between two of the LIFECar team members and the researcher. One team member is explaining the notion of uncertainty to the other team member.

Researcher: The first meeting we ever had you came up to me and said that the biggest problem with whole system design was uncertainty. Has that proven to be a big problem all the way through?

Control and Power Electronic Engineer: Absolutely!

PhD Student: Uncertainty of what?

Control and Power Electronic Engineer: well, when you start off your design it's very uncertain as to what it's actually going to look like so you are going to make initial design decisions but you don't know what the requirements are

PhD Student: so you think the biggest problem of whole system design is uncertainty?

Control and Power Electronic Engineer: Yes, and you've got to be able to manage that. Now the problems that you have right at the beginning in the first year or so is that people would come up with tentative design weights etc. and then they'd be taken as gospel and there's no leeway given for saying well hold on that figure, there's no banding of what the minimum or maximum areas would be for those. And therefore you had no feel for what the overall mass of the car would be like for instance. At the last meeting we still had a thing where the fuel cell stack is probably going to be 20 kilos heavier than all of Toms' modelling figures. And there's no way that that level of uncertainty has been built in at all. And people haven't really recognised that and I think that has been an issue

Figure 20: Discussing Uncertainty

The control and power electronic engineer relates uncertainty to the formalisation of design decisions. It appears that the uncertainty of the design process and subsequently the final design solution makes it difficult to make design decisions early on in the design process. He suggests that even decisions that are made early on are extremely likely to change **[F2]**. It was observed that this management of uncertainty was not acknowledged by all members of the design team early on in the process. Subsequently many figures, calculations and ultimately parts of the design had to be changed resulting in additional costs, time and personnel **[F3]**. This could be avoided in future projects if all team members were made aware of the levels of uncertainty to expect. Additionally the use of mechanisms to address uncertainty such as the implementation of assumptions instead of decisions should be acknowledged.

Decision Making

The later in the design process that design decisions are formalised, the more impact they are going to have on the final design solution. This is because late decisions will unavoidably impact upon other parts of the design and the further the process has gone, the more components will have to be altered. This ultimately results in further costs to the design project as Downey (1969) noted; 80% of manufacturing costs are committed during the first 20% of the design process.

Throughout the LIFECar project the issue of decision-making was brought up and discussed frequently as shown in the following extracts:

"we still don't know what the CdA (co-efficient of drag multiplied by the cross-sectional area of the car) of the car is going to be, you know the Co-efficient of drag multiplied by the cross sectional area, we still don't know what that's going to be so that's going to impact things quite a long way you know that has impact on things like how hot the motors are going to be getting when they're running"

[Power Electronics Engineer]

"when making decisions members need to be aware of, and understand, the parameters and constraints in which that decision is to be made"

[Systems Designer]

One actor suggested a way that decisions could be made earlier on in the process whilst still allowing for alterations:

"The way that we would manage that is by saying ok, give us an upper limit and a lower limit and we will make sure that we can work to within those bounds."

[Power Electronic Engineer]

It is important that actors are aware of the implications of design decisions. This not only concerns how those decisions are going to affect other sub-systems, but also what impact those decisions are going to have if they are wrong or if they need to be substantially altered **[F4]**.

It is recommended that encouraging early assumption-making could help to provide actors with a sense of security and certainty however they need to be aware that these assumptions are ambiguous and allowances should be made for alterations further on in the design process. Treating decisions made early on in the process as assumptions could possibly provide the decision making process with a loose structure on which to hang firm data once decisions have been made.

Key Findings and Implications from Theme 8

[F1] Initially there were many ideas, opinions and expectations but little certainty surrounding what the final design solution was to look like. This feeling of uncertainty was very difficult for the actors to manage;

[F2] Decisions that are made early on are extremely likely to change. This made decision making difficult;

[F3] Actors did not initially recognise the uncertainty of decisions. Subsequently many figures, calculations and ultimately parts of the design had to be changed resulting in additional costs, time and personnel;

[F4] Every design decision made has an impact upon other sub-systems and the final design solution as a whole. This meant that decisions could have a negative impact if a good understanding of other sub-systems and the relationships that linked them was not present.

5.3.9 Theme 9 - Collaboration

As highlighted in Chapter Two, collaboration is a key element to any integrative design project. Collaboration within a whole system design entails the cross-fertilisation of multiple perspectives, disciplines, ideas, backgrounds, technologies and stakeholders to enable a more innovative, sustainable and optimised solution to be reached. Subsequently it has been observed within the current case study that effective and productive collaboration cannot be realised without many of the factors that have been discussed so far. Furthermore the concept of collaboration is accompanied by many other factors which will now be discussed.

Trust

It is argued that trust can lead to, and is a necessary condition for, co-operative behaviour among individuals, groups or organisations (Newell and Swan, 2000). Wilson agrees and suggests that lack of trust can adversely affect member's satisfaction with the team and their willingness to continue working with the team (2006). Newell and Swan (2000) suggest that there are three types of trust:

- Companion Trust – a slow-forming and resilient trust that is based on judgements of goodwill or personal friendship;
- Competence Trust – a swifter-forming but more fragile trust based on perceptions of others' competence to carry out the tasks at hand;
- Commitment Trust – stemming from contractual agreement; each party is expected to gain mutual benefit out of the relationship.

Throughout the LIFECar project it was possible to identify all three types of trust between different members of the team and at different times **[F1]**. Initially the team consisted of a few members who already knew each other as friends and therefore already shared a companion trust. It was clear to see that to begin with there were, in particular, three sets of strong friendships between four team members. As the project continued, two of these friendships, and consequent companion trust, remained and even got stronger, whereas the third friendship deteriorated and subsequently caused a rift in the project team. This eventually resulted in one team member taking a step back from the team and replacing himself with another actor from the company.

Some authors suggest that at the beginning of a project, due to the desire to commence proceedings, trust is often established swiftly and members are forced to 'wade in on trust' rather than wait while experience shows who can be trusted and with what (Newell and Swan, 2000; Luhmann and Vertrauen, 2000). During the initial stages of the LIFECar project this wasn't the case and in fact one company repeatedly put off signing a contract for nearly a year until they were completely happy with its purpose, contents, and additionally the intentions of the other partners. Consequently trust within the team was initially based on the contract and was therefore commitment trust. However, as LIFECar team members were frequently required to trust others with important tasks, in some cases commitment trust developed into competence trust. Frequent comments included, *"can you work this out?"* or *"that's your department"*. When questioned about it, one member in particular commented;

"Its simple; I trust Tom to do a better job than I could"

[Software and Systems Designer]

This occurrence appears to be particularly significant within a multi-disciplinary team as it is inevitable that members are going to have to trust each others' competence and ability to do a good job. Unlike typical collaborative design, however, whole system design involves substantial overlapping of expertise and understanding. It is important, therefore, that team members have faith in each others cross-disciplinary understanding and allow them to make design decisions that will ultimately affect their sub-system and the solution as a whole.

Due to this overlapping of boundaries the issue of roles and responsibilities has occurred several times throughout the project and has sometimes been the catalyst of much confusion and even conflict.

Roles and Responsibility

Within organisations people have designated positions which signify the roles they play and therefore how things are likely to be organised. A team role is described as a tendency to behave, contribute and interrelate with others in a particular way (Belbin, 2007). Partnerships, however, don't usually have such clear role definitions so the partners have to work out the best way to organise (www.ourpartnership.org.uk, 2007). As groups grow in size and complexity, individuals tend to specialise in some aspect of the interaction process. The expectations for behaviour in these specialties are represented by the roles of the group members (Hare, 1962). Hare (1962) suggests that the term 'role' refers to the set of expectations which group members share concerning the behaviour of a person who occupies a given position in the group.

With this in mind it appears that not only do expectations concern behaviour but also the responsibilities and tasks that team members are expected to fulfil. This is demonstrated in the extract below:

"I think Phil's been less involved than was intended, I think he has still been involved in designing suspension and things like that but I think he has been less involved with the design of the car and has been more involved with the mechanical parts of the motor than has been expected"

[PhD Student]

It was apparent that during the project, actors were observed to take on the responsibilities of others, subsequently causing confusion and conflict which, at times, has resulted in the repetition of tasks **[F2]**. In particular, the responsibilities of one partner extensively overlapped with another. Due to a breakdown in communication the identification of responsibility was not addressed and so the issue was not resolved. This caused friction not only amongst the two partners involved but was observed to impact upon the rest of the team. This is shown within the following extracts:

"They were the ones who wanted to take on the title of systems integration but so far they have chosen the tyres and the fuel tank. That is hardly systems integration"

[Systems Designer]

"Some members have to put in a lot more time and effort than others but don't get any recognition"

[University Professor]

"Tasks are ignored and no one takes responsibility until eventually someone is forced to. Usually that task is not that person's role or responsibility"

[Power Electronics Engineer]

"Alan was supposed to be in charge of identifying a compressor, this was noted many meetings and months ago, however, it now appears that there is pressure on Bill to find one quickly as time is running out! When did this hand over of responsibility take place?"

[Software and Systems Designer]

Additionally, due to the uncertainty of responsibility, actors also expressed concerns that certain parts would not be accounted for **[F3]**:

"I always worry that we're missing something; that the consortium is missing something. Obviously you can do the best you can but I always have this horrible feeling that there's going to be a gap between two bulk heads where a wire should be"

[Fuel Cell Project Manager]

At the beginning of the project one team member suggested; “In whole system design roles should not be defined, tasks should not be set out and additionally role spanning should be expected”. In a project with so much uncertainty, team members should be encouraged to explore different roles and responsibilities surrounding the design context. Roles and responsibilities have caused much confusion and conflict, however, and so it appears that, following necessary exploration, formalisation is necessary to avoid unnecessary friction. It has been observed however that role spanning within whole system design is to be expected and even encouraged.

Conflict

It is suggested that conflict exists whenever incompatible activities occur (Lam and Chin, 2005). When social entities work together to achieve their objectives, their relationships may become incompatible and conflict would invariably be induced (Lam and Chin, 2005). Multiple actors working within the same boundaries of a project could be seen as incompatible as they differ in aspects such as background, expertise, motivations, working cultures, and perspectives.

Conflict, however, is not always a bad thing and in fact, if managed properly, could encourage the development of more innovative solutions. Lu and Cai (2001) suggest that in the early design stage, conflicts are treated as a motivation to identify deficiencies among the design team and to generate creative ideas, while at the later stages conflicts should be prevented or resolved to achieve high efficiency (Lu and Cai, 2001). Certainly all partnerships will have tensions to navigate and how they are dealt with can make or break the partnership (Lu and Cai, 2001). Due to the uncertain nature of a whole system design process, conflict could be seen as a natural phenomenon in the integration of multiple actors for the design of more sustainable solutions.

Much of the conflict that arose between actors within the project concerned design issues. Due to the high level of expertise surrounding the separate sub-systems of the design, conflict was often avoided and, as previously discussed, team members were trusted to be making the right design decisions. The two companies and subsequent team members who had the most overlapping roles, however, consequently encountered the largest amount of conflict. It appeared that the cause of this conflict resided in the enthusiasm and ambition of the actors regarding the design of the car and additionally the aspiration to make their own mark on it. Additionally, differences in ways of working, previous experience and expertise also added to conflict surrounding the design of the solution:

"I've got to admit I found some of their ideas of where things would perhaps go slightly odd, slightly strange in that they wanted to put all of these capacitors in the rear, and the fuel tank in the middle, and the fuel cells at the front, which was very odd to me because they were putting all of the weight at the rear and all of the weight at the front and I mean to me from an automotive side that's very odd because these capacitors are the heaviest thing and if they're in the centre of the car they're not going to really make the car, you know it's going to be very much in the centre of the car. Whereas putting them all at the back of the car just struck me as a very odd place to put them and I don't actually know even now what was behind that, it's never been explained to me why that was, it was very unconventional"

[Automotive Designer]

It appeared that conflict over design decisions was unavoidable and in fact was particularly healthy. Push and pull between one company who wanted to drive innovative boundaries and a company who wanted to stay with a more traditional design meant that the final design was a compromise of two very passionate perspectives **[F4]**. The importance of compromise was highlighted by one team member:

"I think they probably got to the point where they thought well if we don't compromise it won't happen. I think that was the real thing. But I mean its fine; from then on it's been fine"

[Automotive Designer]

Occasionally in meetings the absence of conflict was noticed and the smooth running and early finish of meetings was observed. This appeared to coincide with the absence of certain actors. It has been observed however that team members with conflicting or opposing views and opinions are invaluable and are an essential aspect of any whole system design process. As argued by Lu and Cai (2000); often it is not conflict but the absence of conflict that causes problems.

Key Findings and Implications from Theme 9

[F1] Companion, Competence and Commitment trust were observed between actors within the project. Types of trust changed as the project progressed. Trust between actors encourages confidence in collaborative working.

[F2] Occasionally team members were observed to take on the responsibilities of others. This caused confusion and conflict which, at times, resulted in the repetition of tasks;

[F3] Roles and responsibilities between the team overlapped. Consequently responsibility for certain components was not identified. This caused problems later on in the project;

[F4] The team encountered conflict between traditional and innovative design ideas. The conflict was resolved effectively which lead to the final design being a unique compromise of two very passionate perspectives.

5.3.10 Theme 10 - Ownership

Ownership can be separated into two parts: the physical ownership of belongings, work, ideas etc. and the psychological ownership which refers to the feeling of wanting to make a difference. It is suggested that the latter goes beyond duty and commitment in that members of the team begin to tie their identity to a project's outcome, thus injecting extra effort to ensure its success (McDonough, 2000). This certainly appears to be true in the case of the current research and additionally coincides with other themes that have already been referred to, such as identity, autonomy and individual motivation. A sense of ownership can be observed in the following interview extract:

"you've always had a responsibility to say what you think you can achieve and then when you don't you've got to explain why you haven't and why you couldn't achieve that … I think that's what's expected from you"

[PhD Student]

The LIFECar project is a joint venture and, as part of the whole system design process, it was decided that there was to be no 'lead' partner and therefore no individual company that has physical ownership of the project or any resulting solution **[F1]**. This approach is supported by Don Hall, director of brand marketing for the Xbox 360:

"We made a deliberate decision to avoid drawing hard 'ownership' boundaries across key functions. Team members got into each other's sandbox on a regular basis...but we did it constructively. This set the collaborative tone of the program and sent a clear signal to our external partners who responded in kind. While at times the process was messy, ultimately the overlap was not only healthy, but also critical to elevating the end result. Everybody was learning and pushing each other and having fun doing it"

(Hall, 2008)

During the initial stages of the project it was observed that actors were reluctant to take physical ownership of the project **[F2]**. This could have been because the aims of the project were very ambitious and ambiguous and partners were not willing to 'tie' themselves to a venture that could fail.

Issues arising from physical ownership, however, have been observed from the very beginning of the LIFECar project. Many discussions regarding Intellectual Property (IP) were held before one company agreed to sign the initial contract as is explained below **[F3]**:

"One of the key things for us on this as I am sure for everybody is IP … it took an awful long time to get those IP things resolved and it meant we were late signing up and late starting. Quite openly there would have been no point in us signing up to the programme if we couldn't bring in some IP because we would have been developing a product that had no clear rights to exploitation."

[Fuel Cell Researcher]

Within one of the very first meetings a discussion was held regarding who would be 'lead partner' in the eyes of the media and press. It was decided that the managing director of Partner B would become MD of the project. This was discussed further in an interview with two team members and ownership was highlighted as being a significant aspect of the whole system design process. One team member suggested that ownership, particularly in the current context, was closely related to finance, reputation and power.

After the initial stages of the project, the issue of ownership became dormant. It was noticeable, however, that once physical components of the final design solution began to materialise the issue of ownership once again came to light **[F4]**. The figure below is an extract taken from a design meeting of a discussion regarding the display of the car at a prestigious conference. The team members are discussing what should be included in the display.

Systems Designer: *so who will actually design it?*

Project Manager: *we need a volunteer don't we for that*

Systems Designer: *because I mean its one thing to sort of accumulate a couple of pictures and think of a few paragraphs and sort it all out but…*

Project Manager: *it's a question of... it's a design issue isn't it. I assume we would have to have a handout of sorts*

Automotive Designer: *we've done that sort of thing*

PhD Student: *they've got all the pictures of the car*

Project Manager: *ahhhhhh, do you think we could do that in a way that didn't make it dominated by Partner B?*

Power Electronics Engineer: *I think it should be dominated by Partner B actually, personally. Because it is Partner B's car that we are contributing to, that's the leading brand, that's what you are all contributing to and we are like the sub-partners within that and I wouldn't mind if it was mainly Partner B but then all the other partners are on that but not, you know … so people will come up and see a Partner B car, they'll have a look at it and then say oh, I see they are working with Partner F, Partner E, Partner A, Partner C ..*

Systems Integration Expert: *is this all going to be divided up as one of these 5 panels each?*

Fuel Cell Researcher: *no, I don't think it needs to be*

Systems Integration Expert: *oh well I don't want it to be dominated by Partner B full stop…*

Figure 21: Discussing Ownership

Psychological ownership is commonly sought within collaborative projects and is thought to be closely linked to increased productivity, motivation and commitment (Pierce and Rodgers, 2004, O'Driscoll et al., 2006, Vandewalle *et al.*, 1995). Within the LIFECar project there were signs that psychological ownership had been developed by several members of the team. It appears to develop alongside identity and autonomy; consequently it appears that there is a strong connection between these themes.

Physical ownership appears to be a significant attribute within the process of whole system design and incorporates issues such as finance, reputation and status or hierarchy. Although one of the aims of this approach to design is to share ownership between multiple partners it is thought that it is difficult to avoid some form of resulting conflict or tension. As the following comments imply, the ongoing ownership of the final design solution is uncertain:

"in like 7 years time if the car's in possession of somebody and something happens safety wise do they resurrect the old consortium in the court or do they take whoever had it in their garage at the time to court?"

[Fuel Cell Researcher]

"I mean if they need a software upgrade next August who will do that? Its all very unclear. Its all very typical to these projects I think, post project is always very unclear"

[Fuel Cell Project Manager]

Key Findings and Implications from Theme 10

[F1] It was decided early on that there was no lead partner and consequently no hard ownership boundaries. This enabled partners to develop a sense of psychological ownership as they all were equally a part of the project;

[F2] Initially partners were reluctant to take ownership for the project. This was because the project was very ambitious and ambiguous and partners were not willing to 'jump in' when it could potentially all go wrong. This led to un-motivated team members and a lack of progress;

[F3] The initial contract was significantly delayed due to discussions regarding IP. Ownership issues need to be addressed during the planning phases of a whole system design;

[F4] Once physical components of the final design solution began to materialise, the issue of ownership once again came to light. Although one of the aims of a whole system approach to design is to share ownership between multiple partners, it is difficult to avoid some form of resulting conflict or tension.

5.4 Summary

Chapter Five has presented, explored and analysed findings of the current research, developed through close observation of, and discussions with, the members of the LIFECar project team. The findings have been presented as themes that could be common to the process of whole system design.

It has been identified, that to enable a whole system design process to take place, numerous actors with a multitude of expertise, experience, and perspectives are required. Finding the right mix of skills however is not adequate and consequently additional characteristics, such as enthusiasm and the willingness to cross and learn from, disciplinary boundaries are crucial.

Making sense of the complexity involved appears to be a difficult and long, but essential, stage of the whole system design process. Actors must integrate to jointly establish a project purpose as well as the design context, content and process to effectively develop a shared architecture of the foreseeable solution.

One of the most frequently reoccurring issues within the case study appeared to be the relationship between the supporting companies, the project team and the individual project members. This complex relationship draws on many of the identified attributes such as communication, trust, decision-making, identity and ownership. These relationships are pivotal to the facilitation of whole system design and it is thought that a successful project outcome is largely dependent upon this.

The following chapters of the thesis go on to probe more deeply into some of the key themes that have been presented. Further interviews and observations shall be carried out with the LIFECar project alongside interviews with participants with experience of whole system design in other contexts. This is firstly to verify the existence and accuracy of the current findings, and secondly to explore the consistency of themes across design contexts.

6	CHAPTER AIMS	ACTIVITIES	OUTCOMES
	MODIFICATION AND VALIDATION		
	To demonstrate how new data was used to elaborate and validate the initial findings	Focus groups and interviews held with 11 experts from various design contexts. Analysis of data and modification and validation of final framework	- Second Phase Research Findings - 8 Modified Themes

Modification and Validation

This chapter presents the second stage of research and data analysis based on interviews with experts from a variety of design contexts. Initial themes highlighted in the previous chapter have been modified and validated to present a more comprehensive understanding of the whole system design process.

6.1 Introduction and Purpose

Chapter Five provided evidence of how the LIFECar project, the focal case study within the research, has been utilised to identify key themes that enable and inhibit the process of whole system design. Those themes were discussed and analysed through the use of relevant data.

This chapter investigates the themes further by analysing them in different design contexts. Further data collection is carried out through the use of interviews with individually selected participants and subsequently the themes are modified where necessary. Additionally, this chapter provides valuable perspective to the validation of the final themes and the enabling and inhibiting aspects of the whole system design process.

6.2 Consulting Multiple Contexts, Disciplines and Industrial Sectors

To ensure that the findings of the research are as comprehensive and useful to as wide an audience as possible it is important to gain the opinions of professionals from a variety of design contexts, disciplines and sectors. It is crucial at this stage in the research, however, that the participants chosen have substantial experience and expertise in undertaking a whole system design, so as to be as objective as possible.

Data from the U.S. Energy Information Administration illustrates that buildings are responsible for almost half (48%) of all greenhouse gas emissions annually (Prowler, 2008). Additionally, buildings are complex systems not only providing shelter but also incorporating a sense of culture, place, safety, and productivity among many other things. It is understandable, then, that the construction industry is moving towards a more integrated, holistic and whole system approach to the design of buildings, communities and cities. Prowler (2008) suggests that adopting an integrated design approach asks all the members of the building stakeholder community, and the technical planning, design, and construction team to look at the project objectives, and building materials, systems, and assemblies from many different perspectives. He acknowledges that this approach is a deviation from the typical planning and design process of relying on the expertise of specialists who work in their respective specialties somewhat isolated from each other.

Examples of organisations fostering a whole system approach to design are becoming increasingly common within the construction industry (Living Villages, 2008, Bedzed, 2008, Whole Building Design Guide, 2008). Consequently this is one of the industrial sectors that the current research will focus on within this stage of data collection and analysis. Other industrial sectors that have been recognised as utilising a whole system approach to design have been waste, business strategy, social policy, industrial design and health care, and so participants from these areas have been sought and considered for use within this stage of the research.

6.2.1 Methodological considerations

For the second phase of the research it has been decided that semi-structured interviews will be carried out with individually selected participants. Analysing data collected from a variety of design contexts is crucial to the study to provide validation and rigour to the findings, conclusions and contributions to knowledge. Participants have therefore been selected to represent a variety of design contexts to provide varying perspectives to the research.

The aim of carrying out the interviews within the second phase of the research was twofold:

1) to gain individual experiences of undertaking a whole system design from a variety of perspectives,
2) to gain critical feedback concerning the research that has been carried out from professionals from a variety of design disciplines.

The first aim was carried out by asking the participants to describe their experience of working on a project that had adopted a whole system design approach. During the description the participants were prompted with open-ended questions to encourage them to add more detail about the case they had chosen to describe. It was important that they were uninformed of any of the aims or results of the current research to avoid participant bias. Asking open ended questions encouraged participants to speak freely about their own experiences and allowed the author to identify any similar or additional themes to those identified within the first phase of the research.

The second part of the interview was structured around the themes that resulted from the first phase of the study. Participants were asked questions directly related to the findings of the research but asked to provide answers based upon their own experience. This encouraged participants to comment critically upon the key findings of the research and provide valuable validation to the identified themes and the research as a whole.

The interview questions asked of the participants can be seen in full in the appendices.

6.2.2 Selection criteria for interview participants

As highlighted in Chapter Two; the concept of whole system design is relatively new and consequently under-researched. Additionally, due to the large amount of terminology that is being utilised within industry to refer to a holistic approach to design, the term whole system design is not widely recognised. This made selecting participants with relevant experience and expertise in undertaking a whole system approach to design difficult. Therefore a set of criteria was developed to aid the selection process and to ensure that those participants who were selected had experience of participating in projects that were regarded by the current research to have adopted a whole system design approach.

The criteria are based on the literature review and findings from the case study. Interview participants were chosen who:

- had engaged in a partnership between two or more organisations in which there was democratic stakeholder governance;
- had been involved in the utilisation of multiple perspectives to develop a more holistic and sustainable solution;
- had participated in the identification of relationships between components of a system to develop a solution that will ultimately optimise the whole system;
- appreciated the benefit of thinking in a systemic or joined-up way.

6.2.3 Gaining access to participants

Gaining access to interview participants was challenging to the researcher particularly as, during the first phase of the research, contact with the case study was unlimited. However, through the use of a professional network which had been developed through attendance and presentation at conferences, seminars and workshops it was possible to contact 30 participants who met the developed criteria. Although it was not possible to reach some desirable participants, even after making numerous attempts, the researcher managed to secure interviews with 11 out of the 30 selected. All 11 of the participants met the predetermined criteria.

6.2.4 The interview participants

Interviews were carried out with 11 participants from five different organisations. The following section provides details of the participants and the whole system design case that they described; these are referred to as cases.

Case One was unique as it was set up to mutually benefit both the researcher and those involved. The four participants were involved in a project concerning the regeneration of East and South East Leeds (EASEL). They requested that the interview was recorded in a discussion format which could be utilised by East Leeds FM as a podcast. The same questions (as presented in Appendices 2) were used, but they were written down for each of the participants to refer to throughout the discussion. The participants consisted of two architects interested in integrated design and community development, an academic interested in community engagement and the managing director of an organisation which utilises partnerships developed with schools, residents' associations, youth workers, campaigning organisations and health workers to create holistic and creative solutions for a better quality of life.

Case Two was conducted with three participants from an international company which specialises in the design, production and distribution of furniture. The company produces just two ranges of high-quality, long-lasting shelving and seating solutions. The business strategy adopted by the company echoes many of the principles of whole system design and therefore was chosen to provide details of how a whole system approach to design could be implemented within an organisational context. The interview participants consisted of the managing director of the company, the head of sustainability and a design engineer.

Case Three was conducted with an architect from a consultancy specialising in architecture, urban design and master planning. The company is currently involved in the master planning of Stratford City, the city which has been named as the 'Athletes' Village' for the 2012 Olympic and Paralympic Games. This is the case that was referred to by the participant throughout the interview.

Case Four was conducted with two participants from an international firm of environmental consulting engineers. The consultancy aims to facilitate the ongoing development of the built environment in a way that is compatible with comfort, cost efficiency and low carbon emissions. The consultants referred to several cases of urban development and re-generation which had adopted a whole system approach to design. The interview participants were one of the managing directors of the firm and an engineering consultant.

Case Five was conducted with the managing director of a company that specialises in reducing the environmental impact of personal mobility. The organisation is involved in a number of automotive projects and the strategy behind the development of the organisation has also adopted a whole system design approach. It must be noted that although the Managing Director of the company in Case Five was also a member of the LIFECar project, he was interviewed in an independent capacity.

This information is represented in Table 14.

PARTICIPANT	JOB TITLE	DOMAIN	CASE STUDY
C1P1	Managing Director	Community Development	EASEL
C1P2	Architect	Community Development	EASEL
C1P3	Academic	Community Engagement	EASEL
C1P4	Architect within a Sustainable Multidisciplinary Design Practice	Multi-disciplined, integrated design	EASEL
C2P1	Managing Director	Product Design	Business Strategy
C2P2	Head of Sustainability	Product Design	Business Strategy
C2P3	Design Engineer	Product Design	Business Strategy
C3P1	Senior Architect	Sustainable Master Planning	Stratford City
C4P1	Managing Director	Built Environment	Numerous
C4P2	Environmental Consultant	Built Environment	Numerous
C5P1	Managing Director	Sustainable Business and Transport	LIFECar Hyrban Business Strategy

Table 14: Interview Participants

6.3 Data Analysis and Presentation Format

The interviews undertaken lasted from between an hour to 2 hours 40 minutes. Each interview was audio-recorded and the researcher transcribed each in full.

The data was analysed in two ways: first of all, responses to the open-ended interview questions were analysed again using thematic analysis. The researcher searched for patterns, examples and quotes which confirmed and added to the themes that had already been identified within the first phase of the research.

The researcher also searched the data for patterns, examples and quotes which highlighted new themes additional to those that had already been identified.

The second sets of questions asked of the participants were directly related to the initial 10 themes. Reponses to these questions were analysed to provide confirmation or rejection of the themes and additionally to provide examples across design contexts which were used to modify them.

As a result of the analysis the original 10 themes were modified to better represent the data that had been collected from the study as a whole. Figure 22 details the modifications that were made to the original themes.

The themes within this chapter are presented in the following format:

- Theme Heading;
- Reasoning behind any modifications made to the theme heading ;
- Presentation and analysis of data;
- Evidence of confirmation of original findings;
- Evidence of new findings or modification to existing findings.

Confirmation of existing findings **[F]**, evidence of new findings **[NF]**, and modifications to existing findings **[MF]** are highlighted within the text and are then collated at the end of each theme.

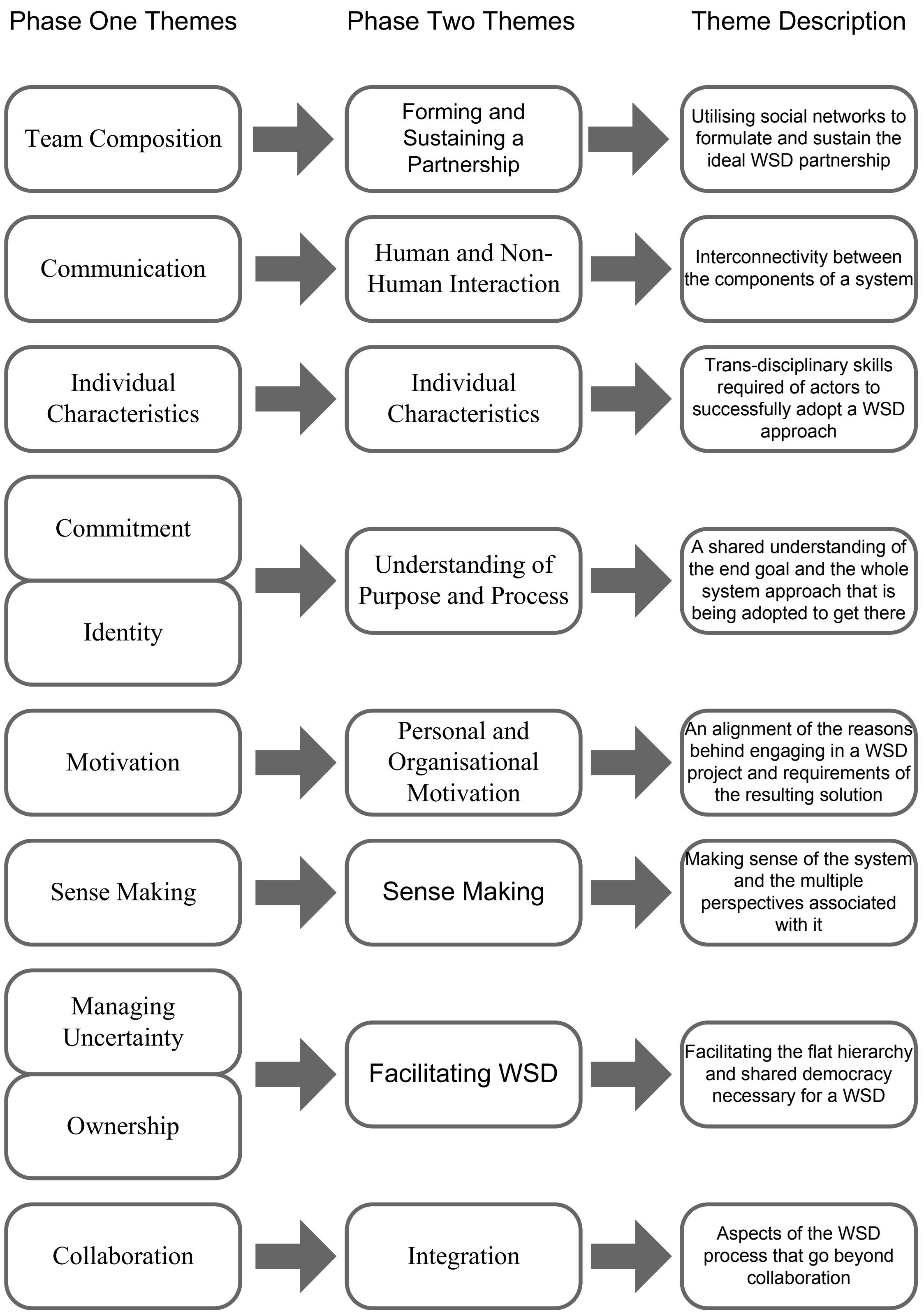


Figure 22: Thematic Diagram

6.4 Findings from the Second Phase of Research

This section presents the findings from the second phase of the research. The people who took part in the interviews are referred to as participants and quotes taken directly from the interviews have been labelled with the case number and the number of the participant who said it, as presented in Table 14 e.g. C4P1 refers to the managing director from case 4.

6.4.1 Forming and Sustaining a Partnership

It has been recognised that the use of partnerships enables the process of whole system design better than the use of sub-contracting or internal collaboration within an individual organisation. One of the primary benefits is the realisation and development of mutually-beneficial relationships between disciplines and components of a system that otherwise may not have been discovered. An example of this is provided by the Living Villages who specialise in forming partnerships with land-owners and other developers to help them to realise a more sustainable and better-designed vision for their land (Living Villages, 2008). For example, a partnership between the Living Village's developers and local farmers is beneficial to three groups of people:

- the farmer is now a service provider and regularly sells and delivers his produce to a ready-made market,
- this service is a novel, sustainable and appealing service to home buyers,
- the developers are able to charge a premium rate for homes with this ready-made, attractive life style.

Another key benefit to the development of partnerships, as demonstrated within the initial phase of the research, is that multiple actors are accompanied by various perspectives through which to observe a design context; this subsequently provides a more holistic and whole system view. This finding was backed up substantially by literature within the field of sustainable and innovative design as highlighted within the literature review. During the second phase of the research it was confirmed by all interview participants that multiple perspectives are required to facilitate whole system design **[CF1]**. Although one actor did suggest that whole system design could be carried out by one person; after an in-depth discussion it was realised, that to facilitate 'good' or 'successful' whole system design, ideally multiple actors would be involved in the design process.

"In one extreme, whole system design can be done by one person but it doesn't manifest the great virtues… it doesn't take advantage of the potentials of whole system design" [C5P1]

Data suggested that projects were often surrounded by strong social networks developed through colleagues, friends and family **[CF2]** and consisting of strong and weak ties **[CF3]**. However, forming the ideal partnership is not straight forward and the data has shown that often the formulation of a project team is founded on convenience as opposed to expertise **[CF4]**. This was confirmed as often companies rely on the same organisations from project to project:

"In my experience in what I do, the design team are known to each other, it is not always the same people but it is often the same companies in a project" [C3P1]

Utilising existing relationships saves time and effort and additionally, due to working on previous projects, trust and confidence has already been established **[MF1]**;

"you trust them to have the level of expertise that they have, I think that's the key thing when you go to somebody like Company Z, you are buying quality from the outset, there's very little risk that you are not going to get what you expect" [C3P1]

Accessing and forming partnerships with new organisations is difficult and time-consuming and projects often have little choice of who to work with, particularly when accessing grants through the funding process. In cases such as this it appears that the reputation of a company can be placed above suitability:

"we didn't have many choices, there were no other options of Fuel Cell companies in the UK whose commitment to the project would have counted on that balance sheet" [C5P1]

For these reasons, among others, whole system design teams often consist of actors and organisations which are not entirely suitable to the design context; they are unable to provide the required expertise or else they aren't compatible with the rest of the project consortium. This can result in inefficiency and slow progress whilst the partnership adjusts and learns to make the most of the expertise that is available **[MF2]**. One company within the second phase of the research acknowledged this pitfall and had developed a rigorous recruitment scheme to ensure that the 'right mix' was obtained:

"our recruitment policy is absolutely based on taking the time; we speak to people on the phone, they then come for an interview, they then have a trial day, we then have a trial period, we then might have an extended trial period, and even at the end of that we still might kick them out. So it might be six months from beginning to end and even as a small business with limited resources we still might sit here and say 'this is not the right person' and we kick them out. So we have taken the time." [C2P1]

This appears to be an effective way of ensuring that a team consists only of people with the ideal characteristics and generic skills to successfully participate in a holistic design **[NF1]**. Additionally, further data collected from the company suggests that this policy has resulted in an extremely cohesive team which has in turn led to good productivity and overall success. However, it is questionable whether the process employed by this company would be feasible to a one off project team. Due to time and cost constraints it may not be possible to induct every team member so thoroughly **[NF2]**. However, there are many lessons to be learnt from this recruitment scheme when selecting candidates to undertake a whole system design; it is sensible to put effort into identifying the ideal organisations and actors as opposed to relying upon existing relationships alone.

Once a partnership has been formed it is still necessary to put effort into maintaining the partnership. Chapter 5 highlighted that team consistency is important to sustain effective knowledge transfer and also to develop and maintain a shared understanding of purpose. The second phase of research has shown that maintaining the original project team is even more difficult than originally thought:

"I've been to a meeting, one of my senior directors has been to a meeting, we all go whenever one of us is free and I think that is just natural, you can't guarantee that the core people will be there" [C3P1]

New perspectives do provide fresh ideas and new questions, however there is a substantial risk that understanding, knowledge and expertise will be lost if a certain level of consistency is not maintained among actors **[CF5]**. When undertaking a whole system design this principle needs to be recognised and efforts to maintain the design team need to be implemented. Additionally it appears that within the construction industry it is still common to only bring in certain members of the design team when they are required;

"the problem with these multiple perspectives; they're all held in different companies and all held under different contractual arrangements and imputed at different times throughout the process." [C4P2]

"every body's trying to pay every body as little as possible then they want them to be involved for as little as possible; you are involved for the shortest period of time possible because you are an expensive person to employ" [C4P1]

However from the data collected there is evidence to suggest that organisations are beginning to acknowledge the advantages of maintaining a core design team throughout the lifecycle of the project **[MF3]**.

Due to the size of some of the cases discussed within the second phase of research a much larger team of actors was required than was observed in the LIFECar project. It is understandable that the more actors there are in a project team then the more complex the design process is going to be.

"It's a paradox, you need numerous stakeholders but the more there are the harder it is to get the system to work in our dysfunctional culture." [C5P1]

Within a large project, such as the design of a city, there are often multiple design teams consisting of hundreds of actors working on individual parts of the system. Maintaining a core design team who are dedicated to adopting a whole system approach is not straightforward and choosing to undertake a whole system design, as opposed to a more traditional disintegrated approach, is not an easy option.

"the more stakeholders involved the more easy it is to persuade oneself that we'll go for a modular disintegrated design because it's too complex." [C4P2]

However, having decided to go down the whole system design route there are numerous advantages of having a large number of actors involved in the design process.

"The numerous stakeholders; the more numerous they are the more difficult it is to get the communication but as I say the bigger the network, which if you can design the network right and get the right level of communication, which may depend on having the right people, the bigger the network the more robust it is." [C5P1]

It appears that a network becomes more robust as the number of actors increases **[NF3]**. This is because the more actors there are the more likely it is that gaps in the system will be identified and the more relationships between parts of the system will be formed. However, this is only true if there is a high level of interaction between the actors in the design team and additionally between the individual component parts within the system. This is discussed in detail in the following section.

Confirmation of existing findings:

[CF1] Multiple perspectives are required to facilitate 'good' whole system design,

[CF2] A wide-spanning social network is necessary to formulate and maintain a whole system design partnership,

[CF3] A network consisting of strong and weak ties provides access to essential skills and expertise,

[CF4] Utilising existing networks for convenience may restrict the availability of skills and expertise,

[CF5] Consistent attendance at meetings by all actors is ideal for the successful integration of a whole system design team, however, this is frequently difficult to achieve.

Modification to existing findings:

[MF1] Existing relationships are also utilised to form partnerships as trust, confidence and reputation have already been established,

[MF2] Forming a partnership due to familiarity and convenience often delays progress further into the project as actors spend time adjusting to an unsatisfactory consortium and learning to make the most of the expertise that is available,

[MF3] A core design team is required throughout the life cycle of a whole system design project to ensure that shared understanding of purpose and process is maintained.

New Findings:

[NF1] Developing a rigorous recruitment process is an effective way of ensuring that a partnership consists of actors with ideal characteristics and skills,

[NF2] Due to time and cost constraints associated with a one-off project it may not be possible to adhere to a rigorous recruitment process. However, actor selection still remains an integral part of forming and maintaining a whole system design partnership,

[NF3] The higher the number of actors there are in a network then the more robust the network becomes.

6.4.2 Human and Non-Human Interaction

Communication between actors in a whole system design team is essential for the transfer of knowledge, the development of a shared purpose and understanding, and to ensure the integration of the final design solution **[CF1]**. Interviews also emphasised the need for high levels of communication to prevent components from being unaccounted for **[CF2]**. Chapter Five highlighted some of the consequences of poor communication and made the point that actors are often unaware of the high levels of communication required of a whole system design team. The second phase of the research confirms these findings **[CF3]** but also suggests that one of the reasons for a lack of communication may be that experts are reluctant to source advice or help from other disciplines **[NF1]**:

"Unless he as an architect perceives that his design can benefit from talking with the engineers, there's nothing in the contractual arrangements that existed. So unfortunately industry is set up to avoid any of this (interaction)" [C4P2]

"As architects, we don't like to admit it, but we do get a lot of advice from mechanical engineers and service engineers who are part of the team. It's not just about the architecture; they bring a lot of expertise on how we can achieve these things" [C3P1]

Communication across disciplines in this context is seen as a weakness; however this mindset needs to be overcome to enable successful whole system design, as one architect commented:

"It's not just about an architect designing pretty things. Building long tunnels into the ground requires a technical design team and, like you were talking about in the approach to a car; everyone's got to come together to produce a sustainable building or you get a building that's just badly done" [C3P1]

Whilst confirming the findings of Chapter Five the second phase of research also draws attention to the communication that is necessary not only between the human actors but also non-human aspects of the process. Consequently it was thought that the theme 'Human and Non-Human Interaction' better represented the overall communication necessary within a whole system design process.

Data suggests that the level of interaction present within a whole system design process generates resilience **[NF2]**. This is not only true for interactions between human actors but also high levels of communication between sub-systems are necessary to decrease the likelihood of components being missed out **[MF1]**. Additionally, interaction is necessary to ensure that sub-systems work together and to assist the identification of advantageous relationships **[NF3]**. The following interview extract provides an example of how high levels of interaction within the whole system design of Stratford City resulted in the waste of one part of the system being utilised advantageously in another part:

"The amount of earth that we have taken from that section of railway means that the entire site in some places has been raised 6 metres off the ground and in doing that it has taken it off the flood plain so it is now one of the few places in London that if the Thames Barrier goes at any point in time then it won't be flooded." [C3P1]

In this case, if the sub-systems hadn't interacted then the soil from the railway line may have been disposed of elsewhere and therefore a mutually advantageous relationship would have been overlooked. It has been suggested that whole system design can produce more than advantageous relationships as one interview participant pointed out:

"I would be a bit stronger about some of the benefits actually in that 'looking for mutually advantageous interactions' or synergies, its more than that, it's opportunities to eliminate components and that's not interactions; that's elimination! Simplification, but it's not simplification as in crude simplicity, its simplification as in sophisticated simplicity" [C5P1]

This concept of elimination was reoccurring within the second set of data **[NF4]**. As an example of this two separate participants highlighted the potential extinction of radiators and eventually central heating in our homes altogether:

"The whole point of having radiators in front of the window is to stop the down draft but as building regulations force us to put in higher and higher efficiency windows that's going to become obsolete" [C4P2]

This optimisation of the house is a significant step forward in innovation and sustainability; however, as several participants commented, it is useless if it is not communicated successfully to those consumers who are going to buy the house:

"as an engineer we don't currently have any communication through to the general public to say 'you no longer need radiators next to the window' therefore people walk into rooms without radiators and think it is going to be cold"[C4P2]

"People won't buy houses without radiators" [C3P1]

Subsequently this highlights the fact that if the system which is being designed doesn't interact efficiently with its surrounding environment then the design will have failed **[MF2]**. Social norms and perceptions mean that consumers are not going to buy a house without radiators if they haven't been informed that advances in window technology mean that the house will be warm enough without additional heating. This is also the case in larger scale system designs such as the design of a city;

"Master planning is not just about developing a community. Its about blurring boundaries all the way around it; it's like a prosthetic it has to work with the rest of it otherwise it would be like a prosthetic arm trying to work on someone else's body" [C3P1]

It appears, in some design contexts, however, that although the system as a whole may be designed to interact with its environment the internal sub-systems are not given enough freedom to interact with the overarching system. This is demonstrated in the following quote in which a master planner is talking about how much freedom the architects are given:

"They'll have a set of guidelines written by us for the overall master plan. They can change the shape and the form of the building but what they have to do is make sure that what they design won't affect the city" [C3P1]

It is understandable that in a system design as large as a master plan there will have to be some guidelines; however, if the buildings within a city do not interact effectively with other parts of the system then vital relationships could go unrecognised. It appears to have been overlooked that some effects that a building has on a city could be positive.

Confirmation of Findings:

[CF1] Frequent communication between actors is essential throughout the whole system design process,

[CF2] Lack of communication can result in linkages between sub-systems being overlooked and components being unaccounted for,

[CF3] The amount of communication required within a whole system design process is often underestimated by actors.

Modifications to existing findings:

[MF1] Frequent interaction between sub-systems prevents components from being over-looked,

[MF2] Interaction within the system is as important as interacting with other systems and the external environment.

New Findings:

[NF1] Lack of communication may be due to a reluctance to seek help or advice from other experts or disciplines,

[NF2] The higher the levels of interaction between human and non-human actors, the higher the level of resilience within the system will be,

[NF3] Frequent interaction between sub-systems ensures that they work together and assists in the identification of advantageous relationships,

[NF4] Adopting a whole system approach to design not only encourages relationships between sub-systems to be identified but also assists in the elimination of components altogether. This greatly enhances the optimisation of the final design solution.

6.4.3 Individual Characteristics

The theme 'Individual Characteristics' was developed from case study data which suggested that, alongside domain-specific expertise, actors undertaking a whole system design are required to have other trans-disciplinary skills. Chapter 5 advised that characteristics such as the willingness to learn across disciplinary boundaries and the ability to think systemically were essential to develop a fully-integrated solution. The second set of data not only confirms these findings **[CF1 – CF3]** but significantly expands upon them and introduces other characteristics that appear to be necessary within the process of whole system design.

All interviewees agreed that the characteristics or set of skills that actors needed to posses when carrying out a whole system design was unique and substantially different from those required when working on a more traditional design process. Quotes such as that below were frequent:

"So it is a completely different skill set … You have to be able to view things from the outside of the object, you have to be able to look down on the object because cities are such complex organisms; you are designing something that lives and breathes, you are not designing something that gets put in a cupboard and gets used once a year or provides a role. Cities don't provide roles, they are the object that everything else fits into and so in designing a city… what skills do you need? It's everything; you have to be able to view the organism and ensure that that organism can seamlessly fit into its surroundings and also be a success in its own right. So it's wide ranging, it's a broad brush touching on everything, it's a holistic view of design but without being complex – so it's completely contradictory, but it is that." [C3P1]

One characteristic that was reoccurring amongst the data was the possession of curiosity or enthusiasm to learn across disciplinary boundaries. This is challenging as it requires actors to withdraw from the highly-specialised, familiar, comfortable sector in which they may have been developing their expertise for many years and to start stepping into other sectors of expertise.

"I am sure that the role or prestige of the specialist has reached its absolute zenith and I think that in the future the role of designers and policy-makers, who I'd also include as designers – I think they are actually, in the broadest possible spectrum, designers who are going to be designing the way, not products, but systems work in the future. There is an ever increasing role for polymaths and I think the day of the polymath is returning because in whole system design that is the core skill" [C5P1]

This is not to say that high levels of domain-specific expertise are not required but, ideally, the people that have that expertise will also have a broad and inquisitive view to make the process of whole system design easier and more successful. The role of 'curiosity' appears to be particularly important as, without someone looking down on the system from above, gaps could easily appear in the design **[NF1]**. If each actor possessed enough curiosity to monitor all of the sub-systems then this would significantly aid integration. This is discussed further in Sections 6.4.7 and 6.4.8.

The ability to think systemically or in a joined up way was highlighted early on in the research as being essential to making sense of complex issues like sustainability (Senge et al., 2007) and therefore fundamental to the process of whole system design. However both the data and literature suggest that trans-disciplinary skills such as systems thinking are not widely shared **[MF1]** (Senge *et al.*, 2007). As the following quotes demonstrate; many interviewees suggested that this inability to think systemically was instilled within society many years ago **[MF2]**:

"we are not trained to look at things holistically" [C3P1]

"unfortunately we have systematically de-sciencified our society" [C4P2]

"It's a different way of thinking completely and I think we do teach everybody not to think systemically and I think that that's a cultural thing" [C1P1]

"We've got some fundamental problems in the way that we teach science. We are asking people to counteract an awful lot of what they've learnt." [C5P1]

One architect in particular suggested that during the 7 years training that an architect receives, only one module is spent interacting with other disciplines:

"I think it was probably in one module in one year; bringing the design team together so that you could work on a real sort of project with the real people, that was a surprise; you don't realise at university that you are going to have to work as a team until you come out and actually start doing it. And it's all about people; it's all about working with other people to deliver something as a goal" [C3P1]

These findings suggest that although thinking in a holistic, systemic way appears to be essential to the process of whole system design, physically implementing the skill is essentially counter-intuitive to everything else we are taught **[MF3]**. This is potentially a huge stumbling block for the success of any whole system design team as finding actors with this ability is difficult.

Other trans-disciplinary skills that were identified as being desirable of actors were intuition, empathy and sensitivity **[NF2]**. As one participant suggested: *"it's an intuitive skill set - you are almost trying to create a spirit or a feeling or something higher"* [C3P1]. There is a concern that characteristics such as those highlighted within this section are regarded as optional extras and are not core to the activity of designing **[MF4]**. Several participants suggested that there was no incentive for actors to learn across boundaries, think systemically or design empathically **[NF3]**. This is one of the reasons why the development of a shared purpose is so important and additionally why the individual motivation behind each actor needs to be recognised. These are factors that could potentially instil incentive throughout the project and therefore instigate enthusiasm amongst the design team. These factors are discussed in Sections 6.4.4 and 6.4.5.

This section has identified that there are a set of skills and characteristics, additional to domain specific expertise, which are required of actors throughout the process of whole system design. Although these skills are thought to be equal in terms of importance to expert skills, they appear to be much more difficult to quantify, explain and primarily teach **[NF4]**. This appears to be a key area of the current research and will be discussed further throughout this chapter and within Chapter Seven.

Confirmation of findings:

[CF1] A whole system design process requires actors to possess a significant level of domain specific expertise,

[CF2] Actors are required to possess the characteristic of receptivity; the ability to apply domain specific expertise appropriately across design contexts,

[CF3] Actors are required to possess a unique set of trans-disciplinary skills including:

- the enthusiasm and willingness to learn across disciplinary boundaries,
- the ability to think systemically

Modification to Existing Findings

[MF1] Finding actors with trans-disciplinary skills is difficult,

[MF2] Historically we have not been taught to think systemically,

[MF3] Asking actors to think systemically is counter-intuitive to the way they work within a more traditional design process,

[MF4] There is a concern that characteristics such as those highlighted within this section are regarded as optional extras and are not core to the activity of designing.

New Findings:

[NF1] The role of 'curiosity' appears to be particularly important within a whole system design as, without someone looking down on the system from above, gaps could easily appear in the design. If each actor possessed enough curiosity to monitor all of the sub-systems then this would significantly aid integration,

[NF2] Other trans-disciplinary skills that were identified as being desirable of actors were intuition, empathy and sensitivity,

[NF3] There is often no incentive for actors to develop or utilise trans-disciplinary skills,

[NF4] It is unclear if and how these trans-disciplinary skills, necessary for participation within a whole system design, can be taught and learned.

6.4.4 Understanding of Purpose and Process

The process of whole system design requires a substantial amount of individual and organisational commitment from the project team, the actors working on the project and the organisations supporting those actors. Chapter Five suggested that this is not only a commitment to provide personnel and time but also those personnel must commit to forming an identity with the project team and to working towards a mutually-shared purpose and vision. Data analysed within the second part of the research has revealed that it is not only essential for actors to have a joint understanding of the project purpose but also to develop a joint understanding of how that purpose is to be achieved **[MF1]**. Consequently, to reflect this finding, the themes of 'Commitment' and 'Identity' have been merged to form a new theme 'Understanding of Purpose and Process'.

Throughout the research process it has been recognised that the concept of whole system design is not easy for everyone to grasp. Interviews have indentified that even those working on a holistic or whole system design process do not necessarily understand that process and the reasoning behind it **[NF1]**. This finding originated from the second phase of research; however, it was taken back to the original case study to confirm its existence. Within the case study it was observed that there appeared to be no consensus between the actors of what a whole system design was, what the benefits were and what a whole system design process entailed. Quotes such as those below were common and demonstrate this point:

"I suppose I struggle with the concept of whole system design as opposed to just system design. So trying to understand the requirements for the whole system; breaking those requirements down, decomposing them, designing options, sub-systems, integrations" [Software and Systems Designer]

"I don't know what a whole system design is expected to be" [Automotive Designer]

It is difficult to ask actors to commit to developing a shared purpose and identity if they are not certain of the process required and the benefits of following that process. However as one participant pointed out:

"at the moment we are not very good at it and we haven't had much practice; no one has, we haven't had very long to work out how to put whole system design teams together at all" [C5P1]

It is recommended that the process of whole system design would be greatly improved if actors were made aware early on in the process of the thinking behind the concept of whole system design and some of the basic principles that go with it. This in turn would help to communicate the high levels of commitment and interaction that are required; which is often underestimated **[CF1]**.

Going beyond the understanding of whole system design the data suggests that there is frequently a lack of understanding surrounding how whole system design fits into the bigger picture and the ongoing quest for more sustainable living.

When developing a shared purpose it is therefore necessary to consider how this fits into the surrounding environment **[NF2]**:

"to make it part of a system it has to be part of something, there has to be a vision and this is the thing that we really struggled with, with EASEL … defining the system in terms of the vision, in terms of it's mixed communities, if it is a sustainable community at least try and communicate what that's all about to your stakeholders" [C1P4]

This is linked to section 6.4.2 in which the importance of interacting with systems outside of that which you are designing is vital for successful integration with the external environment.

One of the most difficult things to grasp about the concept of whole system design appears to be the counter-intuitive aspect. As the previous section highlighted, asking experts to take a step back and start to learn from other disciplines is challenging. Additionally, achieving the optimisation of a whole system often involves adding a component that is heavier, more expensive, less efficient, or even taking away a component that is perceived to be vital.

"its completely counter-intuitive… We are asking people to counteract an awful lot of what they've learnt. How can you seriously expect to get a more efficient, cheaper, or lighter car by choosing a component that's less efficient, more expensive or heavier; I mean it's just inconceivable for most people" [C5P1]

One example was observed during Case Two. The interviewees were from an international company which specialises in the design, production and distribution of furniture. The company has been operating for 50 years and has only ever produced two very simple ranges of furniture. They specialise in encouraging their customers to live intelligently and responsibly by buying less, but of a better quality, and making it last longer. This is counter-intuitive to many modern furniture manufacturers who produce multiple ranges and want their customers to buy as much as possible as frequently as possible. The managing director of the company agreed with the idea that whole system design frequently involves a counter-intuitive aspect **[NF3]**:

“Counter-intuitive; people that know us say that ‘you’re the cheapest shelving that money can buy!’ people that don’t know us say ‘it’s an absolute rip off; expensive!’ Counter-intuitive; it is cheap, it’s the cheapest way you can make furniture because you will be serviced and have it available for the rest of your life and lives beyond” [C2P1]

This demonstrates the necessity for actors to develop a purpose and goal in relation to the whole system including its emergent properties **[NF4]**. Often the benefits of a design cannot be seen as the emergent properties are not being included; from this view it is counter-intuitive. Therefore, as highlighted in Section 6.4.3, the ability to identify linkages between properties and, additionally, any emergent properties of the system is a key skill of the whole system design process. Figure 23 tells a story which demonstrates the relevance of emergent properties.

I've got an Indian friend who's got a resort in the Maldives and he's got a Swedish wife and she and I have both been chipping away at him to reduce the impact of the resort for years. And he has suddenly toggled and decided that he wanted it to become totally zero impact. There was no amount of degree; he's very rich and is used to spending the money and getting what he wants: 'I want to be zero impact'. He said, 'I spend $400,000 a year on diesel for the gen set on the island' and he wanted that to be zero which is not easy when you've got 40 air-conditioned bungalows all over this island; wildly expensive! And ridiculous kitchens and laundries and facilities like that. And I helped find the people to do the work and I sat through the first big report they did for him and they'd made the mistake of putting a table in there of the costs of different forms of renewable energy; the wind turbine was the cheapest, say for argument's sake about 5 cents per KWH and solar PV panels were 40 cents per KWH at the other end. And he just wanted to put in a big wind turbine because it was the cheapest way of getting the electricity. He couldn't understand, because they'd done that table, that actually his capital cost of providing electricity in relativity to host demand profile through the year using environmental conditions which will also fluctuate, he could meet the demand with a lower capital investment with a complex mix that included some solar PV panels. He argued 'a unit of electricity is 8 times as expensive from that what's the point!?' he couldn't get it. Sometimes there is not enough wind and he would have needed to double the size of his wind turbine if he wasn't prepared to have any solar PV but he couldn't 'get it'. So it is this whole business of analysis; optimising all the elements and being conscious of emerging properties and so on.

Figure 23: Interview extract demonstrating emergent properties

Many of the participants interviewed during the second phase of the research talked about whole system design as an *'ethic'* or a *'set of values'* which people either *'get'* or *'don't get'*. This relates back to the theme of identity in Chapter Five in which it was suggested that an important part of the whole system design process is developing a sense of identity. Findings from the second set of data confirm this **[CF2]** and suggest that understanding the principles of whole system design is part of that identity and therefore needs to be achieved by the actors to aid the design process **[MF2]**. This is achievable within a design project like the case study as the majority of the actors are directly involved with the design. However, in larger projects such as master planning there are far more actors to engage within this whole system 'ethic'. One way to achieve a consensus is to include as many actors within each design meeting as possible, however, this too has its challenges as discussed below:

"whether you attempt to change that by enlarging the system boundaries so that you start to include some of this or, so whether you actually say 'yeh lets keep the design team as it is' because you can only work with so many people at once, actually when you get a landscape architect and a architect and an engineer and a structures and a transport guy in one room and then you come up with some pretty good stuff and to try and include anyone else would just be folly or whether you say 'no we really need to include that stuff' (other stakeholders). If you keep it as it is you obviously need to find a way for the disparate systems to talk to each other and stuff. I think defining what you class as a whole system for the construction industry would be pretty crucial and it would be hard." [C4P1]

One company that were interviewed have attempted to over-come this issue by:

a) Selecting suppliers and partners who already hold values and ethics similar to their own,
b) Trying to influence suppliers and partners by providing free consultancy on how their design team etc can be more effectively optimised.

Additionally, Walmart Stores have attempted to instil their sustainable ethics into all parts of their organisation by developing 'Sustainable Value Networks'. These networks bring together leaders from both Walmart itself and from supplier companies, academia, government and non-government organisations to explore challenges and to develop solutions that benefit both their business and also local and global communities (Walmart, 2008). One of the key aims of the network is to help integrate and communicate sustainable practice into all parts of their business and surrounding businesses.

These examples demonstrate the importance of having a core design team or network that not only understands the key principles of whole system design but who are willing and able to distribute and communicate that knowledge into their own parts of a company, organisation or project **[NF5]**. This will enable the continuity of sustainable and holistic practice.

Confirmation of Findings:

[CF1] The process of whole system design requires a high level of commitment from all actors involved; this is frequently overlooked,

[CF2] Developing a sense of identity between the design team substantially aids integration and the achievement of shared goals and purpose.

Modifications to existing findings:

[MF1] It is essential for actors to develop a joint understanding of the project purpose, however, it is also necessary to develop a joint understanding of how that purpose is to be achieved,

[MF2] Forming an understanding of the process of whole system design can be assisted by the formation of a sense of identity by the project team,

New Findings:

[NF1] It should not be assumed that all actors will understand the concept of whole system design without it being explained to them,

[NF2] A joint purpose should address the external environment with which the system is to interact,

[NF3] A whole system design often has a counter-intuitive aspect which cannot be fully understood without looking at the system as a whole,

[NF4] Identifying and accounting for emergent properties is an essential part of the design process,

[NF5] Having a core design team with a shared understanding or 'ethic' of the whole system design process, enables knowledge to be dispersed throughout the project team.

6.4.5 Personal and Organisational Motivation

Within the process of whole system design individual motivation refers to the individual reasoning behind actors wanting to be part of the project. Data has suggested that it is reasonable to expect individual motivations to differ between actors. However, this did not present a problem in the case study, as an alignment between individual motivations and the over arching motivations of the project was established. Within the second phase of research it was identified that if motivations and, additionally, requirements, expectations and needs were not communicated at the beginning of the project then this could lead to conflict later on in the design process **[MF1]**. Although motivations did not conflict substantially within the case study, Section 5.3.5 demonstrated that individual motivations were frequently kept from the project team. It is thought by the author that encouraging open and honest discussions surrounding motivations early on in the design process would lead to a more cohesive team and ultimately a more cohesive and holistic solution **[NF1]**.

The theme of motivation has been modified within this chapter as it became apparent that the motivations behind supporting companies and additionally the project itself were frequently as important as the motivations of individual actors. The theme is now termed ‘Personal and Organisation Motivation’ to reflect this additional data.

Establishing an alignment of interest was confirmed as *“fundamental to getting a whole system design”* [C5P1] **[CF1]**. Establishing an alignment of interest however has been observed to expand beyond the project and the project partners. In traditional design the consumer and the manufacturer are at *“polar opposites”* in terms of needs and requirements; they are often motivated by different things. For example the manufacturer of a motor vehicle wants to make an ongoing profit through regularly servicing the vehicle once it is sold and relies on components needing to be replaced; to an extent failure is built into the design. On the other hand the consumer requires reliability, efficiency and quality and does not want to be frequently spending more money, time and effort on replacing components of the vehicle. Establishing an alignment between the motivations of the project and those of the intended consumer is essential **[NF2]**.

“*the opposition of interests is a terminal barrier to whole system design”* [C5P1]

The second set of data suggested that even if an actor is motivated by the project purpose there is rarely any incentive for him / her to put in more effort than is necessary to fulfil that purpose. As discussed in section 6.4.3 actors within a whole system design team are required to have or develop additional skills to those required in a traditional design process.

“they've increased the remit of planners and building control officers quite enormously but they don't get any more money than they ever used to get so there is no real possibility of them taking on the new professional skills that they need so they don't” [C4P1]

Unless the actors involved have deeper rooted motivations to provide the most efficient and optimised solution possible then most are going to settle with something that is good enough to meet the current target or piece of legislation **[NF3]**. Ideally legislation such as the code for new homes would provide motivation and incentive to develop better, more sustainable homes, however, data has shown that actors are feeling de-motivated by the stringent government guidelines.

“if you go upstairs you will meet a lot of incredibly frustrated people who are being constrained in how they do their jobs and unfortunately this (the whole system design concept) well certainly to me is a lovely concept; whole system design, but I wish the construction industry worked like this but right now we are so far from it and there are so many massive barriers that aren't even

addressable. I mean how do you change the way the government works? And it's not being based on science, that's a problem, it's all being based on PR and newspaper headlines and stuff so maybe you need to include that in your whole system somewhere" [C4P2]

"That (the Code for Sustainable Homes) is not based on experience at all and as sustainability enters compliance requirements the issue is it's not based on experience of any sort. It's a top down policy" [C4P1]

Additionally, there was a feeling surrounding this legislation that it actually restricted innovation as is shown in the interview extract in Figure 24 **[NF4]**:

C4P2: the vast majority of the industry will design to building regulations such as the Code for Sustainable Homes. But it should be right and it certainly can't stop the innovators from innovating which currently it actually, categorically, definitely, absolutely is doing and it should certainly not be pushing the non-innovators down a bad road which it is

Researcher: I was going to ask you actually about the relationship between innovation and sustainability within this new target-driven construction industry

C4P2: it is all targets, the innovation

Researcher: as long as we meet our targets it doesn't matter?

C4P2: actually I would suggest it's even worse than that, in an attempt to lock down and secure compliancy, innovation is being legislated out…So innovation is just being stripped out in a bid to be able to say 'yes that's zero carbon' but of course it is completely the wrong way around.

Figure 24: Discussing Legislation

Confirmation of Findings

[CF1] It is important to establish an alignment between the motivations of individual actors and those of the project.

Modification to existing findings:

[MF1] Un-communicated motivations, needs and expectations can lead to conflict later on in the design process,

New Findings:

[NF1] Honesty and open discussion surrounding individual motivations should be encouraged early on within the design process,

[NF2] It is important to establish an alignment between the motivations of the project and the intended consumers,

[NF3] There is little motivation or incentive for actors to adopt new skills,

[NF4] Legislation can restrict innovation as opposed to increasing motivation.

6.4.6 Sense Making

Making sense of the expectations, requirements and perspectives that surround a whole system design is a key stage in the design process. If this is done successfully then the development of a shared mental model and architecture of the intended solution should be made easier **[CF1]**. Due to sense making activities often occurring sub-consciously, it was difficult for the participants to recognise and relay specific accounts of when they had occurred. However, with prompting questions it was uncovered that sense making activities took place within each case. Every participant agreed that the development of an understanding of terminology and language was essential for inter-disciplinary working **[CF2]**. This was particularly true for architects as not only did they have to understand terminology to enable the integration of ideas but they also had to communicate their own original design ideas to a wide ranging audience. Confirmation of the use of shared mental models between design teams was also identified, however within the cases of master planning; mental models were often represented physically in the form of visual maps **[NF1]**. Although regularly updating visual images was often time consuming and maps soon became out of date, the tool did allow actors to physically identify the interfaces between parts of the system.

It became obvious that sense making not only involved making sense of the requirements of those actors involved in the design process, but also the requirements of the consumers were paramount **[NF2]**. These requirements were sought through community engagement and community consultancy. One participant was not satisfied by this procedure, however, and thought that design within the construction industry could be greatly improved through the use of feedback:

"certainly a whole system to me has to include feedback and it is certainly just completely absent from the construction industry and what I've spent my entire life banging on about is how can you build anything if you don't have feedback; you've got to learn at some point what's happened" [C4P2]

This is also true of other industries and is closely related to communication and interaction with external systems **[NF3]**. Figure 25 presents a picture of a regular take-away coffee cup which has been manufactured out of recycled materials. However, as shown, the waitressing staff within the coffee shop have realised that the material used is so thin that the cups are too hot for the customers to hold when filled with a hot drink. Subsequently this has resulted in two paper cups being used and thrown away for every drink. This completely counteracts the environmental benefits intended by the producer of the product; however, it will never be rectified without the implementation of feedback.

Figure 25: Demonstrating the need for consumer feedback

As previously discussed in Section 2.5.4 the concept of feedback is focal to thinking systemically. In this case the actor is suggesting that literal feedback should take place between the consumer and the designer, however, it is also important to fully understand how that feed back will be utilised and ultimately affect the system as a whole.

Senge et al., (2007) stress the importance of developing a shared conceptual 'systems sense' between the actors. Data within the research supports this and has shown that it is important for the actors not only to make sense of the disciplines, components and sub-systems within the system but to also to make sense of the system itself. During the interviews the idea of identifying the system boundary was discussed several times. In particular it was suggested that, due to the vast number of components that have to be acknowledged when addressing the re-generation of a community, defining the system boundary is very difficult.

"Fiona was talking about a sustainable racing car, well at least you can go 'that's the car' but when you are talking about communities you can't say that's the community because you are talking about people living with a whole series of identities and where do you come from is a big question and you can spend all

day discussing it. So we can't define the system; that's part of the problem" [C1P3]

However, it is not only within the design of communities that the identification of a system boundary causes a problem. It appears that the number of relationships between sub-systems within any whole system design process has the potential to be limitless.

"We are immediately going to say that it's all connected to this, we are all part of the country, we are all part of the world which is undergoing major problems so we can't define a system" [C1P1]

However, as one participant stated, by identifying a system boundary *"we are trying to impose a limit on something that normally grows organically"* [C3P1]. A system boundary is a subjective notion which divides the system from its environment but doesn't necessarily have to correspond to any real-life limit (Collins et al., 2007). Therefore defining the system boundary appears to be less important and may be regarded by actors as a mental limit to provide security or to explain what is inside and outside of the problem or design context as one participant suggested:

"there is no such thing as a system merely a way of bounding a process or problem" [C4P2]

Physical limits may be decided upon and referred to as the boundary of the system; for example, the edge of a city **[NF3]**. However, it is inevitable that parts of that boundary are going to be blurred and crossed and emergent properties in time will expand that limit **[NF4]**.

Defining a system boundary is a way of simplifying the complexity of a whole system design. However this is not always a useful method as eventually the complexity of the system needs to be acknowledged. Several participants were concerned that even when undertaking a whole system design, actors are still too focused on the particular system in which they are working:

"fundamentally people are not used to thinking of buildings as systems; they think of buildings as weather screens within which they do stuff, they keep the rain off me and allow me to read the paper when it's raining without getting wet! But of course these days they're not like that at all and they've got complex air flows and heat flows and there are great experiments where they investigated what affects how a person feels and it's not just to do with the air temperature around them, it's to do with the walls around them even though they're not touching them" [C3P1]

"so as I was saying before we've been looking predominantly at these little systems; individual houses, developments and even larger developments but they all intrinsically fit, you cant get away from the fact that they all fit into part of a bigger system which ultimately is national or international because we've got gas coming in and all the rest of it. I am not suggesting that you could necessarily solve those intricacies but if they were at least acknowledged then they could be managed" [C4P2]

Many factors need to be taken into account when making sense of the intended solution and additionally making sense of how that solution affects and is affected by its surrounding environment **[MF1]**. It appears that the latter is commonly overlooked.

Confirmation of Findings:

[CF1] Sense making activities such as the use of mental models and the development of a shared architecture are used to understand the multiple perspectives, needs and requirements that are present in the whole system design process,

[CF2] Developing an understanding of terminology and language across disciplines enables integration.

Modification to existing findings:

[MF1] Making sense of the system and how it interacts with other systems is an important part of sense making,

New Findings:

[NF1] Representing mental models as physical maps is a tool that can aid the identification of interfaces between sub-systems,

[NF2] Understanding the perspectives, needs and requirements of the end consumer plays an important part in making sense of what the final design solution should aim to achieve,

[NF3] Gaining feedback from consumers and understanding how that affects the design solution should form an integral part of the design process,

[NF4] Defining a system boundary appears to be a useful tool to add structure and certainty to the design process,

However

[NF5] A system boundary is a mental restraint that actors use to define a problem context and therefore care should be taken to ensure that this does not restrict relationships with the external environment from being identified and utilised.

6.4.7 Facilitating Whole System Design

Data and literature alike have shown that the process of whole system design is laced with uncertainty **[CF1]**. Among other factors, this stems from the multitude of perspectives, requirements and expectations held by the actors and partners involved **[CF2]**. It has been observed that, due to this uncertainty, it is often not possible to set precise, well-rounded aims and goals; consequently goals tend to be ambiguous and ambitious, as demonstrated in the extract below **[MF1]**:

"the original brief was to produce a city to house the machinations of the Olympic games; when I say that I mean the reporters, the people taking part in it, and everything that goes along with that in terms of where they eat, sleep, drink, live. So the Olympic games run for a specific length of time and along with it comes thousands of people. And the extension to the brief was, post legacy, post games, what you've created for these thousands and thousands of people has to then become a working city." [C3P1]

This information reinstates the findings of the case study; however, new data suggests that the uncertainty that actors feel is also closely related to the lack of a leader or management figure **[NF1]**.

"so the house builders build their houses, the architects design them, the school workers deal with school issues, the youth workers deal with youth issues, all those sorts of things but who on earth is supposed to manage the system? Because at the moment in East Leeds I have no idea who's overseeing that system approach" [C1P2]

Within a whole system design it is recommended that to encourage joint responsibility and ownership a flattened hierarchy of actors should be adopted and subsequently the role of a leader or manager is not always accounted for.

"a completely different corporate structure, multiple stakeholder governance so you don't have a responsibility to shareholders but to the purpose of the organisation" [C5P1]

There are many advantages of this approach; equality amongst actors should encourage communication and integration, motivation should also be at a high, as each partner is at risk of losing something, and it is everyone's responsibility to ensure the success of the final design solution. These advantages are explained by one of the participants:

"I think open-source software is a great example of whole system design because everyone has access to the open-source code and everyone can look across the whole platform and spot synergies and anybody can spot bugs and comment on bugs and produce solutions and because of the big community and everyone is deeply committed it ends up with only the best solution being adopted and they have this phrase 'given enough eyeballs; any bug is shallow' so if you have 10 pairs of eyes looking for a bug it's a thousand times more likely to be resolved rather than one" [C5P1]

From the data, it was possible to see that sharing responsibility amongst all actors, and giving each the ownership to make decisions and take action resulted in decisions being implemented more quickly and an increase in productivity and efficiency **[NF2]**. It also appeared that job satisfaction was higher as actors felt that they were valued and their ideas were being recognised **[NF3]**. In the following extract the participant is describing how this approach differs from a more traditional organisational structure in which it is not easy for actors to implement decisions:

"people might come up with the ideas, but as Fiona pointed out, they'd dismiss it because they'd think I've got to get approval from another department, so I'm packaging and I'm dispatching, and I've got to get production to agree to the same design changes... ah, forget it. And then, if I get them to agree, I've got to persuade the bosses." [C2P2]

Several whole system design initiatives have highlighted the presence of a flattened organisational hierarchy as essential **[NF4]**. The Zero Emissions Research Initiative (Zeri) specialises in implementing a holistic approach to regeneration and community development. They suggest that current notions of leadership are based on power and control, and that going beyond this means stimulating creativity and innovation, by affirming the creative potential of each individual and their unique contribution towards the development of themselves and their communities (Zeri, 2008). The Neighbourhood Initiatives Foundation agree and have created a means by which local people can be fully involved in the process of change, interacting equally with other stakeholders and wielding real power. They go on to suggest that anything less is unlikely to result in the development of sustainable communities or the implementation of effective neighbourhood renewal. (NIF, 2008). Both initiatives agree that giving actors a voice and the power and ownership to make decisions is an important part of a whole system design.

It was considered to be a common phenomenon across disciplines that, in times of uncertainty and when things appear to be *"falling apart at a systemic level"*, actors would retreat back to their own discipline and *"give up on the larger picture"* [C1P4]. The concept of retreating was put down to a lack of communication, effective collaboration and additionally a lack of empowerment. It was considered that if stakeholders did not perceive themselves to have *"a voice"* or *"an influence"* then they quickly lost interest and struggled to *"define what it is we are trying to achieve"* [C1P3]. One participant suggested that it was understandable that actors were going to need their own space to design their individual parts but added that *"you need to have a context in which to do that if you are going to deliver the high lofty ambitions that were set in the first place"* [C1P3]. And that context can only be developed with the input of the design team.

This echoes the discussion held in section 6.4.4 which suggested that a team needs to form a sense of identity in order to maintain enthusiasm, commitment and motivation. If individuals retreat into their own domain then there is a substantial risk that the project could fail. It appears that adopting a flattened hierarchical approach to design does encourage the communication of ideas; however, it does not always result in equality, particularly within design teams that are not familiar with one another as one participant explained:

“well you have design team meetings for sure so in that respect it is a good example but the problem is in my mind is that everybody has different contractual relationships; some people have more power than others in those meetings and traditionally some people are more listened to, so traditionally if you are having an argument with the architect about something, say, ridiculous PV, rain water collecting, wind turbines! Then traditionally the architect would get listened to… sometimes I think that it just comes down to individuals and their egos.” [C4P2]

The feeling amongst those participants interviewed was that a whole system design process would be made easier and less uncertain if there was an actor to fulfil the role of a facilitator. However, it was seen as important that this role would not detract from the advantages that are gained from a flattened hierarchy. Rather than being a leader or manager the facilitator’s role would be to oversee the system and to encourage integration **[NF5]**. As several participants pointed out, this role would be challenging and would require a unique set of skills, very different from those of a manger **[NF6]**:

“the role of the leader is really different to a hierarchical design team. He is no longer the superstar that bosses everyone about; he’s actually the facilitator of the network which requires different skills. It does require a completely different skill set.” [C5P1]

“I think the chief designer in a whole system has got a completely different role and therefore requires different attributes and characteristics to a chief designer in a disintegrated design team” [C4P2]

The data supported that ownership was an important aspect of the whole system design process, however, as it was deemed to be so closely related with organisational structure and facilitation of the process then the theme ‘Facilitation’ was created.

Confirmation of Findings:

[CF1] The process of whole system design involves a high level of uncertainty,

[CF2] Uncertainty stems from the multitude of perspectives, requirements and expectations held by the actors and partners involved,

Modification to existing findings:

[MF1] Due to the uncertainty present within a whole system design process it is often difficult to set precise, well-rounded aims and goals; consequently goals tend to be ambiguous and ambitious,

New Findings:

[NF1] Uncertainty within the design process is increased by the absence of a leader,

[NF2] The dispersion of ownership amongst actors encourages decision making and increases productivity and efficiency,

[NF3] A flattened hierarchy increases job satisfaction as actors feel valued and that their ideas are being recognised,

[NF4] A flattened hierarchy is thought to be the best model of organisational structure to enable successful whole system design,

[NF5] The role of facilitator is required to reduce uncertainty and increase integration,

[NF6] The role of facilitator requires very different skills to those of a manager.

6.4.8 Integration

Chapter Five highlighted the notion that high levels of collaboration were required to carry out a whole system design. It was also identified that, to enable the development of an integrated solution, actors were required to develop a good understanding of surrounding sub-systems and learn about alternative disciplines, sectors and technologies. Subsequently it was thought that the term

‘Integration’ more concisely represented the high level of commitment, time, effort and collaboration that is required of a whole system design team.

The data suggests that the role of the architect within a whole system design is substantially cross-disciplinary as s/he has to have a good understanding of how all the sub-systems impact upon the overarching building or city **[CF1]**. Additionally it is important for an architect to be able to communicate his / her ideas to a multitude of different actors from a wide range of disciplines.

“There is a lot to learn; there’s a lot to learn about your profession and there’s a lot to learn about other people’s professions.” [C3P1]

However, it appears that the roles of the other members of the team are quite segregated:

“the construction industry is a series of small sub-systems that actually really don’t talk to each other very well, they don’t understand their impact on each other” [C4P2]

“generally the roles are always defined quite well … the electrical engineer will always provide you with solutions for the lighting, for the air conditioning, the back-up generators. The mechanical guy will do the ducting, the chillers. The structural engineer will always provide you with the beam and then the architect has to try and pull it all together… So yes, cross-overs aren’t so much in architecture because it is highly specialised and we all do our own part” [C3P1]

The participant even went onto suggest that as architects are the only actors in a design team who have a holistic understanding of the system then *“it is very easy to pull the wool over the guy sitting next to you if he’s not an architect”* [C3P1].

This has been identified to cause much conflict between disciplines in the design process as there is little understanding of the cause and effects of design decisions on the surrounding sub-systems **[CF2]**. Additionally the lack of understanding and integration between disciplines means that there is no opportunity to develop a shared vision and potentially crucial relationships and synergies are ignored **[NF1]**.

"it got to the stage where the architects and maybe the structural engineer would design the building and get it to a stage where it was how they wanted it. Now bring in the services engineer and make sure we've got heaters in the right place and we've got water to the right places and you are involved for the shortest period of time possible because you are an expensive person to employ" [C4P2]

Data from other sectors confirmed that cross-disciplinary learning by all actors is an essential part of the whole system design process. Although, it was discussed that it was not necessary to fully understand the details of each component **[NF2]**:

"*you don't have to understand every single detail of how they work, it's much more important to have a feel for what they do and how they fit into the system"* [C5P1]

The blurring of roles and relaxation of role definitions was identified as a way of encouraging cross-disciplinary learning **[CF2]**. However, supporting findings from the first phase of the research confirmed that boundary spanning and the blurring of roles creates a risk of overlapping, or else components not being accounted for and being missed out **[CF3]**. A solution was to implement the role of the facilitator, as discussed in Section 6.4.7 or otherwise all actors need to develop the skills necessary to monitor the system as suggested in Section 6.4.3.

“you’d need the blurring of roles and you need, either you’d need someone who is on top looking down or you need a great deal of curiosity from every body involved” [C5P1]

Additionally, the more integrated a team can become the less the responsibility is put on the facilitator:

“if you don’t have a leader you have got to have a fantastically clear purpose and shared interpretation of that purpose… the more democratic you can get, the closer you can get to leaderless.” [C5P1]

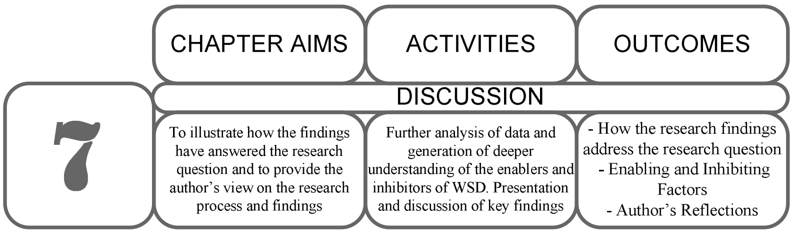
Confirmation of Findings:
[CF1] Collaboration and cross-disciplinary learning is essential to establish the impacts of design decisions,
[CF2] The blurring of roles encourages integration,
[CF3] There is a risk that the blurring of roles could result in components being overlooked .

New findings:
[NF1] The integration of disciplines is substantially challenging within the construction sector.
[NF2] It is not essential to understand how every component of a system works but to gain an appreciation for the linkages between components,

6.5 Chapter Summary

This chapter has presented data gained from the second phase of the research. By conducting interviews across various design contexts it has been possible to confirm, modify and validate the original findings obtained from the first phase of the research. The initial 10 themes have been modified to better represent the data that has been collected throughout the study. The themes ‘Commitment’ and ‘Identity’ have been merged to form the theme ‘Understanding of Purpose and Process’. This was necessary as the second phase of research demonstrated that it was not only important for actors to form an identity with the project but also to develop a shared understanding of the process required of them. The themes ‘Managing Uncertainty’ and ‘Ownership’ have been merged to form the theme ‘Facilitating Whole System Design’. It was observed that the role of facilitator would greatly aid the whole system design process and reduce surrounding uncertainty. The data in the second phase of the research confirmed the resulting 8 themes which have been observed to significantly influence the process of whole system design.

When looking at the whole system design process across a range of contexts it appears that, although parts of each theme can be seen in every case, they appear to have different weightings in each. For example Case Two took place within an organisational context and therefore the theme of sense making was not so obvious, as it is a company with the same people and therefore a mental model which has been built up over a long period of time. However, as new people come in, new suppliers are found, new linkages are identified and the system is gradually optimised. All these extra factors have to be added to the existing mental model; therefore it is still an important part of the process, yet it is less obvious and develops and modifies over a longer period of time.



Discussion

This chapter provides a deeper understanding surrounding the process of whole system design, the enabling and inhibiting factors are presented and the author's reflection is given.

7.1 Introduction and Purpose

This chapter consolidates the findings of the research and directly addresses the original research question. Section 7.2 highlights the enabling and inhibiting factors of whole system design based on the evidence that the study has provided. Section 7.3 reflects upon the holistic topic of whole system design and presents the researcher's own perspective. The remainder of the chapter highlights how the results of the research can be utilised within industry and what the implications are for design practitioners.

7.2 Research Findings

This section demonstrates how the findings of the study have informed and answered the research question.

What factors enable and inhibit the successful adoption of a whole system approach to design?

The question is answered by combining the findings of both the first and second phases of the research. From these findings key factors are highlighted that have been observed to substantially influence the process of whole system design. These factors have been presented as they were observed to either ‘enable’ or ‘inhibit’ the process, however, it is acknowledged that in different design contexts an enabling factor can also be an inhibitor. For example ‘a wide spanning social network enables the formation of a partnership’ however it is also true that ‘the lack of a wide spanning social network inhibits the development of a partnership’. As there are multiple factors to address the findings are presented with reference to the 8 themes presented in Chapter Six; the figures presented within this section demonstrate this.

Selecting and securing the principle organisations to form a successful partnership was identified throughout the study as being a difficult and stressful part of the whole system design process. However, the result of this phase of the process has an enormous impact upon the success of the both the process and the ultimate solution. As represented in Figure 26, findings suggested that having a wide spanning social network can substantially influence the development of a partnership and additionally provide continuous access to resources and expertise. It was identified that having a close-knit network was useful for accessing expertise; however, this often resulted in the continuous use of certain organisations or people between projects. Consequently, it is important to ensure that partnerships are not based on familiarity or convenience alone. These findings are in keeping with those suggested by Granovetter (1983). Utilising a political metaphor he suggested that membership in political movements usually result from being recruited by friends. Consequently any momentum generated in this way does not spread beyond the ‘clique’ of friends or ‘strong ties’. The current research is novel as theoretical notions have been analysed within the context of a live whole system design project. Attention has been specifically drawn to some of the downfalls of relying on close knit networks and ways in which situations such as this can be avoided.

Once a partnership has been developed it is also necessary to invest time and effort into maintaining that partnership. It was identified, particularly within the study of larger projects, that meetings were being attended by a multitude of different actors each time; the most common reasons for this were that actors had busy work schedules and other commitments that prevented them from attending regular meetings. This had a negative effect on the progress of the projects and inhibited the development of shared understanding of purpose and process and design intent. To overcome this challenge it has been suggested that actors should make an effort to identify and maintain a core design team who will attend as many meetings as possible. This will therefore enable understanding to be developed continuously throughout the project

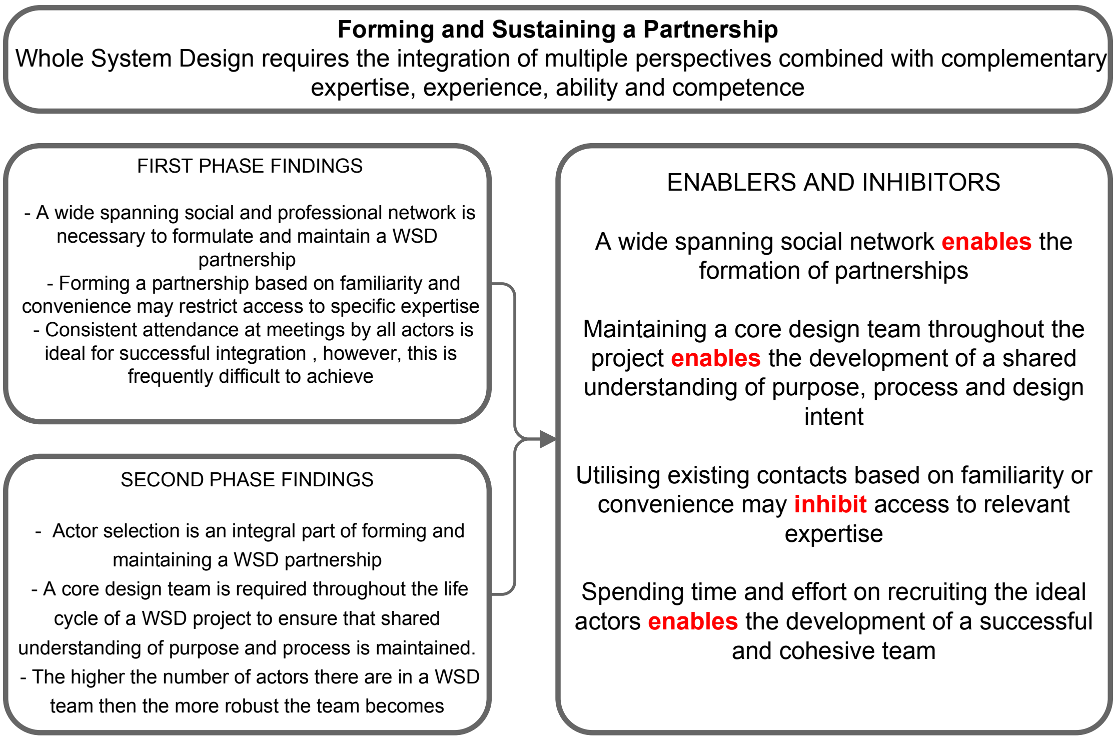


Figure 26: Forming and Sustaining a Partnership: Enabling and Inhibiting Factors

The importance of frequent communication between actors in and between meetings has been demonstrated within the study on numerous occasions and is thought to substantially influence the process of integration. This is supported by many authors including Windahl (2006), Leenders *et al*., (2003), Chiu (2002) and Sonnenwald (1993). Expanding upon findings from literature, the current research highlights the necessity for system-level communication within the process of whole system design. During project meetings it was common for discussions to frequently digress into areas of detailed design. Although this is necessary, it inhibits open discussion and participation during meetings and therefore, as referred to in Figure 27, system-level discussions should be encouraged.

It was found that actors were often unaware of the high levels of interaction required of them outside of meetings which inhibited the progress of integration. To prevent this within future whole system design projects, actors should be made aware of the requirements and expectations that a whole system design process demands.

The findings suggested that familiarity with discipline-specific working inhibited actors from interacting outside of their own discipline or system. Interaction between sub-systems and systems enables advantageous relationships to be identified and additionally ensures that the final design solution will sit in and interact comfortably with its environment.

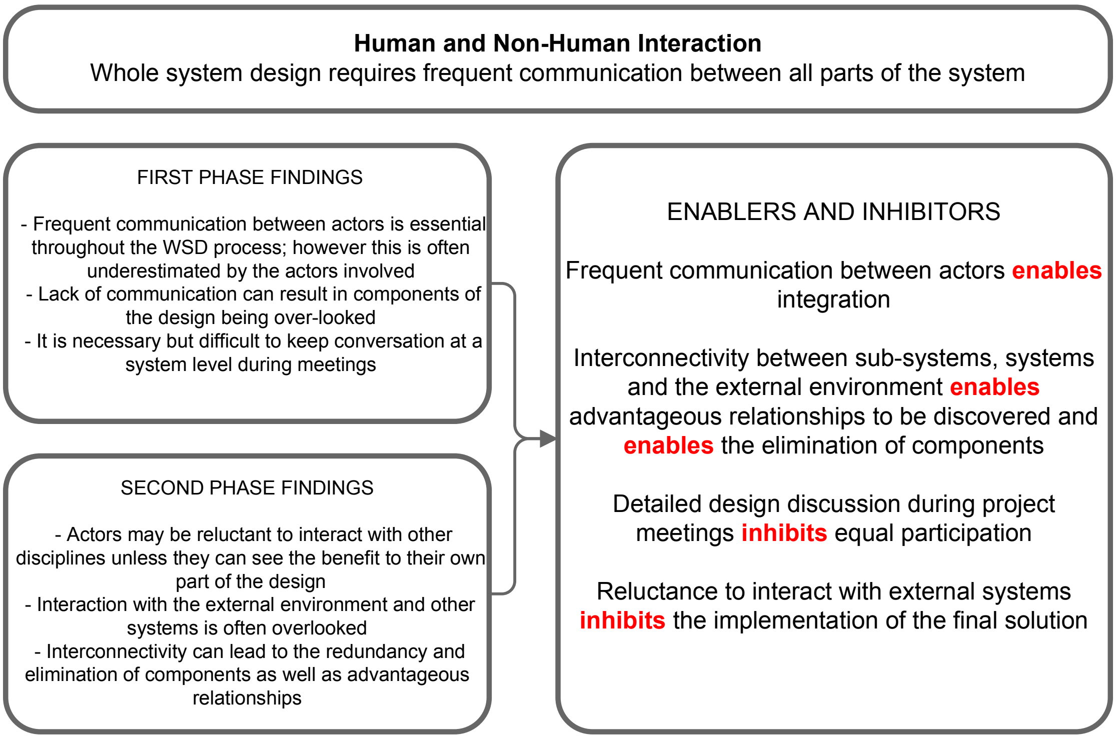


Figure 27: Human and Non-Human Interaction: Enabling and Inhibiting Factors

Findings suggested that it is necessary for actors participating in a whole system design process to possess a balance of discipline-specific and trans-disciplinary skills. Katzenbach (1993) suggests that having a broad mix of skills and know-how enables a team to respond to multifaceted challenges like innovation, quality and customer service. However, within the context of whole system design it was trans-disciplinary skills, such as the willingness to learn across boundaries and the ability to think systemically, that were observed to significantly enable actors to appreciate the impact of their design decisions upon other sub-systems and the final design solution. Cabrera et al., (2008) report a significant increase in the popularity of systems thinking across disciplines and suggest that this is because of the perceived promise to change how people think or view a problem. Like the current research, the work of Cabrera et al., (2008) suggests that there is much uncertainty and ambiguity surround what system's thinking is and how it is to be taught and learnt. Therefore, as suggested in Section 8.6, there is a significant requirement for further research surrounding the concept of systems thinking, specifically within the context of whole system design.

It was identified that those actors familiar with traditional design processes found utilising trans-disciplinary skills difficult. Additionally, those who were unaware of the benefits of possessing and utilising trans-disciplinary skills were reluctant to invest time and effort in learning or developing new skills. It is suggested that sourcing actors who already possess and understand the benefits of utilising trans-disciplinary skills should be part of the recruitment process discussed above. However, these skills are difficult to spot and therefore methods of how to identify those required characteristics should be developed early on. An example of this is the search for actors who display an enthusiasm to further their own learning and development and who show interest in areas aside from their own area of disciplinary expertise. These findings are collated in Figure 28.

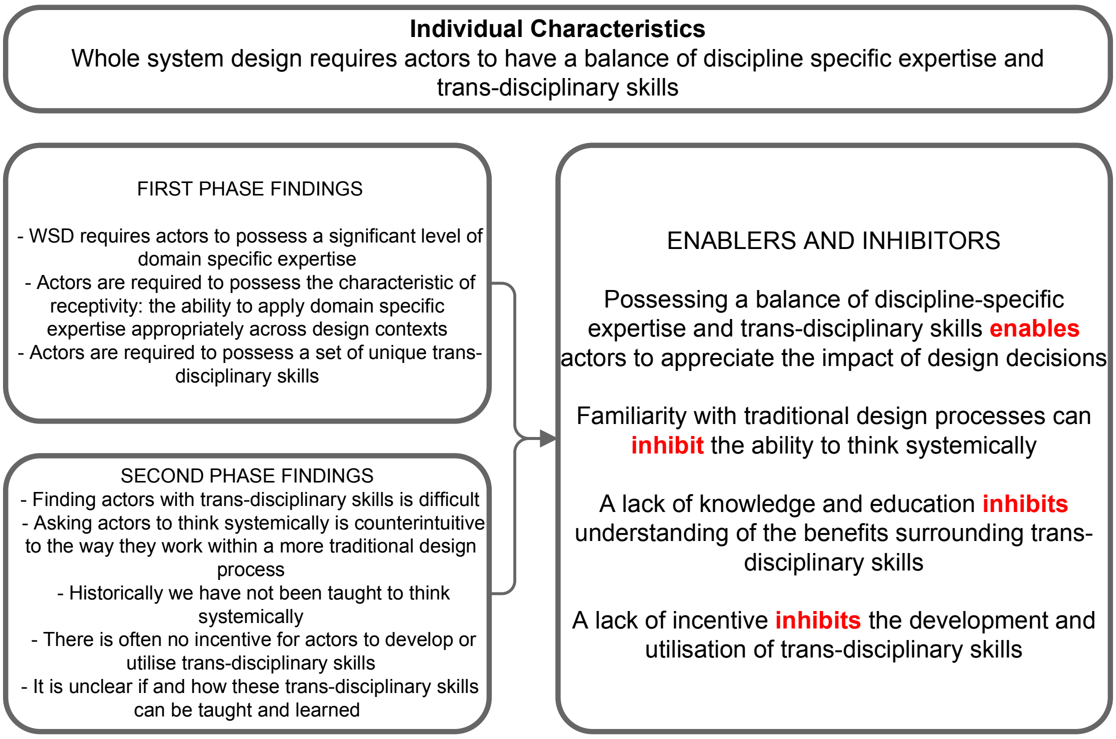


Figure 28: Individual Characteristics: Enabling and Inhibiting Factors

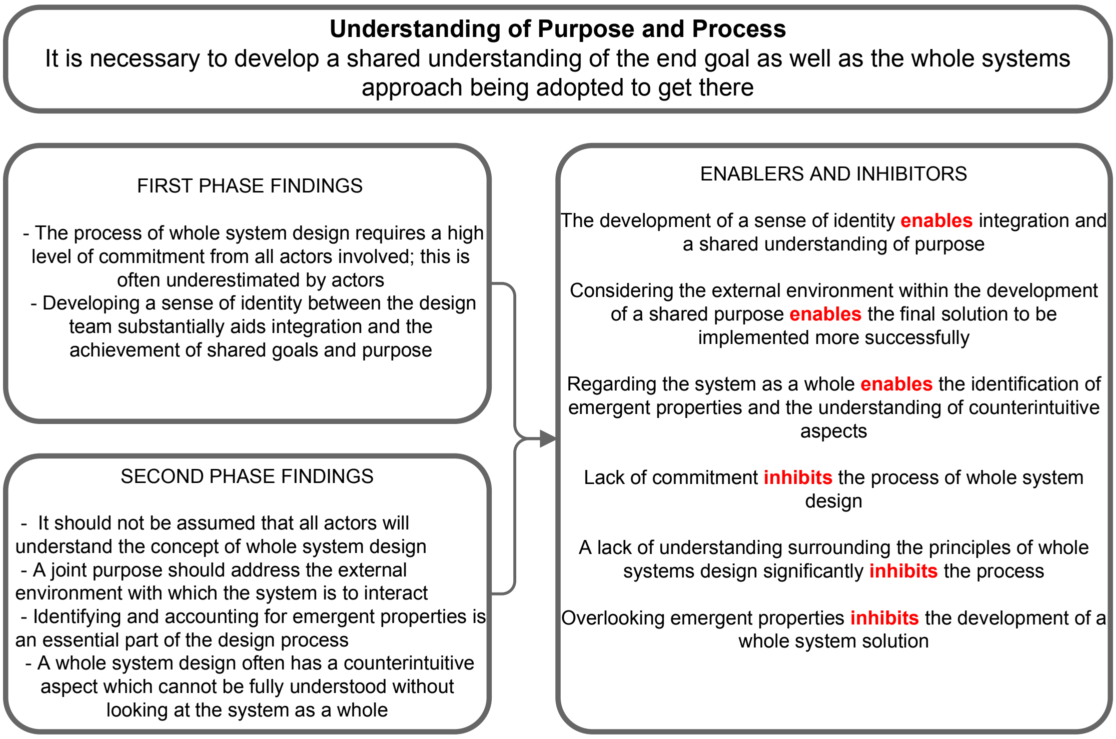


Figure 29: Understanding of Purpose and Process: Enabling and Inhibiting Factors

Frequent system-level communication has been observed to enable many other factors within the process of whole system design including the development of a shared understanding of purpose and process. As presented in Figure 29, the more cohesive a team becomes the easier it is to form a shared understanding of purpose; this was referred to within Chapters Five and Six as the development of a shared identity as opposed to remaining a group of individuals.

Many authors agree that a shared understanding, concerns developing a joint vision of the process required to meet a goal as well as the goal itself (Kleinsmann and Valkenburg, 2008, Kleinsmann, 2006 and Dong, 2005). In concurrence, the study has shown that the development of a shared understanding of process is equally as important within a whole system design yet seemingly more difficult to achieve. The principles of whole system design are often misunderstood and therefore it should not be assumed that all actors have a shared understanding of the process required to reach a whole system solution. One aspect that actors within the study found challenging to grasp was the concept of emerging properties; parts of a whole system design often appear counter-intuitive unless the system is regarded as a whole. High levels of commitment are required from actors to enable a successful whole system design process; this is also frequently underestimated by actors and should be communicated early on in the process.

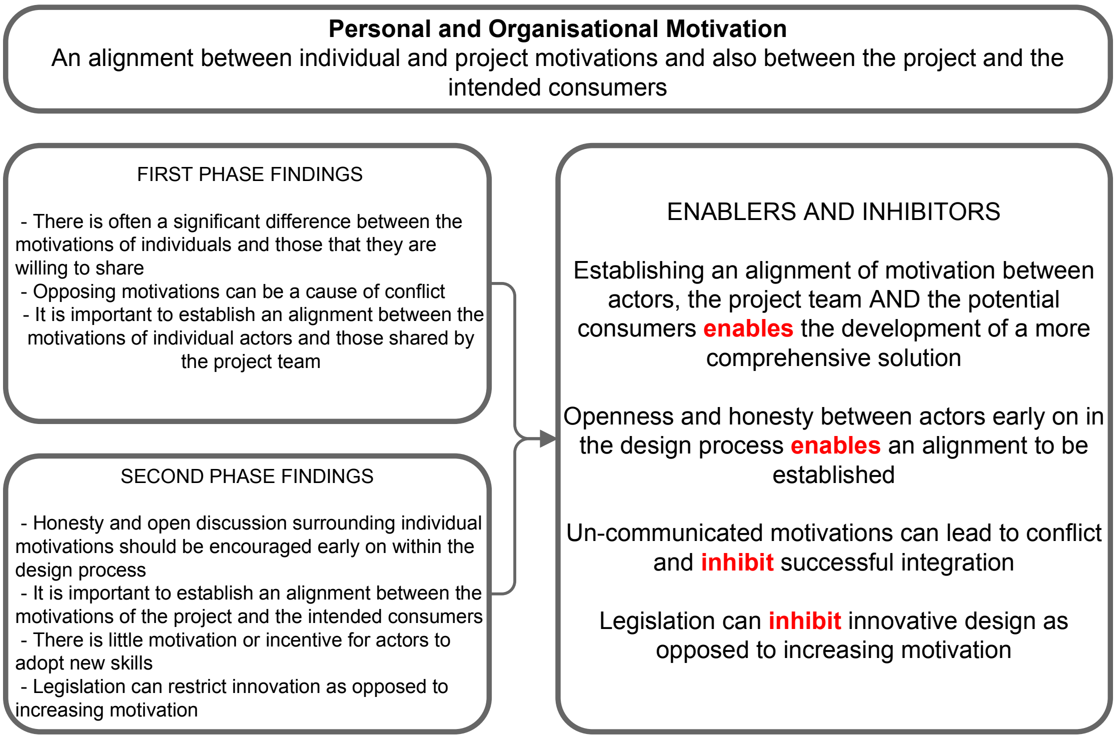


Figure 30: Personal and Organisational Motivation: Enabling and Inhibiting Factors

As presented in Figure 30 the first phase of the study identified the alignment of motivation between individual actors, the project team and supporting organisations as essential to the process of whole system design. The second phase confirmed these findings and expanded upon them, highlighting that it is also necessary to source alignment between the motivations of the project and those of the intended customer and external environment. A study conducted by Stechert and Franke (2008) also reported that the requirements of the customer are frequently very different from those of the organisation. Consequently it was suggested that the identification of 'goal conflicts' is a factor of success for the development process. The current study adds to this and consults the social aspect of realising alignment between differing requirements and expectations. It is important for all partners to be open and honest about their motivations, expectations and requirements early on in the design process, as un-communicated motivations can cause conflict and inhibit successful integration.

The second phase of research suggested that legislation, intended to increase the motivation to design more sustainably, is actually inhibiting innovation in some cases. Although it is not the sole aim of whole system design to provide innovative solutions, it is concerning that legislation should limit innovation. However, this is a substantially large issue and is an area for future research to investigate.

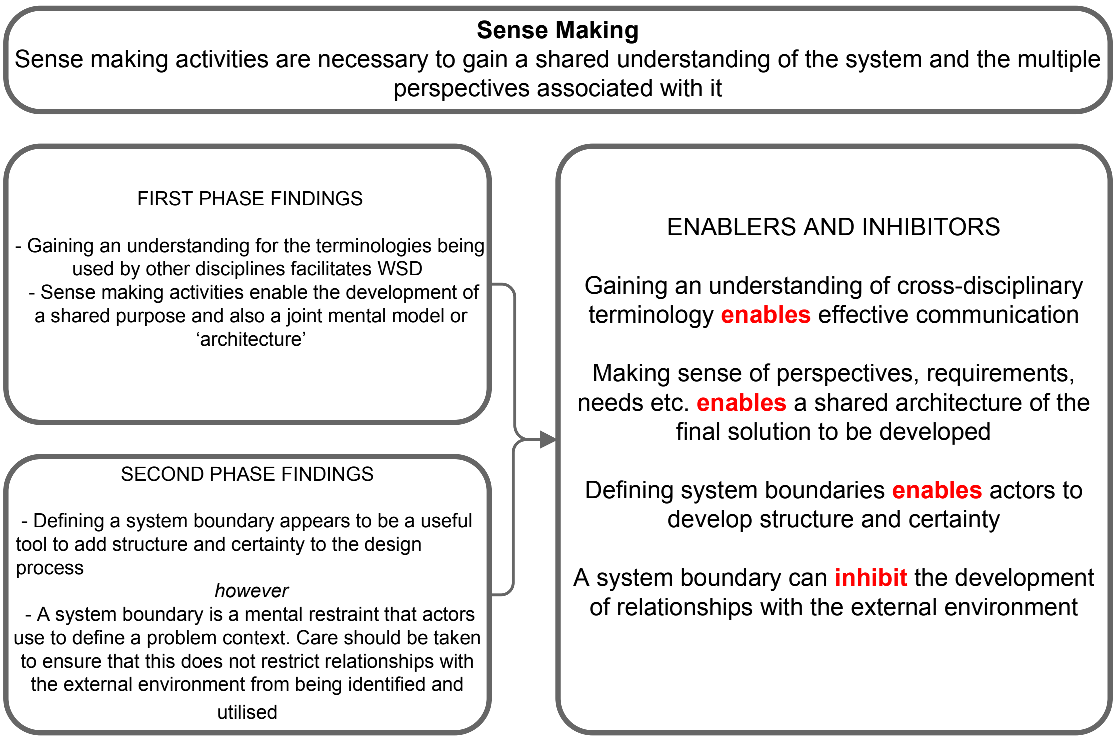


Figure 31: Sense Making: Enabling and Inhibiting Factors

It has already been discussed that honestly and openly communicating expectations, requirements and perspectives enables a shared purpose to be developed. This honesty early on in the process has also been suggested to enable a shared mental model and architecture of the final design solution to be developed as presented in Figure 31. Kalay (2001) suggests that all actors possess an individual 'world view' and that the importance, meaning and value of objects, concepts and situations can only be understood within the socially constructed reality through which they are perceived. This supports the current research findings and explains why actors differ in what they perceive to be the most important aspect of a design. This research expands upon these ideas by introducing the concept of a shared architecture. This allows each actor to view the system from their own perspective whilst maintaining an appreciation for how design decisions are going to impact upon the 'world view' of others.

The development of understanding surrounding disciplinary terminology was observed as a method of making sense of disciplinary differences; this also enables actors to learn across boundaries more successfully. Many authors suggest that to enable successful collaboration a 'common language' should be developed (Kleinsmann, 2007; Dong, 2005; Johnson, 2005). Whilst not disagreeing, the current findings suggest that a common language should be developed out of the terminology and combined understanding of existing discipline specific meanings, rather than the formulation of alternative phrases.

The use of system boundaries was re-occurring within the projects studied and was identified as providing actors with security and certainty regarding the problem context. It was also observed however that occasionally system boundaries could inhibit interaction and the development of relationships with the external environment.

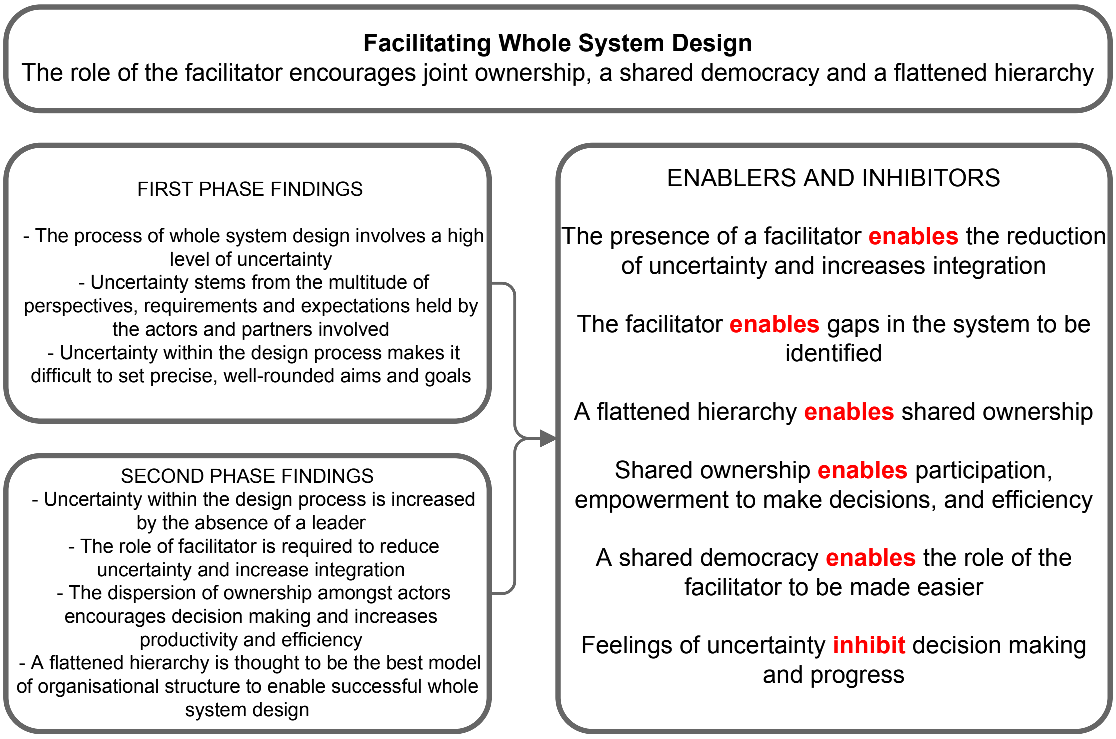


Figure 32: Facilitating Whole System Design: Enabling and Inhibiting Factors

Findings from phase one of the study revealed a substantial feeling of uncertainty surrounding the process of whole system design which was inhibiting progress. Uncertainty and ambiguity within the design process is nothing new as other studies have reported similar findings (Denton, 1997). However, within the current study, uncertainty was closely related to the absence of a leader or manager and therefore different from other studies. Based on the findings, demonstrated in Figure 32, it is suggested that the role of the facilitator is necessary within a whole system design to regard the system from above and to subsequently identify gaps or potentially overlooked relationships between sub-systems.

The role of the facilitator should not be confused with a leader or manager and is complemented by a flattened hierarchy and shared democracy amongst the team. The encouragement of shared ownership amongst the team enables a feeling of empowerment and allows decisions to be made more efficiently.

As presented in Figure 33 the integration of actors and disciplines was identified throughout the study as being central to the identification of advantageous relationships within the system and therefore key to the success of a whole system design. The blurring of individual roles and disciplinary boundaries enables cross-disciplinary learning to be achieved and subsequently the impact of design decisions are more readily appreciated. This finding is supported by literature across disciplines (Brown, 2008, and Wojahn *et al.*, 2001). However, it was identified early on in the study that the blurring of roles can mean that responsibility is not accounted for and can subsequently result in components not being accounted for. This challenge can be addressed through the development of a more cohesive team and additionally by the role of the facilitator.

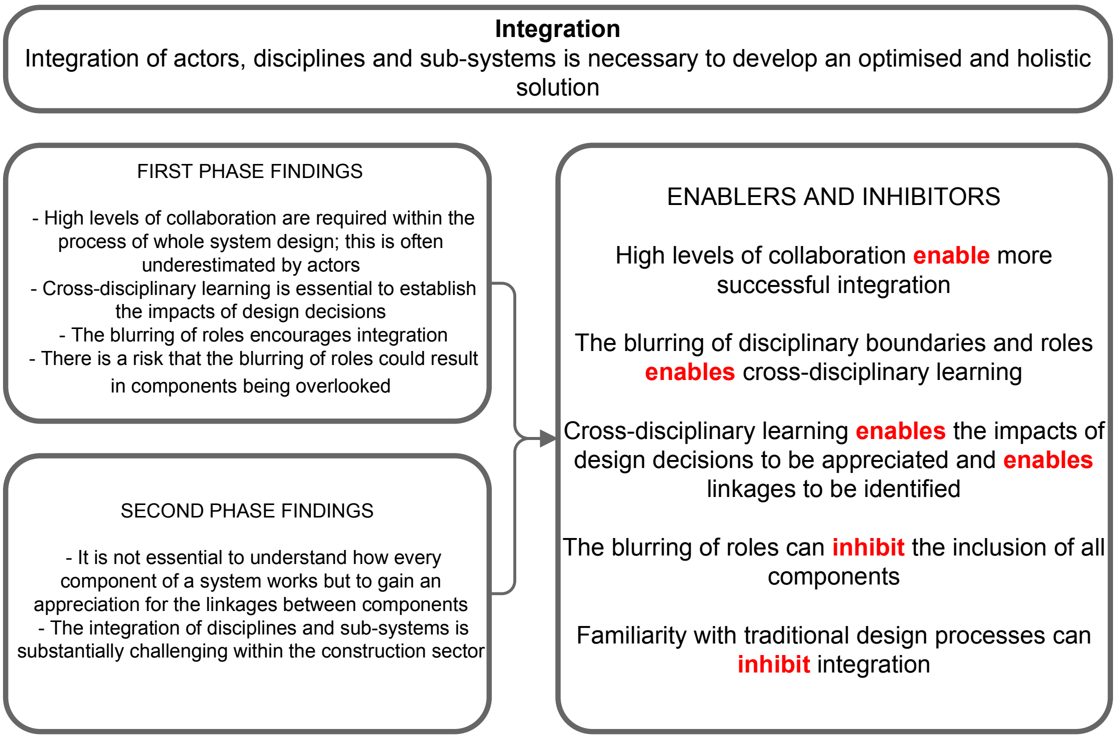


Figure 33: Integration: Enabling and Inhibiting Factors

This section has made the results of the study more explicit by highlighting and comprehensively displaying key findings from phases one and two of the study. The findings from the study are factors that have been observed to substantially influence the process of whole system design; and have subsequently been presented as enablers and inhibiters. This list of factors does are not defining characteristics of whole system design but are factors that contribute to good design practise.

Presenting these factors in this way provides the reader with a structured and systematic account of what influences the practise of whole system design and additionally provides supporting evidence in answering the original research question.

7.3 Positioning and Defining Whole System Design

The previous section presented the findings of the study and identified how they confirmed, disagreed with or built upon existing literature. Many of the factors that influence the process of whole system design apply to other types of design approaches. Subsequently, it is necessary to discuss whole system design within the context of other approaches to enable the factors, which differentiate it, to be made explicit. In particular it has been identified that Collaborative Design, Sustainable Design and System Design share many of the same factors as whole system design. Therefore, this section utilises relevant literature and examples taken from the current study to discuss these approaches.

Literature surrounding sustainable design suggests that, in practise, organisations are still adopting incremental approaches to the development of more sustainable and innovative solutions (Brezet, 1997, van Hemel and Cramer, 2002, Bhamra, 2004, Lofthouse, 2004). Dewberry (1996) highlights that, because of this, sustainable design practise is immature compared with theory surrounding sustainable design as prescribed by authors such as Hawken *et al.* (1999), and Manzini (2003). Although designers are encouraged to take a more revolutionary approach (Bhamra, 2004), and to reach for system level innovation (Brezet, 1997) in response to the challenges of sustainable design, practise has shown that organizational factors are often to blame for holding designers back. Designers work mostly in an operational role and design specifications and important decisions are often made by clients or senior management (Bakker, 1995, Bhamra, 2004). The cases explored within this study highlight that a flattened hierarchy of actors promotes decision making by every member of the design team. This sense of shared ownership in the formation of a multi stakeholder governance has been identified as a factor that significantly contributes to the success of a whole system design and appears to differentiate it from other design approaches.

Sustainable design literature highlights the need to focus on the triple bottom line; to address factors of economic, social and environmental or ecological value (Elkington, 1994), to conduct Life Cycle Analysis (LCA) (Brezet, 1999) or to design the solution from cradle-to-cradle (McDonough and Braungart, 2003) in order to reach a more sustainable solution. In agreement with this approach van Hemel's eco-design principles and strategies suggest that eco-design options should be considered at every stage of the design process from selecting low-impact materials, reduction of material usage such as a reduction of weight through to the optimisation of end of life such as recycling a product. It does not, however, identify that by identifying linkages and relationships between different parts of the design solution, design components could ultimately be made redundant or that through linking different stages of the design process the final design solution could be optimised as a whole. Sustainable design often encourages designers to address each part of the design from a sustainable perspective. However, the benefit of identifying linkages between those parts of the design is frequently over looked. Subsequently this is a factor that is crucial to Whole System Design; differentiating it from other design approaches.

Collaborative design is the process in which actors from different disciplines share their knowledge about both the design process and the design content (Kleinsmann, 2006). It is therefore understandable that collaborative and whole system approaches to design share many common attributes. Some of these include the need for sense making activities to develop a shared understanding (Weick and Roberts, 1993), frequent and consistent communication (Dorst, 2003) and boundary spanning (Sonnenwald, 1996). Authors also highlight the requirement for actors to develop trans-disciplinary skills to enable them to maintain a level of domain specific expertise whilst still being able to look at a broad variety of information (Postrel, 2002; Gibson, 2001). Baird *et al.*, (2000) refer to these actors as 'hunter gatherers' who actively seek data from a range of different sources in order to help them perform their task. Other authors also assign different members of the design team with different tasks to ultimately aid the group as a whole, these include: 'boundary spanners' (Sonnenwald, 1996), 'gate keepers' (Allen, 1971), ' ambassadorial, task coordinator and scouting activities' (Ancona and Caldwell, 1992). These accounts of collaborative design suggest that skills such as knowledge sharing, data gathering and project management can be implemented when necessary and only apply to certain members of the team.

The current study has identified that whole system design requires all actors within a design team to possess a significant number of trans-disciplinary skills. The skills that actors need to possess are frequently context specific and largely dependent upon the emergent nature of the design process. Consequently, actors have to partake in a learning process and develop new skills when and where necessary. Boundary spanning is an important factor of whole system design, however, it is not appropriate to only learn across disciplinary boundaries at certain stages within the process as is suggested in collaborative design literature. Boundary spanning, and similar skills, are required throughout the design process.

The study has provided evidence that whole system design is a learning process in which actors are required to learn and develop new skills across disciplines. These skills are context specific and therefore often cannot be foreseen. This is a significant factor that differentiates whole system design from collaborative design approaches.

Systems design or systems engineering is a process whereby engineers analyse and optimise the whole technical system, which is composed of components, attributes and relationships, to achieve a specified goal (Stasinopoulos *et al.*, 2009). The concept of analysing the system as a whole, and identifying relationships between the components of a design, is very similar to the principles of whole system design. However, as Stasinopoulos *et al.*, (2009) suggest, even when maintaining sight of how one component of the system interacts with all other parts of the system, systems design still performs reductionist analyses of design problems. Therefore design problems are still being broken down into their component parts.

Additionally, as explained by Blanchard and Fabrycky (2006), in system design the objective or purpose of a system must be explicitly defined and understood so that system components can be selected to provide the desired outcome. The process of systems design is very structured and system boundaries are required to be established early on (Stasinopoulos *et al.*, 2009).

It is not necessary to explore the literature surrounding systems design for long to establish that, although the concepts surrounding the design approaches are similar, the process required to carry them out is significantly different. Whole system design is an organic and emergent approach to the design of more sustainable solutions. Multiple perspectives are required to establish linkages between social, environmental and economical phenomena as opposed to limiting the design to individual and predetermined system boundaries.

Additionally, due to the uncertainty surrounding the start point of a whole system design project and the complexity of the design problems the process is trying to provide solutions to, the process of whole system design is messy. It is often not possible to identify a specific goal or outcome of the process or to immediately identify the components that are required to achieve the final design solution. This uncertainty significantly influences the process of whole system design and is also a factor that differentiates whole system design from system design.

Section 2.4 highlighted that due to a lack of literature surrounding whole system design; it was not possible to develop a precise definition. This section has acknowledged that, whilst whole system design shares many attributes with other approaches to design, there are a number of factors that define, and are unique to this approach alone. Following this, and the knowledge gained throughout the study, it is now possible to present a more accurate and informed definition of whole system design.

Subsequently, the author suggests that:

"Whole system design is an integrated and emergent approach to the design of more radically innovative and sustainable solutions. It encourages those involved to look at a problem as a whole; take multiple factors into account and utilise relationships between different parts of the problem as opposed to addressing one aspect at a time"

Additionally, the factors that differentiate whole system design from other design approaches are:

- A whole system design process is organic and emergent. This is due to the uncertainty surrounding the start point of a Whole System Design project and the complexity of the design problems the process is trying to provide solutions to.

- Whole system design is a learning process in which actors are required to learn and develop new skills across disciplines. These skills are context specific and therefore often cannot be foreseen.
- Whole system design requires actors to identify and utilise relationships between sub-systems and systems to optimise the system as a whole. The 'intent' to do this must be recognised and understood from the beginning of the process.

7.4 The Author's Reflections upon Whole System Design

Over the last decade there has been a significant increase in public awareness surrounding the issues we are facing regarding environmental sustainability. Consequently this has also had an impact upon the enhanced understanding of ways in which improved sustainability can be achieved. Although not guaranteeing a more sustainable outcome, whole system design is one approach that has been suggested by authors as providing a way of reaching more optimised and innovative solutions that can achieve higher levels of sustainability at a whole system level. At the beginning of this study in February 2006, understanding surrounding whole system design was limited and there was a multitude of terminology surrounding holistic approaches to design. Three years on, it appears that there is still no consensus as to the terminology being used to describe holistic approaches to design and, additionally, there has only been a limited increase in the utilisation of the term 'whole system design'. There has, however, been a noticeable increase in the understanding surrounding some of the key principles that a whole system approach to design promotes. The development of national and international partnerships across disciplines, thinking systemically, and involving stakeholders within the design process, are increasingly being recognised as necessary components of more sustainable design.

Providing solutions to issues of sustainability still appears to be largely incremental and frequently discipline-specific. Industrial sectors, in many cases, are responding to legislation and targets set by the government in the most cost-effective and quickest ways possible. For example it has been observed that developers of new homes often pay an environmental consultant for a day or two to ensure that their designs meet legislation. Within the following quote an environmental consultant is talking about working for a housing developer:

"so they're saying that we previously paid you for a day to come and tell us if it's going to be hot and cold in the right places and now you are telling me that I can't just employ you for a day to make it zero carbon; you're just trying to get more money out of me! But for the most part they really don't want to hear about it (environmental legislation) and they want it to go away as quickly as possible; they want someone else to deal with it because their business is still building the house and selling it as quickly as possible"

[Environmental Consultant]

Consequently it appears that sustainability, for many, is still an add-on or an afterthought as opposed to being engrained within the design process.

One of the biggest challenges faced by those wishing to promote approaches such as whole system design is the ability to encourage designers, developers, engineers, planners, strategists, and government officials etc. to think holistically and to view the bigger picture. For decades we have been taught and trained to develop disciplinary expertise, and to view the world from within that discipline, and therefore it is understandably difficult and counter-intuitive for experts to begin to learn from, interact and integrate with other disciplines. There is evidence, however, that styles of teaching are recognising the need to think holistically and to develop trans-disciplinary skills and understanding. The Natural Edge Project in Australia operates as a partnership for education and develops curriculum supplements for students from the age of 10 regarding sustainable education one of which is entitled ‘Whole System Design: An Integrated Approach to Engineering’ (TNEP, 2008). Additionally the Schumacher College in the UK has recently introduced an MSc in ‘Holistic Science’ which calls into question ‘western scientific methods which have been dominated by specialisation in disciplines and by reductionism’ and instead ‘explores new trans-disciplinary methodologies that go beyond reductionism in understanding whole systems’ (Schumacher College, 2008). Collaborative approaches to design have been around for a long time; however, as demonstrated within the study, whole system design goes a step further than traditional collaboration. It has been observed that the differences between traditional design and whole system design are frequently misunderstood. This may be one of the reasons why actors have been frequently observed to underestimate the high levels of collaboration, communication and commitment that are required to undertake a whole system design. Although whole system design shares many of the same attributes as traditional design, the research has identified that there are a number of characteristics that define whole system design and consequently differentiate it from a traditional design process. These are summarised in Table 15.

Prior research has gone a long way towards identifying some of the enablers and inhibitors of the process of collaborative design (Kleinsmann, 2006). This literature, as demonstrated in Chapter Two, has provided a strong foundation for the current investigation. Although many of the attributes of collaborative design have been identified within the process of whole system design it has been observed that these alone are not enough. Therefore, as demonstrated within Table 15, the current research has expanded on and added to the attributes of collaborative and traditional design, to effectively put them in the context of a whole system design.

Attributes	Traditional Design	Whole System Design
Focus	The improvement, modification or re-design of individual component parts; incremental innovation	Achieving optimised efficiency within a whole system; a step change in innovation
Technology	Continuing development of new technology	Use and combination of existing technology in novel ways
Process	Stage-gate process governed by deadlines and targets	Organic, unspecified process allowing for emergent properties
Collaboration	Utilisation of known **sub-contractors** who will do the job given to them	The development of **partnerships** with organisations who will provide new perspectives and questions
Structure	Hierarchical design team structure	Flattened hierarchical structure
Participation	Reliance on experts	Shared ownership and open discussion amongst all relevant stakeholders
Outcome	A product, building, strategy, service	A solution consisting of a unique formulation of components; not limited to one form
Communication	When it is needed, between experts utilising jargon and discipline-specific terminology	Frequently, and the development of a common language so that everyone can be included
Knowledge Base	Discipline specific	Trans-disciplinary

Table 15: Exploring the differences between traditional design and whole system design

7.5 Utilising the Results of the Research

Whole system design suggests that, to enable a holistic and optimised solution to be developed, multiple relevant perspectives should be taken into account as opposed to selecting, what appear to be, the key points of the design and focusing on those. Likewise it is the researcher's opinion that when carrying out a whole system design process there are not 5 or 6 key points that need to be addressed to ensure a successful result. The study has demonstrated that there are many aspects of a whole system design process and it is not possible to say that one of these is more important than the others. This is not to say that whole system design cannot be done successfully if a few of these factors are missed out; however, when there is a problem with a whole system design then it could be due to a number of factors. This is because the process of whole system design is complex and the factors within that process are intrinsically interlinked. For example if it occurred that actors were continuously arguing and experiencing conflict, the cause could lie in all, several or one of the following aspects;

- the partnership could lack certain expertise,
- interaction may not be frequent enough,
- actors may not possess an equal balance of interpersonal and technical skills,
- the team may lack a sense of shared purpose, understanding and identity,
- there could be a significant difference in the motivation of actors,
- the requirements, expectations and needs of actors may not have been honestly and openly communicated,
- there could be a lack of facilitation,
- actors may not be attempting to learn across disciplinary boundaries.

Due to this complexity it is not possible to prescribe a detailed design process for whole system design. This study has utilised this complexity to provide a comprehensive and valid account of the aspects of whole system design that actors should be aware of and in doing so is to be regarded as a holistic guide and support as opposed to a set of rules or a mechanical process.

7.5.1 Recommendations for industry

This study is aimed at guiding and supporting those who are adopting a whole system approach to design. As demonstrated in Chapter Two, the terminology surrounding holistic and integrated approaches to design is still ambiguous. Therefore, regardless of the terminology being used, this study is additionally appropriate to those who are embarking on a multi-disciplinary partnership with the aim of achieving a design solution which is optimised at a whole system level.

This section specifically highlights those groups of people that the study can benefit.

Design Researchers

The study has provided the design research community with a detailed literature review surrounding holistic approaches to design that are currently being adopted. Additionally readers of the study will have an improved understanding concerning the process of whole system design and the factors that enable and inhibit that process. The findings of the research provide an evidence based foundation on which to base future research surrounding whole system design and integrated and holistic approaches to design.

Other Researchers

Through the documentation of the flexible methodology utilised to explore socially complex phenomena, the study has provided social researchers with a methodological framework. This framework can be modified and utilised in future research projects addressing similar contexts in which multiple actors from diverse backgrounds are being studied.

Design Consultants

The findings of the research will aid design consultants when working directly with whole system design teams. Additionally the multi-disciplinary nature of the study means that results are easily transferable across disciplines and so can be utilised by design and organisational consultants alike who are working towards the improvement of team effectiveness.

Design Practitioners

Design practitioners involved in the process of whole system design have been provided with detailed knowledge and understanding surrounding how to carry out that process. The study guides designers through the process by warning them of possible challenges and additionally providing detailed accounts of real life whole system design projects. The study also supports designers by providing answers at times of uncertainty within the process.

Facilitators

Facilitators of a whole system design are guided and supported by the current research. It highlights areas of uncertainty and confusion and gives detailed account of the challenges faced. The enabling and inhibiting factors provide facilitators with knowledge regarding what obstacles to look out for, what the causes of those obstacles might be and also ways of dealing with them.

Design Educators

The study provides design educators with a comprehensive account of the enabling and inhibiting factors surrounding a whole system design process; and therefore guides them towards the key messages that need to be communicated to students. These factors can be utilised to demonstrate scenarios across a wide range of design processes and contexts.

7.6 Summary

The initial part of this chapter highlighted the key findings and observations from both phases of the study. These were summarised and the resulting factors, which were identified as enabling and inhibiting the process of whole system design, were presented. This section demonstrated how the original research question had been addressed. The second section of the chapter reflected holistically on the concept of whole system design. The author provided her own views concerning the current state of sustainable design, how the whole system approach fits into this and what the challenging aspects of developing more sustainable solutions continue to be. The findings from the study were used to highlight the differing characteristics of traditional and whole system approaches to design. Finally this chapter has addressed how the research findings are to be used and, in particular, which groups of people they will benefit.

	CHAPTER AIMS	ACTIVITIES	OUTCOMES
	CONCLUSIONS		
8	To summarise the contribution to knowledge , to address the strengths and challenges of the study and to make recommendations for future research	Synthesis of key findings into contribution to knowledge. Reflection of research findings and literature to highlight strengths and challenges and future research directions	- Contribution to Knowledge - Strengths and Challenges - Recommendation for Future Research

Conclusions

This chapter presents the conclusions of the research. The contribution to knowledge is discussed alongside the strengths and challenges of the research. Areas of future research resulting from the study are recommended.

8.1 Introduction and Purpose

This chapter summarises the research study and demonstrates how the findings have addressed the original research question and objectives. The novelty of the research and how it has contributed to existing knowledge is presented. The strengths of the study are highlighted and any challenges that were faced and overcome are discussed. The final part of the chapter makes recommendations for future research based on the outcomes of the study.

8.2 Addressing the Research Question

The research question originally presented in Chapter One was:

> What factors enable and inhibit the successful adoption of a whole system approach to design?

This was addressed in three stages. The first phase of the research, detailed in Chapters Four and Five, took a case study approach and followed a whole system design project from beginning to end over the period of 36 months. A flexible methodology was undertaken consisting of:

- 22 design and progress-meeting observations resulting in over 120 hours of audio data,
- 18 semi-structured and un-structured interviews resulting in 150 pages of transcribed data,
- the analysis of approximately 300 group emails, 25 sets of meeting agendas and minutes and numerous press articles.

This resulted in a multitude of qualitative data from which 10 key themes were identified. The second phase of the research, detailed in Chapter Six, aimed to confirm, modify and validate the initial findings through a number of additional design contexts. The researcher undertook interviews and focus groups with 11 participants from 5 different organisations, this resulted in an additional 100 pages of transcribed data. This data was then compared with the initial data and the original 10 themes were modified to represent the information gathered. This phase resulted in 8 final themes.

Finally, key findings from both research phases were presented and the factoprs that had been observed to substantially influence the process of whole system design were identified (see Chapter Seven). The study has therefore addressed and answered the research question and has provided validated results to support this.

8.3 Addressing the Research Objectives

This section now details the objectives on which the research was based. Evidence is provided of how the study has addressed each.

Identify qualitative factors that are generic to adopting a holistic approach to the design of more innovative and sustainable solutions

This research objective was met by carrying out a comprehensive review of current and relevant literature (see Chapter Two). The review presented, discussed, and compared multiple holistic approaches to the design of more innovative and sustainable solutions. The comparison resulted in the identification of numerous qualitative factors that were found to be generic to the process of holistic design; these were presented in Table 3. These factors were addressed in more detail and were utilised to form the foundation for the remainder of the study.

Undertake a case study to enable a better understanding, surrounding the process of whole system design, to be achieved

This research objective was met by consistently and closely working alongside a whole system design project over a period of three years (see Chapters Four and Five). A comprehensive and holistic perspective surrounding the integrative process of whole system design was provided: by undertaking observations of progress-and design-meetings; by interviewing team members and other experts within the field of whole system design, and by reviewing current and relevant literature.

Confirm, modify and validate findings to encompass different whole system design contexts, disciplines and industrial sectors

This research objective was met by carrying out semi-structured interviews with participants from individually selected organisations (see Chapter Six). Selection criteria were developed to ensure that information was obtained from a sample of people representing whole system design experience within a variety of design contexts, disciplines and industrial sectors. Participants were specifically asked questions regarding the initial research findings and were additionally asked to provide accounts of their own experiences of whole system design. This method was successful in confirming, modifying and validating the original research findings.

Utilise findings to identify qualitative factors which enable and inhibit the process of whole system design

This research objective was met through synthesising the key findings from phase one and two of the research. Further analysis was conducted and the factors that enable and inhibit the process of whole system design were presented (See Chapter Seven).

8.4 Contribution to Knowledge

Research surrounding the design of more sustainable and innovative solutions largely concerns the outcome of the design and the development of tools and methods to assess the success of that outcome. Consequently, there is a lack of research addressing the process which actors should follow to obtain those outcomes. The current study has contributed to knowledge and understanding surrounding the process that actors should follow when adopting a whole system approach to design and has provided a comprehensive account of the challenges they may face. Figure 34 presents the factors which, based on this study, have been observed to substantially influence the process of whole system design. This contribution has been communicated to researchers and practitioners through the publication of six papers in conferences proceedings and journals; one of which was awarded the position of runner-up in an international design award.

Forming and Sustaining a Partnership

Whole System Design requires the integration of multiple perspectives combined with complementary expertise, experience, ability and competence

Enabling and Inhibiting Factors

A wide spanning social network **enables** the formation of partnerships

Maintaining a core design team throughout the project **enables** the development of a shared understanding of purpose, process and design intent

Utilising existing contacts based on familiarity or convenience may **inhibit** access to relevant expertise

Spending time and effort on recruiting the ideal actors **enables** the development of a successful and cohesive team

Human and Non-Human Interaction

Whole system design requires frequent communication between all parts of the system

Enabling and Inhibiting Factors

Frequent communication between actors **enables** integration

Interconnectivity between sub-systems, systems and the external environment **enables** advantageous relationships to be discovered and **enables** the elimination of components

Detailed design discussion during project meetings **inhibits** equal participation

Reluctance to interact with external systems **inhibits** the implementation of the final solution

Individual Characteristics

Whole system design requires actors to have a balance of discipline specific expertise and trans-disciplinary skills

Enabling and Inhibiting Factors

Possessing a balance of discipline-specific expertise and trans-disciplinary skills **enables** actors to appreciate the impact of design decisions

Familiarity with traditional design processes can **inhibit** the ability to think systemically

A lack of knowledge and education **inhibits** understanding of the benefits surrounding trans-disciplinary skills

A lack of incentive **inhibits** the development and utilisation of trans-disciplinary skills

Understanding of Purpose and Process

It is necessary to develop a shared understanding of the end goal as well as the whole systems approach being adopted to get there

Enabling and Inhibiting Factors

The development of a sense of identity **enables** integration and a shared understanding of purpose

Considering the external environment within the development of a shared purpose **enables** the final solution to be implemented more successfully

Regarding the system as a whole **enables** the identification of emergent properties and the understanding of counterintuitive aspects

Lack of commitment **inhibits** the process of whole system design

A lack of understanding surrounding the principles of whole systems design significantly **inhibits** the process

Overlooking emergent properties **inhibits** the development of a whole system solution

Personal and Organisational Motivation

An alignment between individual and project motivations and also between the project and the intended consumers

Enabling and Inhibiting Factors

Establishing an alignment of motivation between actors, the project team AND the potential consumers **enables** the development of a more comprehensive solution

Openness and honesty between actors early on in the design process **enables** an alignment to be established

Un-communicated motivations can lead to conflict and **inhibit** successful integration

Legislation can **inhibit** innovative design as opposed to increasing motivation

Sense Making

Sense making activities are necessary to gain a shared understanding of the system and the multiple perspectives associated with it

Enabling and Inhibiting Factors

Gaining an understanding of cross-disciplinary terminology **enables** effective communication

Making sense of perspectives, requirements, needs etc. **enables** a shared architecture of the final solution to be developed

Defining system boundaries **enables** actors to develop structure and certainty

A system boundary can **inhibit** the development of relationships with the external environment

Facilitating Whole System Design

The role of the facilitator encourages joint ownership, a shared democracy and a flattened hierarchy

Enabling and Inhibiting Factors

The presence of a facilitator **enables** the reduction of uncertainty and increases integration

The facilitator **enables** gaps in the system to be identified

A flattened hierarchy **enables** shared ownership

Shared ownership **enables** participation, empowerment to make decisions, and efficiency

A shared democracy **enables** the role of the facilitator to be made easier

Feelings of uncertainty **inhibit** decision making and progress

Integration

Integration of actors, disciplines and sub-systems is necessary to develop an optimised and holistic solution

Enabling and Inhibiting Factors

High levels of collaboration **enable** more successful integration

The blurring of disciplinary boundaries and roles **enables** cross-disciplinary learning

Cross-disciplinary learning **enables** the impacts of design decisions to be appreciated and **enables** linkages to be identified

The blurring of roles can **inhibit** the inclusion of all components

Familiarity with traditional design processes can **inhibit** integration

Figure 34: Factors that Enable and Inhibit the Process of Whole System Design

Whole system design is a relatively new concept and consequently there are few documented examples of real life case studies that have adopted a whole system approach to design. This study contributes a comprehensive report of a longitudinal case study which had been followed from beginning to end. This provides an evidence-based account which can substantially inform future research concerning whole system design.

Many studies concerning the collaboration of actors have focused on a particular aspect of the process such as trust or mental models. Additionally, many authors approach this type of research from one discipline or perspective such as psychology or engineering. This study has adopted a holistic research approach and has identified and explored many aspects of whole system design, additionally the perspectives of multiple disciplines have been sought; therefore providing a more thorough and trans-disciplinary account.

The initial phase of the study presented 10 themes that were observed as common to the integrated process of whole system design, based on the in-depth study of one case. These themes were then used to inform the second phase of the study in which additional design contexts were addressed within five separate organisations. Ultimately 8 themes have resulted from the research and it is thought that each of these contains information that substantially influences the process of whole system design. It is the framework of these themes, presented in Figure 34, which provides a novel contribution to knowledge. Although, previous research, as detailed in Section 7.2, has investigated factors addressed by the themes, these factors have not previously been studied holistically in one study.

Finally, based on the findings of the study, it has been possible to refine what is meant by whole system design and in doing so move towards a more accurate definition has been developed.

"Whole System Design is an integrated and emergent approach to the design of more radically innovative and sustainable solutions. It encourages those involved to look at a problem as a whole; take multiple factors into account and utilise relationships between different parts of the problem as opposed to addressing one aspect at a time"

This definition highlights the factors that differentiate whole system design from other approaches to design and therefore provides a novel contribution to knowledge and understanding.

The design, production and presentation of this research project has significantly added to and built upon existing research and literature. Subsequently, the study has contributed to knowledge and understanding, within the field of design and, more specifically, to the area of whole system design.

8.5 Reflecting Upon the Research

This section reflects upon the strengths of the research and highlights any challenges that were faced and discusses how they were addressed. Attention is specifically paid to the research methodology, the subsequent data that was collected and the research findings. The suitability of the primary case study is also considered.

8.5.1 Strengths

The methodology was designed to enable the researcher flexibility in data collection. This was beneficial as when working with complex human systems it is impossible to plan for every eventuality; therefore the researcher ensured that the tools and methods selected would reflect this. Additionally the study was conducted in two phases; the iterative process allowed findings identified from the case study to be validated during the interviews carried out in the second phase. Any new findings from the second phase were validated by being fed back into the ongoing case study.

The first phase of data was collected over the three year period of the PhD process from the focal case study. The researcher joined the case study 6 months into it which meant that it was possible to observe the design process from almost the beginning to the very end. In total this consisted of:

- The observation of 22 design meetings producing over 120 hours of audio-data;
- Interviewing 18 participants producing around 200 pages of transcribed data;
- Extensive project documentation including emails, press releases, company websites, meeting agendas, and meeting minutes.

This method was therefore successful in providing the researcher with as many detailed accounts of the process of whole system design as possible.

The second phase of research included the collection of data from 5 organisations that were chosen specifically for their experience of the whole system design process. 11 interviews were undertaken lasting between 1 hour and 2 hours 40 minutes. This resulted in approximately 140 pages of transcribed data.

The research methodology enabled a triangulation of data-collection to be utilised. Frequently a finding that emerged from one method could be confirmed or rejected by at least two other methods. Constant interaction with the case study enabled findings and themes to be verified and discussed with actors as they emerged.

8.5.2 Limitations

The second phase of the research aimed to validate, modify and add to the findings generated by the case study undertaken in Phase One. As whole system design is a relatively new field it was difficult to identify actors with substantial experience in this area. Consequently the second phase of the research was limited to 11 interviews with actors from 5 different organisations and therefore the perspectives of different contexts in which a whole system approach has been adopted is weakly represented. However, the interviews did entail long and in-depth discussions with individually selected experts and therefore provided the study with a substantial amount of high-quality data.

As detailed in Section 3.6, the validity of the research was maintained through a triangulation of data; multiple methods of data collection were used to ensure that the findings being identified were accurate. Interviews carried out towards during the latter stages of the case study included questions that specifically highlighted the themes that had been identified. This ensured that the themes were agreed upon by the actors involved and additionally gave them the chance to highlight any attributes that had been missed out. However, the final results of the study and the resulting 8 themes were not taken back to the original actors from the case study. Doing this would have allowed the actors to visualise the final group of themes and therefore have the opportunity to point out any missing information. This would have provided the findings with additional validity.

The reliability of the study was maintained through clear documentation of the procedures that were being carried out throughout all stages of the research. Subsequently, it is hoped that if the research was replicated then the same or similar findings would be identified. Due to the subjectivity surrounding thematic analysis it cannot be claimed, however, that a researcher from a different background or discipline wouldn't identify additional or different themes from the data. This is not a weakness of the study as the focus of the research was made clear from the beginning; emerging from the gaps in literature and the interests of the researcher herself. This focus subsequently guided the identification of themes when analysing the data.

The findings of the study will help to understand other projects that adopt a whole system approach to design. Robson (2002) suggests that this indicates generalisability of findings. It is not possible to say, however, that upon the study of additional Whole System Design projects the framework would not change to allow for additional design contexts. Subsequently, the findings are not generalisable across design contexts but provide a reliable account of Whole System Design within the context of the cases studied.

8.5.3 Suitability of case study

Knowledge of other whole system design projects has made it apparent that the LIFECar project was an ideal size for a case study. Many whole system design projects, such as the development of the Olympic Village, discussed in Chapter Seven, can involve hundreds of people. It would not be possible to interview every actor and therefore an encompassing vision of the project would not have been gained. The size of the LIFECar project was substantial enough to get a feeling of the complexity involved yet was also manageable from a data-collection and analysis perspective.

Additionally, the LIFECar project involved the integration of 6 partners from a wide range of different disciplines, organisations and backgrounds. This was a challenging yet manageable context in which to comprehensibly study trans-disciplinary integration.

The disadvantage of utilising the LIFECar project as a case study was the risk that aspects occurring in larger projects could be overlooked. This was overcome in the second phase of the research by selecting actors with experience of other whole system design projects which differed substantially from the LIFECar project. It was concluded that many of the observations made were common to whole system design projects, regardless of their size.

8.6 Recommendations for Future Research

This study has concluded that there is a need for further research within the field of whole system design and additionally the design of more sustainable, optimised and innovative solutions in general. The study has provided its audience with key factors that have been observed to substantially influence the process of whole system design. The study does not claim, however, that this list is complete. Subsequently, further research is required to evaluate these factors across multiple design contexts, to explore whole system design from a variety of design and disciplinary perspectives and to develop the framework into a more comprehensive and encompassing account of whole system design.

Additionally, the findings of the study are influencing factors but not necessarily factors that define whole system design. Further work needs to address the definition of whole system design. Research needs to question whether the identified features, within this study, define whole system design or whether there are additional features that more accurately represent its integrity.

Many of the cases studied within the research have concerned one-off projects between multiple organisations. Based on the findings of the study it is suggested that many of the key aspects of a whole system design would be beneficial within the context of a single organisation. Research is needed to establish whether or not whole system design can be applied internally within an organisation and, if so, how it can be successfully implemented.

Findings from the study suggested that one of the most challenging aspects of adopting a whole system approach to design was for actors to think systemically. Literature suggests that the ability to think systemically is increasingly becoming a requirement of more sustainable design. It is understandable then that future research needs to address the concept of thinking systemically and ask questions such as:

- Where is it being taught?
- What methods are available to teach actors to think systemically?
- What other design contexts could benefit from the use of systemic thinking?

Findings suggested that sustainability still appears to be an afterthought of design, particularly within the construction industry. Future research needs to address how sustainability can be more successfully ingrained within the design process and how designers can be encouraged to think of more sustainable solutions as part of their day-to-day activity i.e. without any additional incentive.

8.7 Final Thesis Summary

This study aimed to improve knowledge and understanding surrounding the concept of whole system design by identifying and exploring those factors that enabled and inhibited the whole system design process. The findings of the research have provided the design community and practitioners of whole system design with support and guidance concerning the integrative process necessary to develop more sustainable, optimised and innovative solutions. Suggestions for areas of future research are proposed to enable the field of whole system design to be developed further.

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Appendices

Appendix 1: Interview questions asked to LIFECar project members

This appendix presents the semi-structured interview questions that were asked to LIFECar team members during phase one of the research.

Participant Background:

Name:

Company:

Role within that company:

How long have you been working here?

Personal Involvement with the Project:

How did you become involved with the LIFECar Project?

Why did you want to work on the project?

What is your past experience with regards to the project?

How would you define your role within the project?

How much of your week do you spend working on the project?

Personal Views:

How does this project compare with other projects you have worked on for example in terms of collaboration and the structure of the design process?

What do you think the biggest challenge has been so far?

Do you see this as being the biggest challenge in the future or do you think there are bigger challenges yet to come?

With regards to the project 'team', do you think you are working well together?

How frequently do you interact with other members of the project?
Who would you say you interacted with most frequently?
How do you think collaboration between the team could be improved?

Whole System Design:

What does Whole System Design mean to you?
Do you think the use of this approach is an important factor to the LIFECar project?
What issues do you think WSD raises?

Questions Surrounding Attributes:

Do you think that there is a lead partner within the project?
Do you think there have been or could be any ownership issues?
How important do you think it is for team members to have an understanding of other sub-systems?
What other sub-system do you know most and least about?
It has been suggested that there is a high level of uncertainty within this type of holistic and integrated design process. How would you advise others to cope with this uncertainty based on your LC experience?
Do you think the team have found a common purpose and goal to which you are all working towards?
Ultimately do you think the final design solution will be a success?

Appendix 2: Interview questions asked to participants during phase two of the research

This appendix presents the semi-structured interview questions that were asked to participants during phase two of the research

Participant Background:

Name:

Organisation:

Position within organisation:

How long have you been in this organisation:

Background prior to joining organisation:

Brief description of what organisation does:

Each participant was provided with a definition of whole system design:

> *"An integrated approach to the design of more sustainable and innovative solutions which encourages those involved to look at a problem as a whole, take multiple factors into account and utilise relationships between different parts of the problem as opposed to addressing one aspect at a time."*

Participants own experience of whole system design:

Is 'Whole System Design' a term you of heard of before or would use?

Please could you describe a project that you are working on or have worked on which fits into this definition?

What do you think enabled or facilitated this type of design?

What do you think hindered it?

How many people were involved in this project and from how many different organisations / sectors?
What were the benefits of having multiple people on the project?
What were the challenges?
How important do you think the aspect of sustainability is within this type of design?
How do you think this project differs from a more straightforward collaborative design?

Thematic Validation

It is thought that seeking multiple perspectives is a good way of expanding the boundaries of the problem and therefore developing a more inclusive and holistic solution. I have observed however that partners or stakeholders bring with them very specific expertise and are familiar with individual ways of working. Have you found this and if so how was it ensured that the integration of stakeholders ran smoothly?

I have found that there was uncertainty of roles and responsibilities within the project team. How were roles and responsibilities managed within the team in your own experience?

Within a team consisting of multiple experts in multiple areas there was a worry that integral parts of the system could be overlooked. Was this a concern in your project? How was it managed?

Did you feel that there was a difference between the motivations or purpose of individuals or of individual organisations and those that were shared by the project consortium as a whole? If so do you think this had an effect on the project?

How much understanding of the other parts of the design do you think you need to have in order to maintain a vision of the whole system?

How far do you think this understanding goes? i.e. does it stop with the stakeholders that are involved in meetings on a regular basis?

Do you think the use of similar terminology or a common language between the stakeholders is an important part of this type of design?

How was this developed between the partners within the project that you are involved with?

Did the project that you were working on take longer than planned? Why was this?

Have you considered that this type of design takes longer for commitment and trust to develop between those involved? Do you think that commitment and trust are important factors of project success?

Did you feel that this approach to design gave you more flexibility to be innovative?

I found that having no 'fixed' goal induced a feeling of uncertainty early on amongst the project team. Did you experience this? How was this managed?

In a traditional design process decisions are made as early as possible whereas in a WSD this is often not possible. It was observed that this lack of certainty therefore continued throughout the majority of the project and that those involved had to learn to work with this. Did you experience this? Do you think it is possible to allow for uncertain decision making within this type of design process?

How much do you think your project team relied on it's surrounding network of expertise?

What generic characteristics or skills do you think you need to have to successfully work on a holistic design project?

Did you find that attendance at meetings and / or the consistency of team members was a problem? What influence did this have on the rest of the team?

I found that individuals who were not used to working in such a close knit team found it difficult to share their work – particularly handing over unfinished designs. Did you experience this?

It is suggested by many authors that undertaking a WSD requires designers to adopt a 'change in design mentality' or to start 'thinking differently'. Do you agree with this?

Do you think the way in which you were trained helped or hindered your ability to think in a joined up way / more holistically?

Appendix 3: A sample interview transcript

This appendix provides an example transcript taken from interviews carried out with LIFECar team members during the first phase of the research.

FC: so just background to begin with really. What role do you play within [company name] and how long have you been here?

P1: I am what's called a lead researcher for the project and I've worked for [company name] for 11 years and on LIFECar since we first heard about it which I think would have been about 2006 maybe

FC: How did you first become involved with LIFECar? What were your motivations?

P1: I was asked to draw up an outline plan as to how we might build the Fuel Cell and to start costing our part of the project

FC: What is your past experience with regards to the LC project?

P1: Not as a lead researcher but I've done, we've worked on Dti projects before. As a lead researcher I've done two maybe three fuel cell projects with small fuel cells and fuel cell testing and things like that but for smaller systems and no real automotive stuff and certainly not on this scale.

FC: how do you define your role within the project?

P1: My role is day to day to make sure that the work is done; to do all the testing and the construction and the ordering and all that type of thing and to keep the project manager informed as to whether that's going well or not and to basically manage on a practical level all of the [company name] activity within this project. Yeh I would have said that was it on a more day to day basis; so I don't have to worry too much about the financial side of it although I have to not spend like mad but yeh to make sure it's done.

P1: I can ask for extra people to be involved and if not … I should be able to do everything that's in the project and whether I have help or not that's really the case with being a lead researcher

FC: could you estimate how much of your week you spend working on the project?

P1: on average through the whole project it's probably been about 75%

FC: how does this project compare with others that you have worked on for example in terms of collaboration and the structure of the project?

P1: well we've worked on collaborative Dti projects before and I've been involved with them with not as many partners but still the same trouble you get with collaboration deciding who gets what done so yeh it compares to that one and we've done lots of projects where we've collaborated with other groups in [company name] so that's quite a similar thing in coming up with a system but most of the projects, the smaller projects, are just within the groups… on the ones where we've collaborated its been almost, well it's an identical kind of set up with Dti funding and equal partners.

FC: what do you think the biggest challenge has been so far?

P1: the biggest challenge has been to develop from scratch the fuel cell for this project within the budget and because in most cases to develop something from scratch to the level it needs to be, driven by somebody in the car, most companies would be spending a budget in the region of £10 or £12 million and we're doing it obviously for a lot less than that and so that's basically made it extremely risky and it's been a real challenge. And the second big challenge has been fitting in with a consortium that was sort of already together and already had an idea as to what the fuel cell partner would be bringing to it. And marrying that up with what we thought we were bringing to it, we've kind of been the late joiner into the group and so that's been quite a challenge to work with. And the third one obviously has been controlling our suppliers (laughs) and making them supply! But the main one has been the actual activity of developing the fuel cell; it's been rock hard!

FC: and do you see those challenges as carrying on as the main obstacles or do you see others emerging as the project draws to a close?

P1: challenge number one which is developing the FC will obviously carry on because it is obviously not finished. By the end of this project it will be a demonstration FC of a certain output but we obviously want it to get better. Challenge two sort of disappears because we are not in that consortium any more and challenge number three will probably be about maybe the same supplier maybe a different one but we have sort of learnt a lot of lessons about how we control those so we have … what's that term for doing a review after a project? Where you work out what went wrong? And put up signs saying don't do this again?

FC: lessons learnt?

P1: lessons learnt that's it. Yeh that's one of the big lessons learnt is putting penalty clauses in

FC: and do you see any new challenges yet to come?

P1: I think that all this stuff about interfacing may prove to be a key challenge within the integration of the car because right at the beginning, as we were talking at lunch time about [actor name] telling us to write down where we saw our system stopping and the next one starting, that was done ages ago but then even at the last meeting people were still discovering aspects of the car, parts of the electrical system that had not been covered.

P1: it is hard to tell who on the project is responsible for sorting out those last minute niggles. I mean I know [actor name] has asked for a whole lot of new testing for the voltage monitoring on the super caps and the smoothing capacitors which just weren't in there at all.

FC: with regards to the team, the consortium, do you think you are generally working well together?

P1: I think we've worked really well with [company name]'s group, with [actor name], that's been really good and I've learnt quite a lot from it and we've helped them out a little bit with software and it's also interesting. I've found working with [actor name], with [company name], good as well. I don't know whether I've been fast enough with replying to [actor name]'s questions, so I don't know whether he'd agree! So that's been good and actually the only actual testing between people in the group has been between me and [actor name] and [actor name] and the [company name] guys and we were present at that as well and that's like actually getting part of the system working before the final build and its sort of calmed [actor name] down with his worries about his system but it's also made sure that we know that things which are new to us – we didn't know that we were going to need to do any controls – and we got the opportunity to test them early on. So the three way thing there has been good. And also with [company name] as well; I've been swapping drawings with [actor name] for some time now and talking about how things fit in. So yes between the actual partners who are delivering stuff I think it's been pretty good. We've tried to help out in different places by providing different information on things they might not have known about like what was in a super capacitor because they were thinking they might abuse test them and obviously they've got to worry about what comes out of those. So we sent them some data on that; samples and stuff. So it's been good.

P1: See I cant agree with say somebody from [company name] that we're going to do a whole load of their work or a whole load of work for them because obviously payment comes into that but when you come to a kind of unofficial like for like swap that works quite well. So we sort of did the software but they gave us a lot of tuition about the CAN interface and we took our student up there and it was a little fair swap really.

FC: Yes, I guess it's difficult in any sort of project where you do actually become friends and you learn things off each other and do favours for each other but there still has to be a certain level of formality to it.

P1: Oh yes if it got any bigger than that it might actually not happen because you know I can't agree to buy something for [actor name] or [actor name] no matter how much I like him (laughs). But I certainly think that there are people on the consortium who we'd probably work with again

FC: how frequently would you say that you interacted with other members of the project?

P1: there was a time when me and [actor name] were on the phone to each other loads of times a week. But that's not happening at the minute. Depending upon what we are doing it has been quite frequent but at the moment it's not.

FC: Earlier you said you had spoken to [actor name] this morning?

P1: I spoke to [actor name] this morning yes; I can't remember what about. He phoned up about something. About hydrogen yes. And [actor name] used to call quite a lot in the early evening (laughs)

FC: who would you normally speak to on the project team?

P1: Mainly [actor name] or [actor name]. That's because we've got a thing going on. There's something in the current plan that we need to speak to them about. I don't think we would normally you know all the way through it

FC: how do you think collaboration between the team could be improved?

P1: Locality. I think having so many sites over such a great distance is always going to be a hindrance in such a geographically diverse project. I think; we have these huge meetings with loads of people say for example the one they had down here where this entire room was full of people. And it's very difficult to actually get on with the technical side of it at a technical meeting when every single person … I know the whole system design thing means that somebody might chip in but actually at these LIFECar meetings quite often I've got a list of things that I need to discuss with [actor name] and [actor name] and [actor name] and it probably could have been improved when we all got together that day for there to be kind of a session in the day where we could just do our own thing

FC: especially as you are travelling so far anyway it would be nice to get the opportunity

P1: yes face to face to get everything ironed out and then … I noticed well [actor name] noticed that when you take your notes Fiona that you quite often draw a diagram showing that in the big meeting there's 3 people who are actually having a discussion and that's the way it goes normally is that there's a discussion which happens obviously in front of quite a lot of people but then quite a lot of them at lunch time everyone's collaring each other saying 'that thing we're doing you know…' it doesn't need discussing in front of everybody but it just needs to be sorted out and its better when they're face to face, people actually agree what they're going to do

P1: The start-up meetings were technical when everyone was discussing everything. They were quite useful obviously because we were all new and finding out that this works like this because we could hear [actor name] talking about the electronics but the more recent ones have turned into more like reviews where its gone 'right motors; when are they going to be done? Car body, fuel cell, when's it going to be done? Why not?' and he is just going through the list like that and that's basically it. You get through that and then you actually get on with the useful work of the day which is you know 'here's a drawing of where these holes need to be'. So it was useful at the beginning to have everyone together but I think now its kind of .. we just need to get it done now.

FC: we kind of discussed this earlier in the day but I've got the question what does whole system design mean to you?

P1: until you described it (earlier in the day) I though whole system design was where you worked out exactly how you were going to do something before you actually did it. And you worked out how everything was going to effect everything else before you did it, and I thought that was kind of what we were doing because everybody at the beginning was saying 'right I, in order for me to do this you need to do that, I need this from you' and these kind of boundaries between the systems were being ironed out and that's what I understood to be whole system design; where everyone was coming up, as a group, with a complete design and then were going to build it and it would work. That's what it thought it meant, and I suppose the weakness of that is that no one has actually tested it to see whether it was going to work before they .. or any of the components on it – which is easy enough if you are using off the shelf components because you know that they are going to work but if you are developing something from scratch there is always that thing where; of course I can say it is going to do this but it might not.

P1: In order to do what you were talking about before lunch where you go around and you find out that if you make his lighter you don't need so much there and you don't need so much there, well that's surely what happens after LIFECar because they get the car now and go well actually we can make that lighter so then we go through a revolution and we have version two which is lighter and has a smaller fuel cell and you find out that because you have done that you can do the next one. That's the innovative part of it but as far as I can see in the original proposal it was very much 'well this is the idea you don't need such a light car so I recon it should be this heavy and you don't need such a big fuel cell to do that so it should be about this powerful and therefore it should have about this much super capacitor' and those values have never really changed in the two years since the day I did the costing

FC: that's interesting

P1: in the first meeting I was told 'could you please keep it to under 200 amps so that we don't need big components'; so that's where the 200 amps came from. And also in the first meeting I pointed out that was 200 the output from the fuel cell or was 200 the output to the motors? Er sorry 20 kilowatts. And he said that the output to the motors so I added some on for the ancillaries and in my note book I've got that written down and that is almost exactly what we've attempted to build including the size. So there's been no ... that was the target. The weight has obviously been a target that was brought in later and trying to fix the efficiency. So yes I cant see any kind of loops where we've gone through and gone 'right that's gone well lets try and feed that .. because that's gone well we can try and take weight off that' which is the way that you were describing it before… I think wasn't it?

FC: yes it was. And do you think that this whole system design is an important factor to the project?

[SILENCE]

P1: yes, you cant do it the perfect way of doing it is everybody's into it and so everybody's prepared to do what it takes to absolutely make it go round. Take the loops, do this sort of thing, take on bits of work where 'hang on lets completely change the motors and do a new type of motor', that's perfect, what I would of thought, whole system design because it means that the technology is always improved. The trouble is all these people are, in most cases companies, who have a certain amount of budget and a certain amount of funding because it's Dti and so that limits it because it means that not everybody can go all the way into, being solely into the project. And also it means that the company who are investing in the part funding who in our case it's [company name] who are putting half the money in

P1: over half the money in so if our business decides that the type of fuel cell we are going to do needs to be a certain type of fuel cell for our business plan and LIFECar are pulling us towards a different type of fuel cell we wont do it. Well one or other side will win but we'll probably end up loosing half of our funding if we go too far towards the whole system; it's like loosing yourself in it.

P1: The whole thing could have been done in different ways. This whole weight reduction thing; that way of doing the car, it's an idea that I suppose [company name] and a few associates have got from the American group that did some car work in this area. And a lot of the calculations in the project were based on basically what he came up with and if they'd spent a period of time actually doing an outline design of the car and then telling all the people 'right your motors need to be this power and this weight, your fuel cell needs to be this power and this weight' and then we bid for it we could have said yes we can do it or no we can't. And once we're into it then we have to do it. With this whole system thing, when things fall over on specification, there is no specification, but you still have to assume a specification for the purpose of costing it and you reach a point where you go 'we can't do anymore'. It's bound to be for everybody. I think [actor name] has hit the buffers on his more or less, we're up against them. I think it's happening to quite a lot of the group now. There's now a limit to how much more flexible things can be.

FC: in your opinion do you think there is a lead partner within the project

P1: Yes [very quick to answer] …. Laughs

FC: could you elaborate?

P1: yes, I mean there's a lead partner from the Dti paper work point of view which is [company name] but they're not the lead partner in taking decisions on the project. It's clear that [company name] or [actor name] came up with the concept; he's done most of the work pushing it through into the Dti and stuff and is now having the final say and its actually written into a lot of the minutes isn't it that things like weight budget; he has the final say over whether you can have or can't have something within the car.

P1: [actor name] doesn't attend the meetings; he's not the one making the final decisions

FC: he did attend quite a few meetings at the beginning didn't he?

P1: yes, he's still interested in it but he doesn't go to the meetings and actually [company name] now seem to be being used as the kind of fund for buying things that no one thought of at the beginning … and assembling the whole thing … where as at the beginning there was lots of talk about exciting new bodies and wind tunnel tests and all that type of thing, I don't think that they were actually able to do any of that.

FC: do you think there have been or could potentially be any ownership issues?

P1: well from our point of view the only issue we have with the future use of the car is that we are not entirely convinced that the fuel cell is safe enough to take on a public road. We have said in the past, I think what's been pretty much ignored, is that we are not really happy for someone to drive the car with the fuel cell in it at this stage. Obviously after the dynamometer testing, a bit more testing and the hazop itself; there should be shock and vibrating testing done on it before its driven. So the ownership of the car thing is that we don't know where our liability is if somebody say working for [actor name] in the future, lets say for example that he holds on to the car, there's no problem with that as far as I am concerned but if somebody got in that and drove it around and the fuel cell caught fire that then could become an issue for us and that's why we have a slight issue with future use. But I don't know about what the rules are for Dti things, who gets the equipment at the end, the demonstration equipment, I don't know who you know in like 7 years time if the cars in possession of somebody and something happens safety wise do they resurrect the old consortium in the court or do they take whoever had it in their garage at the time to court!?

P1: actually the last thing that was asked as a decision from the consortium was over this compressor business, this compressor company wanted to become a partner

FC: yes, I was just about to ask you about this

P1: do you want me to wait?

FC: no, I just wondered what you thought about it

P1: the email came around saying that they might be able to give us a discount if we can call them a partner. So I though that this has probably got something to do with the contract so I will go and ask [actor name] and he said 'well I don't care so long as you make it clear that we're not liable for any more cost' and I said 'well if I just put in my email: there's nothing wrong with them being called a partner as far as we are concerned' and he said yes that right so I did that and sent it back and I thought if anybody's going to get shitty about this it's probably going to be our legal department. But then [company name] saying 'no they've got to be an associate' and 'I'm not happy' and there was [actor name], everybody said no!

FC: I think it was more sort of, it got them heated about 'no we've worked on this the whole time and now we've got someone else coming in and calling them selves a full on partner'

P1: yes I suppose so, associate partner, there were all sorts of things being pushed through

FC: how important do you think it is for team members to have an understanding of other sub-systems? And what level of understanding do you think is necessary?

P1: it's crucial … I didn't really understand much about how cars, much about car design and things like that so that's been interesting but obviously the fuel cell is supplying DC DC convertors that's a big part of hybrid vehicles it is important that we know it. From the point of view of doing the project the one we really needed to understand was obviously the CAN, we had to learn a bit about that and what we are actually attaching the fuel cell directly to. But yes I don't need to know too much about the suspension but I need to know about the hydrogen tank and all that so yes it's pretty important. But it's also interesting as well

P1: And quite often you are representing the entire consortium if you are asked about it, so you do need to understand the whole thing. Especially when it first got released to the press, it was done through the [company name] press office and the [company name] press office didn't have much actual information on the technical side and my name was in their list and so I got like 5 phone calls a day from news papers asking me about LIFECar. You kind of need to make sure that you understand what the whole thing is otherwise we are not going to represent kind of [company name]'s effort properly or something like that. Because people are quite, especially, you tend to notice it a lot with the university side of it, they are really quite strict on how their input is represented and it has to be represented well and properly. Presumably that's the same for us although I don't actually know how it's being represented outside of us.

FC: what are the sub-systems that you would say you know most about and least about?

[Long silence]

P1: that's tricky … I probably know least, well no probably I don't know the least, the one I'd like to know more about is the motors because, but they are quite complicated, I don't know whether what I know about motors is the same as I know about the rest of the car but it's just such a big field. Because I come from this group the one area that we probably know most about is the capacitor but I am not very up on DC DC power electronics so, but I've learnt quite a lot of that from [actor name] during the course of the project. Understanding the system like that I am probably OK with. High pressure hydrogen storage is something that we've done before or had a look at before so I understand that quite well but actually doing it for an on the road vehicle, that aspect of it is probably what I know least about. I had no idea you could just slap a car together and put it on the road I thought you had to get permission from somebody but apparently you don't.

FC: quite a few people have said that one of the challenges of this project is the high level of uncertainty that there is particularly at the beginning. How would you advise other people who are embarking upon this type of project to manage that level of uncertainty?

P1: the way I would do it is that I would break it into 2 projects. I'd have the first project where we'd go through all these discussions about how we are going to do it; modelling who wanted what and where all the boundaries were and things like that. And that [actor name]'s modelling was done which gave answers to how big things need to be and all this type of thing and gave you an idea of how things should behave. And the weight budget would be produced which said that this is your limit and everything. And that would produce a specification for each partner that was a kind of to be better than but no worse than. And then each partner could then go away and assess whether it was possible to do what they were being asked to do. And that means that during the initial phase people are much more willing to put in ideas about technology because they don't already have it in the back of their mind the one that they are costed to buy, or what they thought they were going to have at the beginning, and it also means that it reduces the risk in the project because it means that if you cant find someone to do what you've decided needs to be done to do the project then you have to look else where. It might be the case that what was being asked for was possible but not for the money do you know what I mean? That may not have been true for every other partner but because we came into it late we didn't actually know, well we thought we knew, but it actually turned out that we didn't know exactly what it was that we were going to be supplying and by then we were already signed up. So that's why it's been even more technically risky because we've actually had to add things into the project and take them out somewhere else. And so I think the way to do it would be to arrive at the decision we arrived at half way through which was actually how much it should weigh and all these types of things and how powerful it should be and what we are actually supplying and then have another project where people actually do it and test it. Even if it's the same project but with 2 parts with the funding not going ahead until everybody's certain that they can actually do what they said they were going to do.

FC: do you think that as a team you have all found a common goal and purpose that you are all working towards? I know you all got your own goals like you obviously want the fuel cell to work but do you think that there is actually a shared common goal?

P1: well yes I do, I think that everybody's on board for making a working car, everybody's got this image in their head of a Morgan, is it the Aero 8? I think it's the car body design now. I think that everybody is fixed on this I think that there is a common goal.

FC: Even though I think you already proven me wrong on this, [company name] appear to be quite a large company in comparison to [company name] or maybe even [company name], what effect do you think this has on the dynamics of the team?

P1: it does seem to make people think well because you work for a big company you'll be able to get things done better or quicker or 'you should be able to, surely you have lots and lots of people who could do this type of thing'. And because [company name] is a big company and probably could do all of those things it would probably charge more and be more ridiculous to get it all organised because it is like little gangs. So it's true we do have a big marketing group and that is a thing that we don't have to pay for in addition to what we'd normally contribute towards the kind of corporate centre. So that's a free thing for us so of course we use it.

P1: so when they handled the initial kind of press stuff, although they didn't do it in an entirely satisfactory way for everyone on the consortium, it was, a lot of it certainly got done because it is a big group and in fact there's more people in marketing than I think in our group, and so we of course got it done because we can just ask them to do it. And they're obviously desperate for things to market. So that's a good advantage of it but the bad thing about it is that people assume that a big company just looses its costs in itself. So to a company like [company name] surely this is nothing whereas this is being scrutinised just as much as if we were a 1 person organisation. The scrutiny is the same and the pressure to achieve your budget is the same.

P1: also because its match funding, because it comes internally from [company name] we as a business group have the permission to make that loss so if we're fully booked up with work i.e. the person sitting at the next desk to me can't work on LIFECar a) because they've got enough of their own work to do and b) because they're into something completely different. So if I was going to get somebody to help me with LIFECar, as has happened earlier on in the project, I have to get somebody down from another group in Farnborough whose not got any work and is completely new to the work.

FC: finally, by the time of the Geneva Motor Show do you think that we will have a fully working sustainable sports car?

P1: Sustainable?!

FC: that's what it says in the proposal

P1: what does it mean by sustainable?

FC: Zero emissions

P1: what the car? OK do I think that we'll have a working car? 50:50

Apendix 4: An example of notes taken during LIFECar meetings

This appendix demonstrates the format of the notes that were taken during the LIFECar Project meetings. It provides an example of how specific parts of the meeting were transcribed if a relevant discussion took place.

Wednesday 4th July 2007

Location: Malvern, [company name]

Time: 10.00am – 4.00pm

Attendees: Participants 1 - 13

Appologies: None

Meeting Co-ordinator: P2

Conditions: Noisey room, people walking through, no windows, dull.

Temperature: Average – cold, drizzling outside (time of the floods and lots of rain).

Aims of the Meeting (see agenda):

- Quarterly meeting to communicate and assess progress

P1, P9 and P13 arrived at 10.30am – meeting had already started

OBSERVATIONS	COMMENTS	CATEGORISATION
Via email prior to the meeting P12 had asked members if they would like to be involved in the Grove Fuel Cell Conference as [company name] already had a place.	Unusual and appreciated initiative from [company name] and P12 in particular	**Commitment** **Communication**
During the discussion P2 went around the table asking if each partner was in agreement and if so what they would like to display		**Autonomy**

P2 suggested that [company name] should play a big part in the display. P4 agreed. P2 asked if it would be possible for [company name] to design part of the display which was not dominated by [company name]. P5: “I think it should be dominated by [company name]” P3: “I don’t” A discussion took place around who should be seen as the lead partner; if anyone	It is interesting that the partners appear to have different views when it comes to perceived ownership of the project. I think that the universities in particular are happy to go under the [company name] brand.	**Ownership**

Transcription: OWNERSHIP

P2: I think the one thing that we do know is that with a six partner project that there can be some issues about what goes on the thing and obviously your people will want a good crack of the whip
P12: well we’ve got our own separate stand but we’d quite like to have the car there as well and obviously have some [company name] stuff on it. I think the sheets are about £300 each and I think we’d need about 5. So if somebody wanted to do one sheet I thought we could split it up like that
P2: do we want to quickly ask how many of the partners are likely to want to put some time and effort and money into publicity there; is that worth finding out? …Do you imagine [company name] would want to be part of that?
P4: I would have thought so, sure
P2: Would you imagine [company name]would like to?
P8: well the, when I spoke to P12 about it last week my thinking was we do a lot of conferences and things in general rather than spend £300 on something new we could add some stuff that we could kind of dust off and bring along that would .. see I wasn’t thinking of necessarily spending lots of money on it but I think we’d be interested
P2: are you nodding at that as well P4?
P4: yes, I’m sure we’ve got stuff like that
P3: it might be difficult to integrate it
P2: the trouble is its all going to be very bitty isn’t it, its going to be very bitty and there’s going to be all different sizes of bits
P8: well that’s what I was thinking initially when I was speaking to P12, I guess there’s kind of a spec for this thing
P2: Visually I suspect, it would be strange if you used the same colours and style and stuff as your stuff
P10: I mean really it needs one person to take charge of the whole thing
P2: in an ideal world, in an ideal world
P10: its a lot of work
P2: there’s no question

P12: what about then if I send around the web page, the lady organising the hall has got a web page which has got these things on so you could see what it will look like and then you might have some already and [company name] might have some already and we can go from there. If more people were interested but didn't want to spend the full amount to get one then we could maybe just get one and we could maybe just put one with information on it and
P2: yes that could be done, there clearly needs to be some information, a specific .. otherwise it will look pathetic
P2: is [company name] sort of keen on that? That sort of thing?
P3: yes, yep, yep
P2: and anyone who isn't? what about the universities?
P1: yes, I mean if we are only talking about £300 something like that then I mean its not a great deal of money
P12: you could probably get quite a lot of info on just one of them
P5: or we could get one and go half's with you
P1: so who will actually design it?
P2: we need a volunteer don't we for that
P1: because I mean its one thing to sort of accumulate a couple of pictures and think of a few paragraphs and sort it all out but I don't know what [company name]'s like but at the moment we have quite strict controls over anything that goes out, because [company name] is paying for all this re-branding, so anything that goes out needs to meet the [company name] brand spec.
P12: everybody has that
P2: it's a question of... it's a design issue isn't it. I assume we would have to have a hand out of sorts
P4: we've done that sort of thing
P10: they've got all the pictures of the car
P2: ahhhhhh, do you think we could do that in a way that didn't make it dominated by [company name]?
P5: I think it should be dominated by [company name] actually, personally. Because it is a [company name] car that we are contributing to, that's the leading brand, that's what you are all contributing to and we are like the sub-partners within that and I wouldn't mind if it was mainly [company name] but then all the other partners are on that but not, you know … so people will come up and see a [company name] car, they'll have a look at it and then say oh, I see they are working with [company name], [company name], [company name], [company name] ..
P3: is this all going to be divided up as one of these 5 panels each?
P12: no, I don't think it needs to be
P3: oh well I don't want it to be dominated by [company name] full stop…

P6: I think your follow on is the Geneva Motor Show, and this is just a suggestion, but I think you might want to consider the leaflets and hand outs at Geneva and just bring it forward a bit so that you don't have to do the job twice
P3: well the Geneva motor show is a [company name] event really
P2: it will be on the [company name]stand

P3: the [company name] stand and clearly will be dominated by [company name] but I don't think that this is the same thing at all and [company name]'s have been dragged to it kicking and screaming

…

P3: Geneva is an awful lot more expensive and I don't think all the partners are going to be
P2: represented?
P3: paying their 5th or 6th of the cost, I think its going to be down to [company name] and I think it's going to be a [company name] event but this is a completely different kettle of fish
P4: yeh, I mean you are talking hundreds of thousands to go to Geneva
P3: yeh
P10: that's our budget gone P5!

P2: right well we don't want to spend too long on it with all of us here but I think we need a process for that. You are not comfortable with it being a [company name] dominated thing?
P3: I think all the partners should have
P2: more or less equal weight
P3: yes, they are going to have more or less equal contributions, I mean apart from anything else [actor name] just isn't interested in the Grove event! Whereas the other partners are much more directly involved in the Fuel Cell world…
P9: it seems that [company name] have enabled this and if there's going to be a dominant partner then its going to be [company name] because they are paying in the same way as [company name] are paying to organise Geneva they will be the dominant partner. Not only is it impolite but it is incorrect to mention LIFECar without mentioning the other partners. But mention is not that they must have equal standing at Geneva because we wouldn't expect it. So here its either [company name] dominating because they are paying and we are taking the same strategy as Geneva or its equal. I can't see how [company name] take precedence.
P2: do you think that somewhere in your wonderful nether regions of [company name] that there would be some designers who could accept the brief that this is a 6 partner project which we want to give more or less equal well exactly equal weight actually but it can be a [company name] branded display
P9: its [company name] explaining a project to which it is a partner
P12: [company name] already has a stand separate to this which we're going to have all our stuff on anyway so I think my
P9: your view is that this is a LIFECar
P12: my boss thought it would be a good idea to have the car there so that we have something else to show but also that it could be a LIFECar project's exhibition
P3: is there a fee attached to this?

P12: it all depends on how much people are stumping up for the cost of the backdrops and
P2: if it's a few hundred quid P12 then I don't think that's going to be a big deal
P3: are we paying for the actual space as well?
P12: I don't know what the cost of the space is but I think we have to pay for it yes, but we have got that already
P9: I think the idea of making it a LIFECar stand with the LIFECar as the dominant brand with equal partners. And partners that put in more effort and more words and pictures might end up with a little bit more space but the logos and the names have to be the same size … if you put in more effort then you get more space but the name is a LIFECar stand and the logos and the names of the organisations are equal size.

The discussion ended when P3 announced that he had a guy working for him on the marketing and communications for [company name] and that with him he would take ownership of the display

OBSERVATIONS:

Interesting relationship between money (who paid for the stand) and ownership and also effort = more space = perceived ownership

Ownership has come up in this meeting more than ever before, I think that this is because they are getting nearer to having something solid and visual to own rather than a rather uncertain idea. The need for ownership changes with the project – at the beginning when the idea was ambiguous no one wanted to necessarily be held responsible – now they are arguing over it!

There was a discussion around the project end date. P6 stated that in the eyes of the Dti the report is the final submission. It was decided that the report needed to be submitted at the end of March 08 and that P9 would create an outline of the required contents		
There appears to be a slight reoccurring friction between P9 and P2. When P9 is present at meetings he sometimes takes on a PM role		**Conflict** **Roles**
P6 presented a form of current and predicted project spends which was the catalyst for a lot of confusion as several	Surely it is important for the project team to be updated on what the other	**Knowledge Sharing**

members didn't recall seeing the form before. Earlier P1 had also mentioned that the Quarterly reports submitted to the Dti were no longer shared with the project partners	partners are spending and also what is being sent to the Dti each quarter	
It appears that over the last few months P4, P15 and P1 have met up to work together		**Collaboration**
P1 "usually you approach one area of uncertainty at a time, test it, make sure it all works and then move on to the next. In this project all the sub-systems are going to be put together at once and see if it works – which it wont"	It appears that members are keen to try and integrate / test the sub-systems separately but due to a lack of time (organising a suitable date) and effort it hasn't happened yet	**Uncertainty** **Commitment**
It was discussed that until you put 2 sub-systems together to see if they will 'talk to one another' the uncertainty and risk is going to be high. Therefore one piece of 'jigsaw' needs to be introduced at a time to ensure that each piece fits rather than putting all the pieces together at once	Getting the sub-systems to 'talk to one another' is a common phrase. Other phrases such as referring to each sub-system as a 'jigsaw' piece are quickly adopted and used by the whole team	**Common Language**
P1 said 'P14 is confident that the breaking system will work … that is based on his experience rather than any solid facts'	Shows the confidence P1 has in P14 and also the level of expertise that is required and used. It also says something about the relationship between P1 and P14	**Experience / expertise**
New project members from [company name] are going to work on the motors with P10 over the Summer. [company name] have hired a guy who will work on the project full time from August	Having P11 at the meeting did not appear to effect the team dynamics. He did not say anything however.	**Team Composition**
P1 revealed that he only spends	Due to the fact that	**Commitment**

2 days working on the project and in fact that he is now only contracted for 2 days – this was not the original plan as he was employed to work full time on LC	not many team members worked full time P1 had little to do as he was constantly waiting for information from others. Subsequently he got involved with other projects and work	
P6 "I think we can capitalise … oh excuse me saying 'we', I mean I think the project can capitalise on this"	P6 perhaps sees himself as part of the team but actually he is not. He is a project monitor for the Dti. P1 and P9 discussed that he is in an awkward position as if the project fails then the Dti will look badly on him as he was supposed to be supervising	**Identity**
During the meeting the integrating and testing of sub-systems was discussed a lot. It appears that the project is entering a new phase: each partner has gone away and designed his own sub-part and now they are coming back together and hoping that it will all integrate successfully.	As this stage is new it feels a bit chaotic and uncertain. Also there is only 8 months of the project left which doesn't seem long for such a challenging stage. Due to this and the fact that the 'space' in between the sub-systems is no mans land – no one wants to accept reponsibility	**Uncertainty** **Responsibility**
As the car is to be tested at facilities at [company name] P9 asked / told P1 to be responsible for organising this. P1 was clearly unhappy about this and said that it was not his responsibility as P3 has previously put his name against	Later in the car JM stated "[company name] wanted to take on the title of system integration but so far they have only chosen the tyres and a fuel tank!"	**Roles** **Responsibility** **Conflict**

'System Integration'		
P12 said that the first time the FC will be tested for any length of time will be in the actual car. It is unclear how and where it will fail. Due to this the issue of use on public roads was brought up again. P1 suggested that they should revert back to the voting system which was discussed at the beginning of the project (one vote per partner) It was decided that this was not necessary as it had already been decided that it would not go on the road		**Autonomy**
P8 recognised that the plan for testing was so important that he thought it should be designated a permanent slot on the meeting agendas from now on		**Project Management**
P6 reminded the team that during testing the original objectives of the project needed to be refered to e.g. is it a car that, as we projected, will go from 0-60 in x seconds?		**Aims and Objectives – joint architecture / understanding**

LUNCH – 40 Mins

OBSERVATIONS	COMMENTS	CATEGORISATION
A discussion took place around what type of compressor was needed.	This was a good example of cross disciplinary problem solving; P4 needs a specific compressor and P14, P2 and P12 have all individually searched for one. Use of cross disciplinary knowledge as P5 spoke of the compressors that are used in CNC	**Common Understanding** **Collaboration** **Cross-Disciplinary Knoweldge**

	machines and P3 those that are used in motor bikes.	
There is a possibility that a company would be able to make a custom built compressor cheap as they want to get involved with the fuel cell business	Now that the project has gained more recognition, companies are willing to offer support / want to get involved	**Networks**
P3 said that he was going to consult an 80 year old 'fountain of knowledge'		**Networks**
There appears to be a big difference between sub-sys conversations now and at the beginning of the project. This is due to the level of understanding shared by all members	P8 is the only person who is lacking an understanding of systems aside from his own, he doesn't interact much within the meetings and appears not to have the same level of understanding and knowledge as the others … I think this is because he has attended significantly less meetings – at the beginning it was thought that he was not required as the re-fueling system is a separate entity however this is having a negative impact now	**Common Understanding** **Commitment**
The discussion did once again get very deep into a particular sub-system, so much so that P1 commented that he didn't understand P3's terminology	This confused people and it was subsequently decided that P3 should be responsible for the cooling system	**Common Understanding** **Responsibility**
It was acknowledged by P2 that this was a detailed design issue and that the meeting should move on		**PM**
P4 expressed his concern at the		**Knowledge Sharing**

previous conversation as if design changes keep cropping up and no decision is made then it is difficult for [company name] to finalise the exterior car design. He is worried that they will end up 'designing on the run' and 'knife and forking' bits onto the car rather than following the traditional CAD process		**Decision Making** **Design Process**
P5 appears to be a 'bottle neck'. He is so busy that he has not done his work and subsequently the whole project is slipping. Consequently tasks that he could do best, due to his expertise, are being tackled by other members for the fear that P9 won't get it done	See P9 interview transcript for time spent on LC	**Commitment** **Expertise**
When anyone asks P12 a question he always appears to have the answer. It appears that he is working really hard on the project	This is quite a big difference from the start of the project; it appears that his enthusiasm has grown	**Commitment** **Enthusiasm**
P8 is concerned about the H&S of the testing of the car due to the use of hydrogen, he wanted to inspect where the car was to be tested.		
As the discussion once again was getting too detailed P9 nudged P2 to say that the meeting should move on		**PM**
The final hour of the meeting was spent designing a testing plan		