University of Strathclyde

Department of Design Manufacture and Engineering Management

Enhancing the Design Dialogue: A Study of Engineering Design Meetings

By

Alastair Peter Conway

A thesis presented in fulfilment of the requirements for the Degree of Doctor of Philosophy

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This thesis is the result of the author's original research. It has been composed by the author and has not been previously submitted for examination which has led to the award of a degree.

Signed: Date: 10/05/2011

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Successfully undertaking a PhD can be a frustrating task requiring a high level of self discipline throughout. However it is an accomplishment which I believe cannot be rivalled. For this work there are several people who have helped guide and motivate me towards achieving this accomplishment, and to them I owe a debt of gratitude difficult to express in these short words.

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Abstract

This research investigates the phenomenon of knowledge and information loss within engineering design and develops a prescriptive framework which if applied to teams working at an either co-located or distributed level, can aid in the identification and subsequent capture of critical informal product and process information.

The work reported within this thesis stems from the current paradigm shift from product delivery to through-life service support within the engineering industry. The focus of this research is on synchronous engineering design meetings and social interactions, where traditional records fall short of documenting many important design decisions. Many companies are now faced with the challenge of creating accurate and reusable documents of design activities in order to support their products through life. The aim of this work is to assist design engineers to record more information and knowledge than traditionally documented, providing a much richer product history and allowing the design process to be revisited and subsequently reused. This thesis addresses one key aspect of this challenge: the need to create richer and more accurate records of synchronous design activities and in particular meeting based activities. The development of enhanced documentary systems complemented with multi-modal data objects such as audio and video has the potential to improve the recording of knowledge and information throughout meeting activities for re-use at latter instances in the product lifecycle.

This thesis develops a framework specifically to enhance the capture of discursive and collaborative aspects of synchronous design activities, and in doing so, document not only the discussions and decisions made therein but also the information resources utilised within such design episodes. The mechanism to validate and analyse the framework is demonstrated through the development of a prototypal system. Through the undertaking of design based case studies and experiments, the records generated by the system provide on average a 54% more accurate and therefore complete depiction of activities undertaken. In addition, time savings of up to 51% are recognised through the eradication of additional post processing activities. In summary, the development and application of the framework is shown to provide positive direction for future development of such documentary activities.

PART A: INVESTIGATION

Chapter 1: Introduction

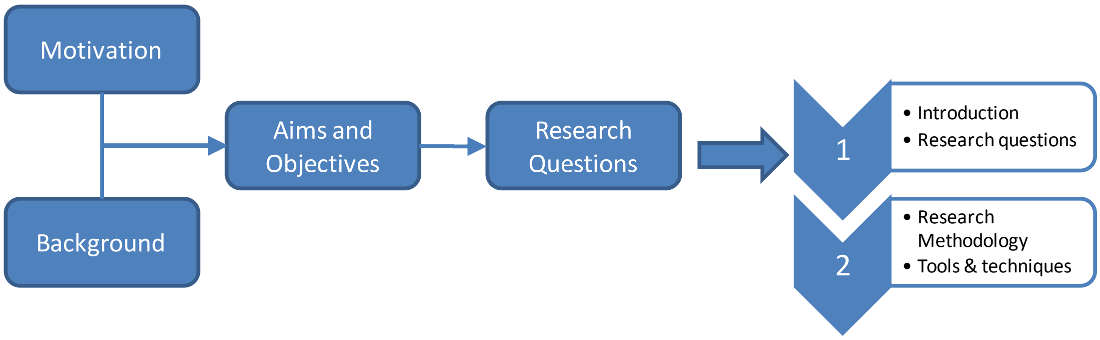


Figure 1.1 Chapter structure

Much of human history and what we know of how the world has been shaped over the centuries, has come from surviving written accounts, paintings or documents constructed from witnesses' recollections. However, as new and advanced scientific technology becomes available, the accuracy of much of these recollections and records of events is increasingly thrown into question. Reliance upon human memory and opinion can often lead to inaccuracies and distorted viewpoints and as one of the 20th century's greatest thinkers is reputed to have stated:

"(Human) memory is deceptive because it is coloured by today's events."

(Albert Einstein)

It was not until c.1826 that the first entirely accurate, permanent record of an instance in time was successfully captured, in what is believed to be the world's first photograph (Marien 2006). Since then the use of audio-visual technology has greatly enhanced the capture of historical events and our understanding of what occurred in recent history. One only has to enter phrases such as 'World War', 'Apollo Moon Mission' or 'Berlin Wall' into an internet search engine and we are provided with an array of documents, reports, images and video which captured these events as they occurred, providing future generations with entirely accurate representations of many of these significant events in human history.

The same multimodal data capture principles are rarely applied to the development of many of today's complex engineering products. In the current global environment, organisations supplying large made-to-order products are undergoing significant change from product delivery to through-life service support (Ding, Ball et al. 2007). To remain competitive in the global market, organisations are increasingly required to supply products and to provide support services throughout the product lifetime, which can encompass 5, 15 or even 30 years into the future, (Davies 2003; Oliva and Kallenberg 2003). With a significant change in working practices comes the need for the development and application of business, operational and information system models for these extended lifetimes (Morelli 2003; Prencipe 2003). Continuous improvement in service support for long life products such as in the ship building or aerospace industry depend greatly upon the implementation of effective Knowledge Management (KM) systems within dynamic learning environments. Undertaking complex engineering design projects invariably results in the generation of a significant quantity of information, not simply on the artefact being developed but on the process through which this development occurs. However, previous studies show that current documentary approaches are ineffective in documenting activities and decisions accurately (Moran, Palen et al. 1997; Lalanne, Lisowska et al. 2005; Huet 2006; Conway, Wodehouse et al. 2007), leading to organisations revisiting and even reworking design decisions in order to fully understand previous design rationale.

1.1 *Background and motivation*

Design itself is an activity, (Pugh 1991) the principal goal of which is to give substance to an artefact (Carroll and Moran 1996). That is: to design is to transform a set of criteria or requirements into a solution; physical or theoretical. Throughout the undertaking of design there is a massive amount of information generated, i.e. a collection of data and/or facts both on the artefact being designed and the process by which it is created. However, not all of this information is recorded or documented sufficiently during the development process (Huet 2006). With the current emphasis being on companies to supply products and provide support services throughout the product lifetime, the realisation is that the design information being lost can aid in both product lifecycle support and also the development of new products (McMahon, Giess et al. 2005). To support these activities, information capture systems and models are required, which allow the information to be stored and used thirty years or more into the future.

It has been argued that knowledge and information is integral to engineering design (Blessing, Chakrabarti et al. 1995) and that during the design process, a designer can spend over 50 percent of their time handling these precious commodities (Court, Culley et al. 1993). Thus, the efficiency of the design process, and indeed the quality, depend considerably on how well designers are able to access, process and utilise large amounts of information (Dong, Song et al. 2001). The transfer of designers' and engineers' knowledge and information to others and also the application within different contexts is termed *design reuse* (Duffy and Duffy 1996) and is widely recognised as being extremely useful but capturing this informal information, knowledge and decisions for reuse is notoriously difficult. Throughout the undertaking of design there is a massive amount of knowledge and information generated both on the artefact being designed and the process by which it is created. However, much of the literature (Moran, Palen et al. 1997; Lalanne, Lisowska et al. 2005; Huet 2006; Conway, Wodehouse et al. 2007; Conway, Giess et al. 2008) stipulates that not all of this is recorded or documented accurately during the development process.

In the knowledge management literature, authors report that workers spend between 40 and 60 percent of their time looking for information to perform their tasks (McCampbell, Clare et al. 1999). This is compounded during engineering design, where studies have shown less than 50 percent of the information required by design engineers to complete their jobs was actually available and even then, only 20 percent of this information can be provided for reuse by existing applications (Wood, Yang et al. 1998). This significant loss of information during the design process can have adverse effects on the productivity and efficiency of a company during the later stages. For example, in the shipbuilding industry where many companies base their design activities on lessons learnt and information generated from past designs, the recording of information generated throughout the ship design, manufacture and also life cycle is crucial. If this critical knowledge and information is not documented or recorded correctly, companies can find themselves replicating costly mistakes, which could have been avoided.

1.1.1 *Industrial context*

The motivation for this research comes from the realisation that to aid the creation and through-life support of large complex engineering products, organisations are placing a greater emphasis on constructing complete and accurate records of design activities. These issues are compounded further when put into the context of companies moving from delivering products to providing service based operations throughout the lifetime of their products.

Much of the work reported within this thesis was completed in conjunction with Company A, a multinational marine defence contractor with facilities based in Glasgow, UK. The researcher was first exposed to the company whilst working a larger investigation on knowledge and information management, the KIM Through-Life Grand Challenge Project (McMahon, Burt et al. 2006) of which the company were a key collaborator. At the time of this preceding work, the company were in the process of transitioning from product delivery to product service. This meant they were actively engaged in knowledge identification, capture and retention activities in a bid to provide the best possible service and maintenance operations for their customers. Previous research work had been performed within the company within the KIM Project context looking at the level of information captured within design documentation; therefore a pre-existing working relationship was present. Company A provided an ideal opportunity for the researcher to undertake studies into the information and knowledge requirements of a large product based engineering firm and thus provide a platform upon which the research could be undertaken and presented.

1.2 *Research Focus*

Current and traditional documentary approaches are no longer sufficient to capture activities and decisions in their entirety. In the case of engineering products which can be in service for 10, 20 or even 30 years, this can lead to organisations revisiting and in some cases reworking design decisions in order to understand previous design episodes and provide adequate through-life support. Consequently, there is a need for research into the development of models, tools and techniques to better support through-life engineering and promote best practice in documentation of engineering design activities.

1.2.1 *Research Aim and Objectives*

The ***overall aim*** of the research is to aid the process of capturing information and knowledge for engineering design episodes. This comprises the following objectives:

O-1. Describe the extended engineering lifecycle process and its application and diversity within industry:

a) Undertake a range of design activity and industrial case studies and experiments in order to develop an understanding of the role of information and knowledge throughout the extended engineering lifecycle;

b) Develop an understanding of the issues encountered with information and knowledge capture and usage within the engineering lifecycle.

O-2. Describe state of the art for information and knowledge capture in terms of social and collaborative situations:

a) Identify the key issues related to information and knowledge capture and retention within social and collaborative situations;

b) Ascertain the key differences between formal and informal information and therefore the need to capture the latter;

c) Ascertain the key differences between decisions and critical decisions and therefore the need to capture the latter;

d) Review existing capture technologies and methods.

O-3. Develop a research focus which constitutes aiding through-life engineering design activities.

O-4. Utilise appropriate methods or modelling techniques to enhance the information and knowledge working of engineering design practitioners:

a) Identify key elements of information and knowledge capture practices and areas suitable for development;

b) Develop an effect system architecture which is high value in terms of information and knowledge capture yet of low impact to the ongoing design process;

c) Evaluate the efficiency of the information capture system architecture through application to industrial based problems.

1.2.2 *Research Questions*

To meet the research aim and objectives, four primary research questions were derived. These are as follows.

1. *Does the identification and retention of product and process information impact upon the engineering lifecycle?*

This question aims to meet objective O-1 through establishing the context of the research problem, gaining a better understanding of how and where product and process information and knowledge are used within the engineering lifecycle.

2. *Are there specific stages of the engineering design process where knowledge and information capture is inefficient?*

The second research question looks to build upon objective O-1 by identifying particular stages or phases of the generic engineering lifecycle where the process of capturing of knowledge and information has been recognised as being inefficient or problematic and thus working toward O-2.

3. *Are there specific activities employed within the engineering design process where knowledge and information capture is inefficient?*

Research question three aims to identify particular activities undertaken within the generic engineering lifecycle where the process of capturing of knowledge and information has been recognised as being inefficient or problematic. This question further defines the focus of the research and helps guide the author on the development path required meeting objective O-3.

4. *Can a framework model be developed to enhance the practice of documenting design knowledge and information at the point of generation?*

The fourth and final research question is fundamental to evaluating this body of work's contribution to knowledge and meeting the final objective O-4. Only if the solution model can be proven to enhance the practice of knowledge and information capture will the overall aim of the research be achieved.

1.3 *Structure of Thesis*

The thesis is comprised of four main elements of work. First, the research approach and methodology is described defining how the research was undertaken. Secondly, the context and research focus of the thesis is narrowed through the study of literature and experimental case studies. Thirdly, the primary contribution of the research is presented and evaluated – a framework and associated model set developed to aid information and knowledge capture. The fourth and final section of the thesis incorporates the summary of the research contribution and indication of further work. Each of these areas is reflected in the structure of the thesis; core chapters can be grouped into four key phases – investigation, description, prescription and analysis. The research map presented in Figure 1.2 shows the research methodology adopted for this research and the how each of the objectives are addressed within the thesis.

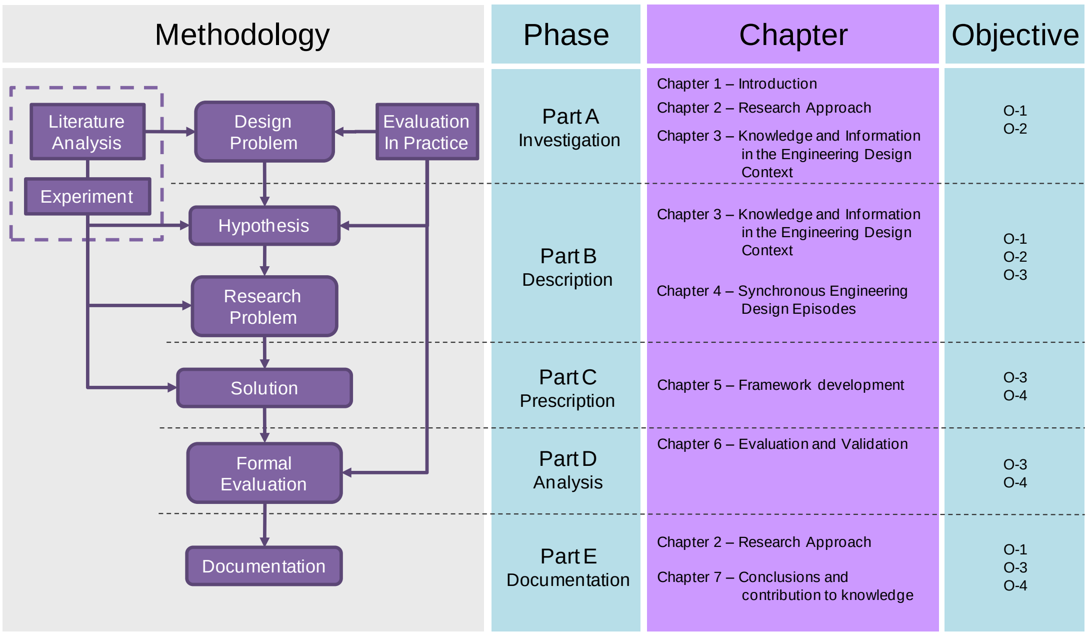


Figure 1.2   Research map

The following sections give a brief overview of each chapter, highlighting the key developments and research work arising from within each.

PART A: Investigation

1.3.1 *Chapter 2: Research Approach*

Chapter 2 outlines the overall design of the research approach taken to meet the aim, objectives and answer the research questions detailed in chapter 1. The chapter begins with an introduction to the paradigms of research as defined in much of the social science literature and describes how this work conscribes to what is known as the *positivist* or objective research approach. Through a review of some of the key research approaches proposed in both the engineering design and management literature, the research methodology adopted for use within this doctorate study was defined as that of a descriptive approach. This approach included the identification and amalgamation of two existing descriptive research methodologies to ensure a robust process was followed throughout the work. The chapter outlines the research methods and tools which will be utilised throughout the work and seeks to provide the reader with a greater understanding of how the work and indeed the thesis are structured.

1.3.2 *Chapter 3: Knowledge and Information in the Engineering Design Context.*

Chapter 3 begins with the exploratory literature review. This review looks at the relevant literature within the information and knowledge management work field, investigating synchronous and asynchronous methods of communication within engineering design as well as examining previous studies on the formality of knowledge and information. The review presents an analysis of core theoretical and technological concepts and models of knowledge and information capture. The findings from the exploratory review highlight that the need to effectively capture knowledge and information comes directly from an industrial need. Many large made-to-order engineering product organisations are transitioning from product delivery to through life product support and as such the traditional product development lifecycle is extending. With a significant change in working practices comes the need for the development and application of business, operational and information system models for these extended lifetimes.

PART B: Description

1.3.3 *Chapter 3 (Contd.): Knowledge and Information in the Engineering Design Context.*

From section 3.2, this chapter presents a review of knowledge and information usage within industrial lifecycles supported by an industrial based review. The literature is examined within the broader context of through-life knowledge and information applications and through examination of previous work and case studies, the chapter explores the effect unproductive documentary procedures have on engineering companies. The literature review is supported by an industrial review performed within Company A, a multinational engineering firm located in Glasgow, UK. The industrial review is completed through semi-structured interviews and qualitative analysis methods and includes the social science basis for the interviews and the specific needs of the participating companies. The conclusions from this chapter reinforce the need for better documentary procedures within engineering design activities and identify synchronous design episodes such as Design Reviews as specific cases where better documentary procedures are required.

1.3.4 *Chapter 4: Synchronous Engineering Design Episodes*

Within this chapter, the research issues and main perceived need for improved knowledge and information capture practices are presented and examines key work performed by Badke-Schaub et al (1997) on the concept of critical situations within design. From the review of literature and also interviews undertaken within an industrial context, the focus of this research is presented as the enhanced capture of process information and context within engineering design meetings and synchronous design episodes, where traditional records fall short of documenting many important design decisions. Chapter 4 presents a focused literature review of engineering design meetings followed by the investigation, methodology and findings gathered within experimental case studies. Through a combination of evaluating previous work and undertaking a series of experiments, this chapter presents the observation, identification and evaluation of critical instances of information and knowledge generation amongst engineering design teams whilst performing conceptual design activities within meeting situations. The work presented in this chapter highlights, through experimentation, that traditional minuting techniques fail to capture all decisions made throughout the course of design development. It was also found that many of these decisions stem from informal information sources and therefore the rationale and intent becomes difficult to identify and subsequently capture. The specific interest within this thesis is on the capture and storage of process information and context within a synchronous environment, thus through reviewing and analysing both research literature and commercial systems available and informed through experimentation, the key requirements can be identified, which would make up the basis of an effective information capture system architecture.

PART C: Prescription

1.3.5 *Chapter 5: Framework Development*

Chapter 5 summarises the key findings from the research and translates these into a specification and architecture for an effective information capture system. The identification of key requirements for the system provides a platform upon which to develop the system architecture. The system requirements can be grouped into two areas, physical and virtual. Only if the system can adequately support both environments will it become effective in its use. This research differs from previous research in that the approach taken is to develop a generic framework which can be applied within any engineering context without disrupting or interfering with the design process or removing the designer from their natural working environment. This chapter also presents the development of the proposed solution framework, incorporating the specification outcomes developed in Chapter 4 and the proposed architecture along with the findings from the earlier research. These factors combine to develop three models of synchronous design episodes; an organisational model representing the level of formality of the meeting, a process model showing the most effective method of conducting a synchronous design episode and an information capture solution, designed to enhance the documentation of the synchronous episode. The overall framework is critically reviewed. As well as proposing a viable solution to the problem, this framework provides a system architecture upon which demonstrator software systems can be developed. The Knowledge Enhanced Notes (KEN) demonstrator system development is described, and its perceived benefits discussed.

PART D: Analysis

1.3.6 *Chapter 6: Evaluation and Validation*

The Synchronous Knowledge and Information Capture framework is evaluated through application to the sample case scenarios. This chapter describes a series of experiments designed to evaluate the effectiveness of the proposed synchronous knowledge capture framework. The framework and underlying models are applied to a series of practical engineering design applications with a view to analysing and exploring the validity and effectiveness of the framework in promoting positive effects on knowledge capture. The organisational model and process model are applied to the activity protocol, ensuring a uniform structure and method of undertaking is applied to each synchronous episode. The capture architecture was applied through utilisation of the Knowledge Enhanced Notes (KEN) demonstrator system, developed to aid the documentation of synchronous episodes. Validation of the overall synchronous knowledge capture framework is achieved through evaluation of the application of the models within synchronous episodes of varying formalities compared with the running of the synchronous episodes without the application of the models. The perceived benefits from the application of the framework are discussed and evaluated within the context of the focus of engineering design and through-life knowledge applications.

PART E: Documentation

1.3.7 *Chapter 7: Conclusions and Contribution to Knowledge*

The final chapter presents a summary of core work and evaluates the contribution against the research questions set for the research. Throughout each chapter of this thesis a summary has been presented, highlighting the key elements of work and significant findings which have arisen. The aim of this chapter is to conclude and summarise the key findings of the work, and in doing so, answer the research questions and provide an overview of the contribution to knowledge that this thesis has made. First, the findings of the study are summarised based on how they answered the research questions. Second, the distinct contributions of this research are presented and summarised. Thirdly, the limitations of this research are discussed and outlined and the recommendations for future research provided. Finally, the key points of this research are concluded and summarised.

Chapter 2: Research Approach

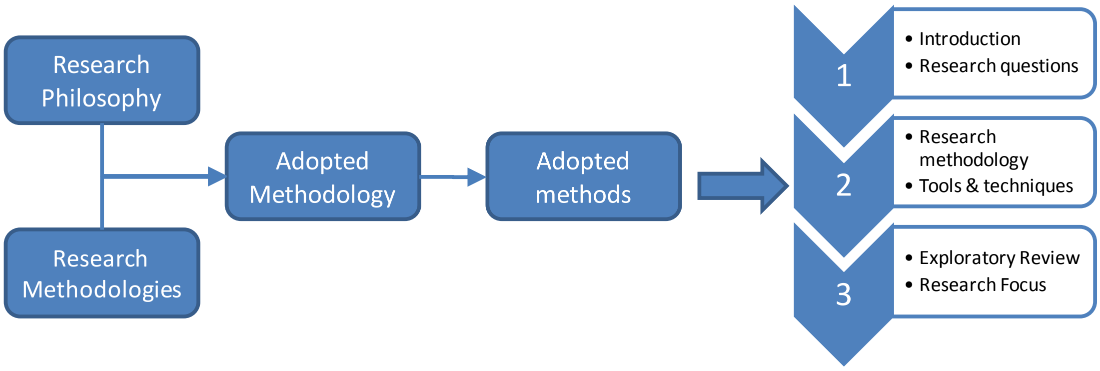


Figure 2.1 Chapter structure

The process of constructing the approach and identifying methods for undertaking research, universally known as *research design*, has been argued to be the most critical phase of undertaking research (Mendibil 2003). This view is compounded within the book 'Case Study Research: Design and Methods', where Yin gives the definition of research design as *"the logic that links the data to be collected and the conclusions to be drawn to the initial questions of the study" (Yin 2009)* page 24. From this understanding, it can be derived that effective research design is a critical element of the overall research study, ensuring that the research approach adopted meets its objectives. Essentially the research approach presents a basis for carrying out the research and acts as a template that is subject to alteration depending upon the nature of the work (Duffy and O'Donnell 1998), that is it provides a roadmap for undertaking the research work but also remains flexible enough to alter according to the ongoing work. The author recognises that there have been a multitude of studies published on research approaches within the social sciences literature (Dick 2004; Wisker 2007; Ates 2008) and this thesis does not seek to replicate these.

Chapter 1 of this thesis has presented the background and research questions for this study. As is evident in Figure 2.1, this chapter will now identify the research approach for this thesis, detailing the methodology, methods and techniques adopted for the overall undertaking of this work and collection of the data to provide conclusions to these questions.

2.1 *Research Philosophy and Design*

The Oxford English Dictionary (1998) defines philosophy as *"A set or system of ideas, opinions, beliefs, or principles of behaviour based on an overall understanding of existence and the universe*". In the context of academic research, many different branches of philosophy have emerged presenting researchers with theoretical frameworks into which their work can be positioned. Understanding the philosophy within which their research activities fit can aid researchers in establishing the foundations influencing the research goals and questions, data collection and analysis methods and tests of the quality and validity of the study (Easterby-Smith 2003; Maguire 2010). Further, Easterby-Smith et al (1991) proposes three reasons as to why even a rudimentary knowledge of research philosophies can aid in the undertaking of research:

1. It can help to clarify the approach taken to the research and provide greater understanding of why approaches are required.

2. It can aid researchers in identifying what research approaches will work and what will not, reducing the number of 'wrong turns' taken throughout.

3. It can help researchers adapt or develop approaches to undertaking research based on fields of study out with their own experience.

In essence, an understanding of research philosophy, however rudimentary, can aid researchers in establishing effective and viable approaches to undertaking research successfully. In the literature, the process of constructing the research approach and identifying methods for undertaking research is termed *research design* (Mendibil 2003). The definition of research design can be given as the overall configuration of the research; what evidence is gathered from where; and how the interpretation of this evidence is conducted to provide answers to the research questions. Research design is a topic not particularly well defined within the engineering design field of study (Finger and Dixon 1989). The exact reasons for this remain largely unknown; however, it is possible to reason that a lack of understanding of the terminology may be a primary driver. For example, a lack of understanding can manifest through misinterpretation of the term 'design' when used in the context of research (i.e. how can something which is largely intangible and organic be designed?) or perhaps through a lack of clarity on how designing the activities to be undertaken can enhance the research undertaking. In truth, the designing of the research approach is no different from undertaking any engineering design problem. In order to produce a design which satisfies the requirements of the problem, you must develop or adopt a well-defined process to achieve this.

To allow a choice of methodology and appropriate methods for conducting the study, the research must first be categorised. Easterby-Smith et al (1991) tell us that there are two key paradigms within research philosophy, the positivist (objective) paradigm and the phenomenological (subjective) paradigm. The key features of each are presented in Table 2.1 below.

Table 2.1 Positivist vs. Phenomenological research paradigm adapted from (Easterby-Smith, Thorpe et al. 1991)

	Positivist paradigm	***Phenomenological paradigm***
Basic beliefs:	The world is external and objective	The world is socially constructed and subjective
	Observer is independent	Observer is part of observation
Researcher should:	Focus on facts	Focus on meanings
	Look for fundamental relations	Understand what is happening
	Identify the simplest elements through reduction	Look at the totality of each situation
	Develop hypotheses and test them	Develop ideas and explain them
Establish:	Measurability	Different views
	Large samples	Small samples

Although universally recognised as a key philosophy within the methodology literature, Easterby-Smith et al's paradigms are the topic of debate with many advantages and disadvantages recognised within each (Maguire 2010). The Positivist paradigm is regarded as being over simplistic and the adoption of approaches such as reductionism (breaking problems down into smaller elements to aid understanding and processing) and the identification of fundamental relations rather than understanding the totality of situations can be construed as contributing to a loss of meaning. However the positivist (objective) paradigm is accepted as an optimal approach for understanding relationships where a small number of well-defined problems exist (Easterby-Smith 2003). Interestingly, the phenomenological (subjective) paradigm has also been derided for developing theory that is too specific to individual cases yet is hailed as vital in understanding the relationships and meanings of phenomenon occurring within specific cases (Easterby-Smith 2003).

The two paradigms form opposite ends of the research spectrum; however as is true with almost every research undertaking, the majority of researchers will not find themselves accepting one paradigm over the other (Maguire 2010), instead identifying elements of both which are applicable to their study and integrating them.

2.2 *Research Methodology*

The Oxford English Dictionary (1998) definition of *methodology* is given as *"The branch of knowledge which deals with the methods of a particular discipline or field of study."* Therefore in this context, a *research methodology* can be defined as an approach taken to research which incorporates different models and methods for conducting research. The nature of this research can be described as conscribing to the *Positivist* paradigm proposed by Easterby-Smith et al (1991), whereby to achieve an accurate view of engineering design activities, the research study must be objective and the researcher removed from the activities. To do this, the research must conduct studies, focusing on establishing facts and fundamental relations which appear within the engineering design activities whilst being removed from the process under study. However, throughout this process, it is also critical for the researcher to appreciate the totality of the situation and gain a greater understanding of how the identification, capture and documentation of knowledge and information affects the overall engineering design process which are key elements of the *subjective* paradigm.

2.2.1 *Descriptive research methodologies*

Descriptive research studies aim to find out more about a phenomenon and undertake to observe and analyse activities whilst remaining unobtrusive to the ongoing work process (Huet 2006) and therefore according to Easterby-Smith et al's classification are *Positivist* or *objective* models. The objectivity demonstrated throughout descriptive research approaches stems from the need to observe and analyse the activities throughout and allows the researcher to gain an understanding of what is happening within the given scenario without guiding or influencing the activities. Examples of descriptive research approaches and their application can be seen in core engineering design texts such as Conceptual Design for Engineers (French 1999), Engineering Design: A Systematic Approach (Pahl and Beitz 1996) and Mechanical Design: Theory and Methodology (Waldron and K.J. 1996). For this study, two key descriptive methodologies were further reviewed; Blessing, Chakrabarti et al's (1995) Design Research Methodology and Duffy and O'Donnell's (1998) Design Research Approach.

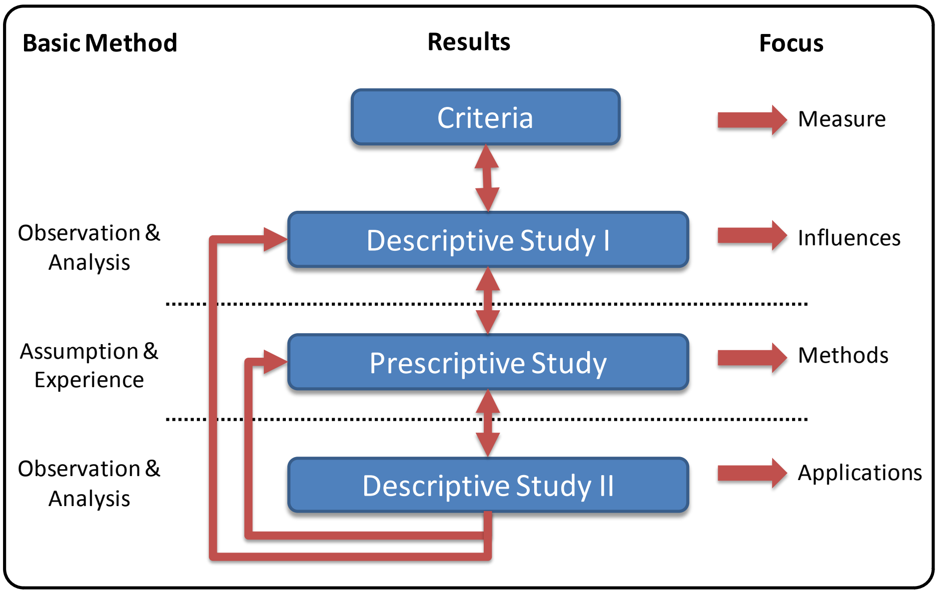


Figure 2.2 Design research methodology (Blessing, Chakrabarti et al. 1995)

Blessing's design research methodology includes stages of description, followed by prescription with a second descriptive study used to validate the results of the prescription and description as illustrated in Figure 2.2. The methodology starts with the identification of the research criteria including the aim of the study, the focus and initial research questions. This is then succeeded by the first descriptive stage which includes the review of literature and relevant theories. Initial experimentation activities are also undertaken within this stage, using observation and analysis to gain greater understanding of the research problem. The prescription study stage includes the development of the proposed problem solution, whilst the second descriptive study provided the validation of the solution through case based evaluation.

The process defined by (Blessing, Chakrabarti et al. 1995) is similar to the Duffy and O'Donnell (1998) model (shown in Figure 2.3) in terms of structure and flow. Duffy and O'Donnell's methodology begins with the generation of a hypothesis of how to better support design, stemming from an established problem. This hypothesis is then formulated into a defined research problem within the field of interest, for example knowledge and information management. From a combination of literature analysis and evaluation in practice, a solution to the research problem is then developed, evaluated and the overall results and appropriate documentation generated.

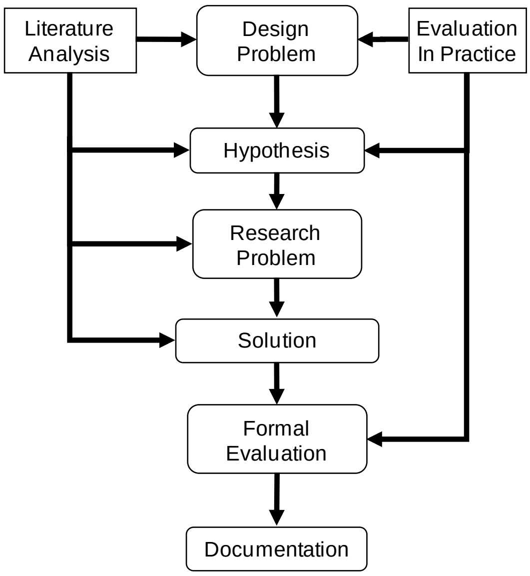


Figure 2.3 Research methodology (Duffy and O'Donnell 1998)

However, although fundamentally similar in structure, a notable difference between the two methodologies is the development and adaption of the 'validation template' by Duffy and O'Donnell. They argue that *"In order to provide some evidence of* *support for the research work any hypothesis, solution, etc. must be based and logically argued upon sound theories or models"* (Duffy and O'Donnell 1998) page 7. To illustrate this further, a validation model (Figure 2.4) was created. The theories themselves build upon axioms, literature, experiments and models and the models are themselves built and influenced by findings in literature, experiments, known theories and reality. For this thesis, the incorporation of such a validation model becomes critical to providing adequate validation of the outputs from each of the research stages.

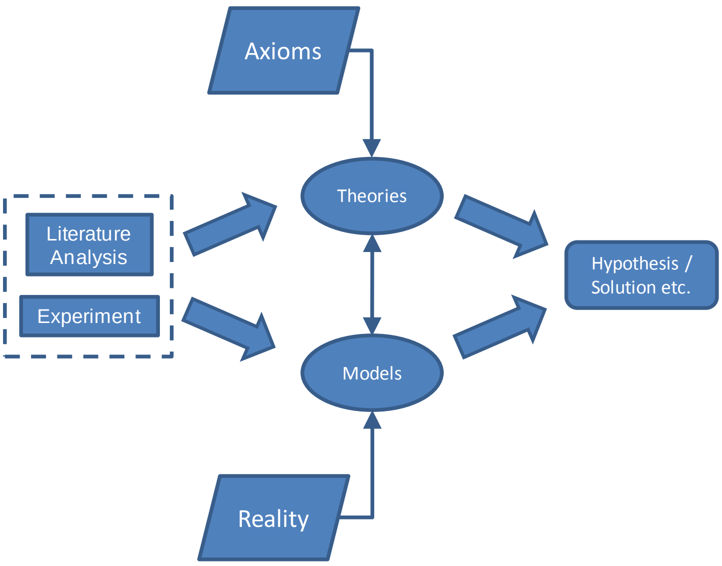


Figure 2.4 Validation template (Duffy and O'Donnell 1998)

2.2.2 *Methodology adopted for this study*

The research methodology adopted for this research is based on Blessing's descriptive study methodology (Figure 2.2) and incorporates aspects of the design research methodology and validation template proposed by Duffy & O'Donnell (Figures 2.3 and 2.4). The adapted methodology is shown in Figure 2.5.

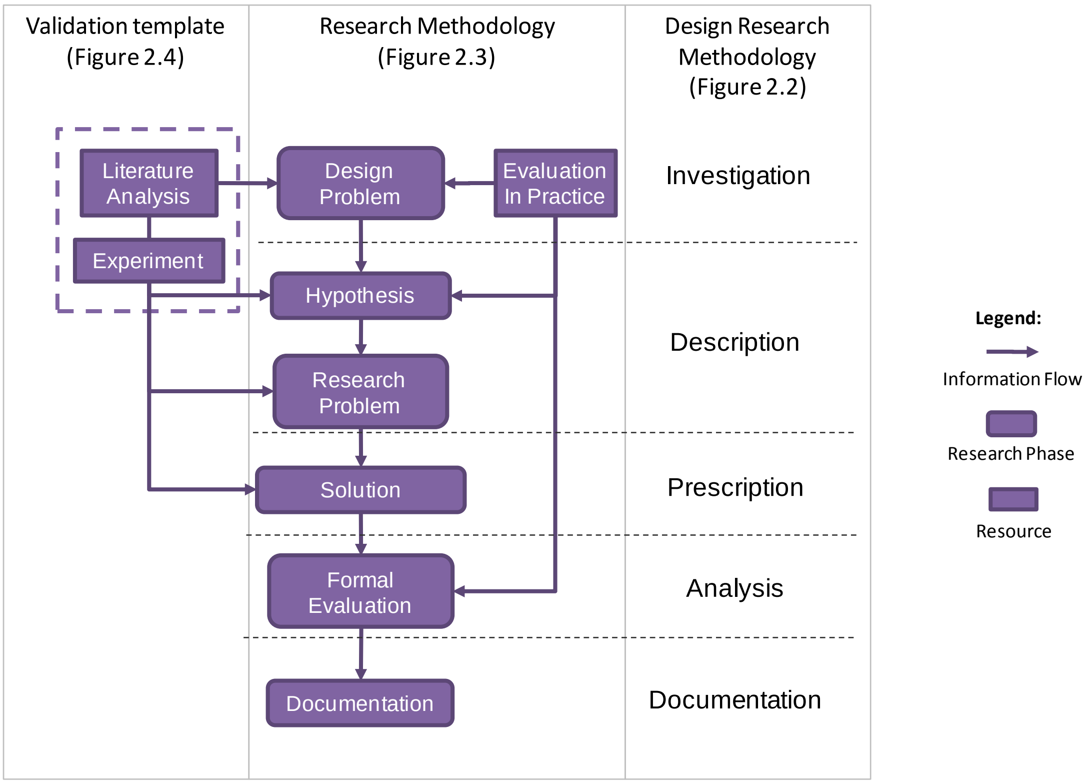


Figure 2.5 Research methodology adopted for this study

The adopted research methodology begins with the *Investigation* phase; whereby an investigation is performed into the identified design related problem. This phase of the research can aid in focusing the research study. The investigation phase of the research methodology incorporates literature analysis and experimental studies in addition to initial evaluation in practice thus helping to establish the state of the art in the field of study and subsequently formulate the research focus.

The second phase of the methodology is termed *Description*. With the research focus identified, the description phase as proposed by Blessing, Chakrabarti et al (1995) incorporates a focused review of literature and relevant existing theories. Initial experimentation activities are also undertaken within this stage, using observation and analysis to gain greater understanding of the research problem and develop the research hypothesis.

Again adopting the methodology proposed by Blessing and Chakrbarti et al (1995) the third phase of the research is known as the *Prescription* phase. This phase includes the development of the proposed problem solution, incorporating the validation template proposed by Duffy and O'Donnell (1998) as a means of validating the solution against the literature and through experimentation. Evaluation in practice is also carried out within this phase with the identification of specific applicable case studies.

The fourth phase of the research is termed *Analysis* and includes the formal evaluation of the proposed solution against the objectives of the research study. The analysis phase remains critical in defining and evaluating the solution against defined metrics to provide sound justification of the proposed solution meeting the research objectives.

The final phase of the research methodology is *Documentation* where the studies, results and conclusions from the research activities and synthesised are presented in documented form. The key contribution to knowledge which all doctorate level research must produce is drawn from the results and presented within this phase along with the recognised limitations and possible future continuation of the work.

The research methodology adopted for this study presents a number of challenges in identifying appropriate methods for evaluating and validating the research undertaken. For example, the validation template adopted as part of the methodology for this research is prescriptive in terms of providing a framework for effective validation of the work; namely through axioms and reality in combination with the literature and experimentation. However it does not provide guidance on the methods and techniques required to actually provide this validation. Similarly, the design research methodology proposed by Blessing, Chakrabarti et al (1995) and adopted for this study prescribes *"Observation and Analysis"* as a method for developing and evaluating the research work; however the methodology does not provide prescriptive steps on how to undertake these observation and analysis techniques. Therefore for this study it is necessary to identify methods which lend themselves to the adopted methodology and can provide the evaluation and validation required of the research work. The key methods identified for this doctorate study are *case studies, experimentation and transcription analysis*. These methods will be discussed further in the following sections.

2.2.2.1Case Studies

Case study research methods are applicable in a multitude of disciplines and can provide insights into practice which other research techniques such as document analysis and modelling cannot. Case studies emphasise detailed contextual analysis of a defined number of events or conditions and their relationships. Yin defines case study research as *"an empirical inquiry that investigates a contemporary phenomenon within its real-life context; when the boundaries between phenomenon and context are not clearly evident; and in which multiple sources of evidence are used"* (Yin 2009) page 18. However, case studies are used for other purposes; to communicate findings, primarily as a teaching method in education (MacGregor 2002) or in some instances as a method of drawing comparisons on methods, tools or theories (Cross, Christiaans et al. 1996). In the context of this thesis, the adoption of case studies presents an opportunity for this study to understand, first hand, the knowledge and information practices of organisations within the engineering design context. For this study, case studies will form an integral part of creating the understanding of the problem and thus collection and validation of data from a company or companies becomes critical. To generate the case study data sets, interview techniques were identified as the method most suitable and, in particular, *semi structured* interviews.

2.2.2.1.1 ***Semi structured interviews***

In qualitative research, the conducting of *open interviews* is becoming more prevalent and widely used as the preferred method for data collection (Flick 2002). An open interview does not follow a set sequence of questions like a structured interview. Instead the interview relies on discussion between the interviewer and the interviewee with the questions being asked incidentally or on an ad-hoc basis. *Semi-structured interviews* are a variation on the open interview style in that this technique involves the interviewer developing an interview guide or set of points which he or she wishes to cover during the course of the interview. However the questions themselves remain relatively open. The recognition is that the interviewee's views and opinions are more likely to be expressed in an open or semi-structured interview setting than in formal and standardised interview situations or through the use of questionnaires (Flick 2002; Yin 2009). For the purposes of this study the development of a semi-structured interview protocol was deemed appropriate.

2.2.2.2Experimentation

The undertaking of *experimentation* or conducting *experiments* during research is something which is so integral to the development of human understanding of the world that it is impossible to accurately trace its roots. Scientists and philosophers have been undertaking experiments since the time of Galileo (Orne 1962) in an attempt to understand phenomena with the definition of an experiment widely accepted as a research method designed to elicit some sort of behaviour, typically conducted under closely controlled laboratory circumstances (Milgram 1974). Essentially, experiments are a robust, scientific method of evaluating or validating competing theories, solutions or hypotheses within research. In this context experimentation is a powerful method of working whereby one or more variables within a pre-defined environment or context are consciously manipulated by the researcher(s) and the outcome or effect of that manipulation on other variables is recorded. Experimentation can also be used to test existing theories or new hypotheses in order to support them or disprove them. For this reason, experimentation is a research method employed heavily in the science and engineering disciplines and as such will be adopted throughout the course of this doctoral study. Throughout the undertaking of experimental research, methods of accurately documenting the activities are required to provide the analysis. For this study ethnographic analysis was selected and is discussed in the following section.

2.2.2.2.1 *Ethnographic analysis*

Ethnographic analysis is a research method involving the direct observation and analysis of human activity in order to understand how that activity is accomplished (Tang and Leifer 1991). To achieve the most accurate results from ethnographic analysis the participants should be observed in their natural working environment whilst addressing a ‘real’ task or in a simulated environment replicating their natural working environment. The key features of ethnographic research include (Hammersley 1990):

- People's behaviour studied in everyday contexts, rather than under experimental conditions created by the researcher.

- Data are gathered from a range of sources but observation and/or relatively informal conversations are usually the key sources.

- The focus is usually a single setting or group of relatively small scale. In life history research the focus may even be on a single individual.

- The analysis of the data involves interpretation of the meanings and functions of human actions and mainly takes the form of verbal descriptions and explanations with quantification and statistical analysis playing a subordinate role at most.

A critical element of ethnographic studies is that the researcher or the observer does not interfere in the group's activity once the task has begun. This aligns with that of descriptive research studies and Easterby-Smith et al’s positivist or objective research paradigm in ensuring that the researcher remains unobtrusive to the ongoing work process. Ethnographic activities are typically documented using audio and /or video recording equipment which is then analysed to identify patterns in how the participants accomplish or are hindered from accomplishing their work (Hammersley 1990; Tang and Leifer 1991).

Ethnographic analysis techniques ensure that the research activities being studied replicate ‘real world’ scenarios and provide critical understanding of how activities occur in practice. The aim of the experimentation and validation to be undertaken within this research study is to observe or to replicate how design activities occur within industrial practice and, as such, ethnographic analysis techniques provide a sound basis upon which to construct these experimental activities.

2.2.2.3 Transcription Analysis

Transcribing is a practice used greatly in social sciences and the study of linguistics and has, to a certain extent, been developed within the engineering domain to aid in the documentation of interviews, meetings and other social episodes (Huet 2006; Conway, Wodehouse et al. 2007). Accurately transcribing interviews is a time-consuming and highly labour intensive activity. However, accurately documenting the flow of conversation and the general topic of discussion can aid greatly in generating the context necessary for a reader or an interested party not present throughout the episode. In fact, the process can trigger specific memories of those who were present and can even lead to retrospective understanding of comments which may have escaped the interviewer/scribe at the time. The process of transcribing can be viewed not simply as a data collation activity but as an applied data analysis method (Silverman 2005). Although mentioned frequently in the social sciences literature, there does not appear to be official or standardised conventions for transcribing. The transcription methodology applied within this thesis was identified as the Transcript Coding Scheme (Huet 2006).

2.2.2.3.1 *The Transcript Coding Scheme*

Within recent work performed during his PhD studies, Huet (2006) produced several transcripts of industrial based design meetings conducted within a large multinational organisation. Through analysis of the audio recordings taken at the time of the meeting, Huet developed a coding scheme (Figure 2.6), which was used to codify the transcripts of these meetings. The aim was to provide not only information on which meeting participants commented on certain topics but also to allow the classification of information type (product, process, resource or external factor), artefact type (drawings, calculation, component, testing etc.) and the relevant topic or description.

MEETING TRANSCRIPT | CODING SCHEME

ID (1)	TRANSCRIPT (2)	TIME (3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
GH	We used 3 sections // and optimised the path through the pylon	00:10:03	S	INF	Prod.	Slide #1	Co	Systems design	Design of the fuel line between the fuselage interface and the engine interface	P
SJC	/Good/ I see you used standard fittings to join all the elements	00:10:06	S							
CAM	What about the pressure loss? Did you do any calculations?	00:10:08	Q	CLA	Proc.					
[GH]	[ ]= audio not understood	00:10:11	A							
CAM	Ah! OK, sorry … so can you explain how you achieved this?	00:10:16	Q			Slide #2	Co			

LEGEND

1. IDENTITY OF THE SPEAKER (initials);
2. TEXT TRANSCRIBING SPEECH;
3. TIME WHEN THE INTERVENTION ENDED (hours:minutes:seconds);
4. INTERVENTION TYPE (statement (S), question (Q), answer (A), or feeling/emotion (F));
5. EXCHANGE ROLE (informing (INF), exploring (EXP), resolving problems (RES), managing (MAN), evaluating (EVA), debating (DEB), digressing (DIG), clarifying (CLA), or decision making (DEC)
6. INFORMATION TYPE (product (Prod.), process (Proc.) resources (Res.), or external factors (Ext.));
7. SUPPORTING ARTEFACT;
8. ATREFACT TYPE (Office (O), Drawing (D), Activity management (AM), Information management (IM), Calculation (Ca), Communication (Co), Component (C), Testing (T));
9. TOPIC / DOMAIN OF COMPETENCE (structures design, systems design, manufacturing & procurement, aircraft configuration & architecture, certification & testing, project management & business, production, in-service etc.);
10. TOPIC / DESCRIPTION;
11. TOPIC / ORIGIN (predetermined (P), derived (D), or unexpected (U)).

Figure 2.6 Transcript Coding Scheme (Huet 2006)

In addition to the more commonly found *Identity*, *Transcript* and *Time* categories, Huet generated eight additional categories to aid in the codification. These were as follows (Huet 2006):

1. *Intervention Type:* Statement (S), Question (Q), Answer (A), or Feeling/emotion (F);

2. *Exchange Role*: Informing (INF), Exploring (EXP), Resolving problems (RES), Managing (MAN), Evaluating (EVA), Debating (DEB), Digressing (DIG), Clarifying (CLA), or Decision making (DEC);

3. *Information Type:* Product (Prod.), Process (Proc.) Resources (Res.), or External factors (Ext.);

4. *Supporting Artefact*; (e.g. Slide #1)

5. *Artefact Type*: Office (O), Drawing (D), Activity management (AM), Information management (IM), Calculation (Ca), Communication (Co), Component (C), Testing (T);

6. *Topic / Domain of Competence* (structures design, systems design, manufacturing & procurement, aircraft configuration & architecture,

certification & testing, project management & business, production, in-service etc.);

7. *Topic / Description*; (e.g. "Design of the fuel line between the fuselage interface and the engine interface")

8. *Topic / Origin*: Predetermined (P), Derived (D), or Unexpected (U).

With the additional codification categories, The Transcript Coding Scheme (TCS) created by Huet becomes an extremely useful tool for analysing the interactions between designers in design situations. For example, the codification of the information exchanges coupled with the codification of supporting artefacts give the reader an overwhelming quantity of information which may not have been possible to record through traditional documentation techniques.

2.3 *Chapter summary*

Through a review of some of the key research approaches proposed in both the engineering design and management literature, the research methodology adopted for use within this doctorate study was defined. The research approach chosen for this study was that of a descriptive approach, whereby the research would undertake to observe and analyse activities. This approach included the amalgamation of two existing descriptive research methodologies to ensure a robust process was followed throughout the work. The adopted methodology was based on Blessing, Chakrabarti et al's descriptive study methodology (1995) and incorporates aspects of the design research methodology and validation model by Duffy & O'Donnell (1998). Blessing's design research methodology starts with the identification of the research criteria including the literature and research questions. The methodology includes stages of description, followed by prescription with a second descriptive study used to validate the results of the prescription and description.

The research methodology adopted for this study presents a number of challenges in identifying appropriate methods for evaluating and validating the research undertaken. For this study it was necessary to identify methods which lend themselves to the adopted methodology and can provide the evaluation and validation required of the research work. Therefore the adoption of case study research methods such as ethnographic analysis, semi structured interviews and transcription techniques was chosen. Case study research methods are applicable in a multitude of disciplines and can provide insights into practice which other research techniques such as document analysis and modelling cannot.

In all, the combination of the methodology, the research methods and the overall descriptive research approach lends itself to providing a robust and traceable structure to the work, ensuring that each element of research undertaken will contribute directly to achieving the overall aim of the PhD, which is to aid the process of capturing information and knowledge for engineering design episodes.

PART A: INVESTIGATION (CONTINUED)

Chapter 3: Knowledge and Information in the Engineering Design Context

Over the past two decades there has been significant research into engineering knowledge and information. This body of work has helped define and document many interesting theories on how information and knowledge are critical to the product development process, the development of tools, techniques and strategies to improve the capture mechanisms, and identify how knowledge and information are critical components in the engineering product lifecycle.

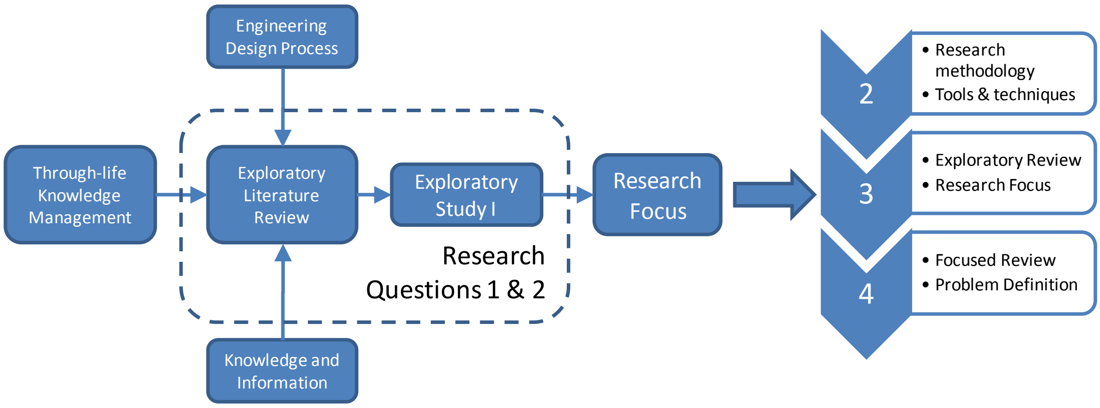


Figure 3.1 Chapter structure

Within much of the engineering design literature, the terms data, information and knowledge are inextricably linked into the design process and as a consequence the terms are often mistakenly used interchangeably (Nonaka 1994). However, for the purposes of this research it is critical to establish how these terms differ. Data is defined as being raw fact or figures with no context or meaning but simply representations of statistics, objects or events (Liebenau and Backhouse 1992). As alluded to by Court, data can be considered as *"almost useless until described or interpreted in some way."* (Court 1997), page 125. From this understanding, information can be derived as the combination of raw data and context which allows interpretation. In the field of interaction design, Shedroff further develops this concept and proposes that information can be transformed into knowledge by adding the value of experience and learning (Shedroff 1999). By derivation then, knowledge is the understanding and application of information through observation, education or experience. Finally, cognitive understanding of the processes and relationships gained through evaluation and interpretation of these knowledge items can provide wisdom (Shedroff 1999). Many authors extend these definitions to include wisdom as a separate entity (Zeleny 1987; Ackoff 1989; Rowley 2007); however, the line between knowledge and wisdom is sufficiently blurred and becomes difficult to articulate. For this thesis the consideration of wisdom as a separate entity was not deemed appropriate due to its intangible and tacit nature.

The relationship between the key terms data, information and knowledge is documented explicitly in the information science and management literature as the Data, Information, Knowledge, Wisdom (DIKW) hierarchy (Fricke 2009) and presented graphically within the DIKW model (also known as the knowledge pyramid) shown in Figure 3.2. The pyramid serves to demonstrate a key element of the DIKW model, that knowledge and information are extrapolations of data.

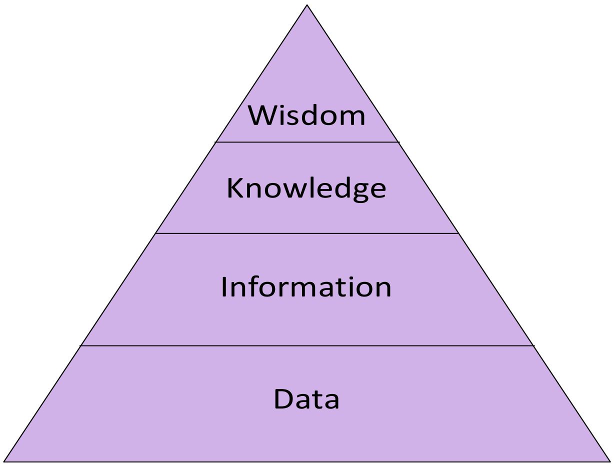


Figure 3.2 The DIKW model (Fricke 2009)

These definitions serve a dual purpose within this thesis. Firstly, to ensure clarity on where the boundaries lie between these distinct entities and secondly to help provide focus for the first of the research questions:

1. *Does the identification and retention of product and process knowledge and information impact upon the engineering lifecycle?*

To answer this question it is necessary to first address the impact of both knowledge and information within the engineering design context and determine the process stages at which this impact becomes most prevalent.

3.1 *The Engineering Design Process*

A process is a sequence of steps that transforms a set of inputs into a set of outputs (Ulrich and Eppinger 2000). When undertaking the task of designing an object, the designer will more often than not follow a predefined or recognised process, commonly referred to as a design methodology. Methodologies are structured approaches to the design process often presented in the form of a design model. There are a number of accepted methodologies for the design process and as a consequence there is not one specific process model which every designer will follow (Wynn and Clarkson 2005). However, the engineering design process is typified by a series of stages through which designers must pass in order to generate well defined and robust solutions to a given problem, therefore commonalities and the generic stages of design can be identified and subsequently extracted.

3.1.1 *The Generic Engineering Design Process*

In order to extrapolate the generic process steps involved in design, it is necessary to gain an overview of the key design models available and their applicability to general engineering design problems. In their book chapter "Models of Designing" Wynn and Clarkson (2005) review a number of existing design models from the literature and provide a classification of these models as being either *stage based* or *activity based*; *solution oriented* or *problem oriented*; *abstract*, *procedural* or *analytical* models. Definitions of each classification are presented in Table 3.1.

Table 3.1 Classification of the various design models (Adapted from Wynn and Clarkson 2005)

Classification	Description
Stage-based	Linear, sequential models with the process defined by several stages or phases leading to the solution.
Activity-based	Cyclic, non linear models presenting the design activity as an iterative process converging on a solution.
Solution-oriented	Definition of an initial solution which is analysed and repeatedly modified as the design requirements develop throughout the activity.
Problem-oriented	The emphasis is placed upon abstraction and thorough analysis of the problem structure before generating a range of possible solutions.
Abstract model	High level, generic descriptions of the design process. Relatively low number of stages/phases.
Procedural model	Detailed, prescriptive models of the design process. Generally include a high number of stages and specify techniques used within each stage.
Analytical model	Highly detailed models used to describe particular instances of design projects. Consist of two parts: a representation used to describe aspects of a design project, and techniques, procedures or computer tools to improve the process of design.

From this extensive study, Wynn and Clarkson conclude that in the context of design, much of the existing process models can be classified as highly procedural, stage and activity based, problem oriented models (Wynn and Clarkson 2005). To express this another way, the study concluded that current design models are strongly focused on the technical aspects of solving design problems, describing or prescribing the steps necessary to progress from problem definition to design solution.

In his PhD thesis, Huet (2006) expands on this work by presenting (in tabular form) many of the key design models, described using a categorisation scheme adapted from Wynn and Clarkson (2005) and O'Donovan et al. (2005). Huet's matrix clearly identifies the key models with emphasis on design and product development and how these models interact with what he terms the "typical classification schemes" (Huet 2006). An extract from this matrix is presented as Table 3.2.

Table 3.2   Design Model Categorisation (extract from Huet 2006)

			Description Using Typical Categorisation of Design Models						
Emphasis	**Author or Model Name**	**Reference(s)**	Stage-based	Activity-based	Problem-oriented	Solution-oriented	Abstract Approaches	Procedural Approaches	Anlaytical Approaches
Design	Pahl & Beitz	Pahl & Beitz (1996)	●		●			●	
	Hubka	Hubka (1982)	●	●	●			●	
	Design Spiral	Evans (1959)		●		●		●	
	French	French (1999)	●		●			●	
	Product Model / Chromosone	Andreasen (1992)		●	●			●	
	Total Design	Pugh (1991)	●		●			●	
	Darke	Darke (1979)	●		●		●		
	PDI Model	March (1984)		●		●	●		
	Jones	Jones (1963)	●		●		●		
	Axiomatic Design	Suh (1990)		●		●	●		
	Cross	Cross (1994)	●		●	●	●		
Product Development	IPD	Andreasen & Hein (1987)	●		●			●	
	Ulrich & Eppinger	Ulrich & Eppinger (2000)	●		●			●	
	Ullman	Ullman (1988)	●		●			●	
	Waldron	Waldron et al. (1989)		●	●	●		●	

These useful studies provide a sound basis upon which to select the key models by leading authors in engineering design for further analysis and illustrate the commonalities within the various approaches. The models selected include the Total Design model (Pugh 1991), the Design Process model (French, 1999) and the Planning and Design Process (Pahl and Beitz 1996). All of the models are stage based, problem oriented and procedural models, thus representing three of the most common characteristics within the general models used within design as alluded to by Wynn and Clarkson (2005).

3.1.1.1 French - Stage Based model

French’s model is one of the most common and widely cited models. First published in 1984, in comparison to other later models French's picture of design can be considered relatively simple. The process shown in Figure 3.2 is based on design practice observed in industry and provides a high level description of the key stages of a design activity.

The process starts with a need and proceeds sequentially through formal stages with feedback. It consists of four stages (French, 1999):

Stage 1. Problem Analysis - The process begins with the observation of a market need, which is then analysed, leading to a problem statement.

Stage 2. Conceptual Design - During conceptual design several concepts are generated, each representing a problem solution. These abstract concepts are evaluated and one or more are chosen to form the basis of the final solution.

Stage 3. Embodiment Design - The chosen solution is then refined in the embodiment phase, where the concept is transformed into a definitive layout.

Stage 4. Detailed Design - Detailing of the solution occurs and any ambiguity removed from the solution. Approved working or manufacturing drawings are created and the solution is released for manufacture.

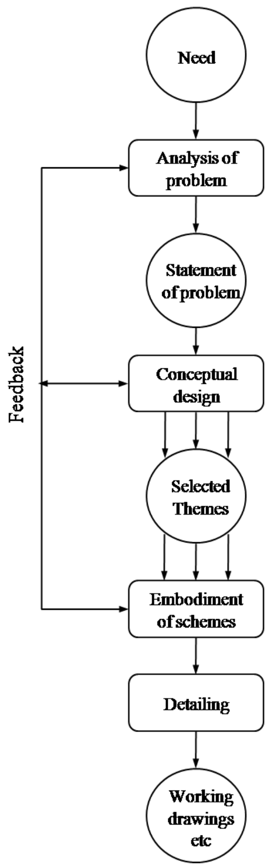


Figure 3.3 Design Process (Adapted from French, 1999)

A key aspect of French's model is the inclusion of feedback throughout. At almost every stage, the process indicates the generation of feedback to earlier stages allowing for design iterations to ensure consistency and feasibility in the latter stages. It can be said that French's model highlights a key element of the design process; design is an iterative process in that it progresses in a cyclic fashion with feedback being incorporated until a satisfactory solution/scheme is found.

3.1.1.2 Pahl and Beitz - Planning and Design Model

The planning and design process model published by Pahl and Beitz (1996) is recognised as a core element for students of mechanical design engineering to familiarise themselves with. At the core of Pahl and Beitz's model (Figure 3.4) lies a series of stages not unlike that proposed by French; *planning and clarification of the task*, *concept design*, *embodiment design* and *detailed design* (Pahl and Beitz 1996). However where the models differ is evident in the level of detail included at each stage. Pahl and Beitz define each stage in terms of procedure and expected outcomes whereas French’s model does not give detail to this level. Pahl and Beitz are also explicit about the need to feedback information from each stage and show the iterative nature of design through a series of feedback loops, something which French alludes to. Both process models are expressed in a linear fashion and detail the design process from initial idea or task through to the final detailed solution. Given the early publication of French’s model (originally 1984) and its reference within their textbook “Engineering Design: A Systematic Approach”, it is reasonable to conclude that Pahl and Beitz’s model is influenced by this earlier work and extends and builds upon the French model.

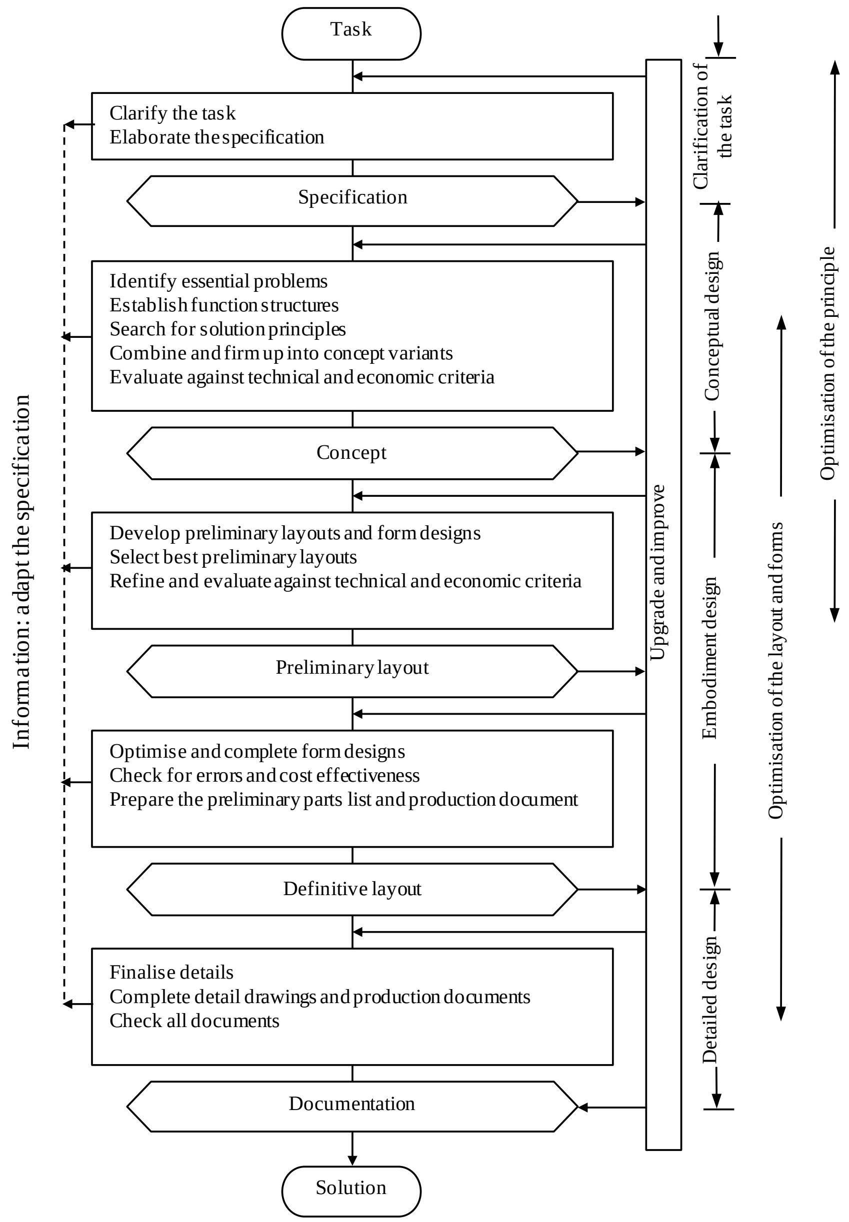


Figure 3.4 The planning and design process (Pahl and Beitz, 1996)

3.1.1.3 Pugh - Total Design

"Total Design is the systematic activity necessary, from the identification of the market/user need, to the selling of the successful product to satisfy that need – an activity that encompasses product, process, people and organisation." (Pugh 1991) page 5.

Stuart Pugh's Total Design methodology is recognised as one of the first published models of the design process which encompasses elements such as marketing and sales factors commonly thought of as external to the design process. Embracing the principles of concurrent engineering (a systematic approach to the integrated concurrent design of products and related processes), Pugh's *Total Design* methodology details the entire design activity from inception to manufacture and sales as demonstrated in Figure 3.5. At the centre of Pugh's Total Design model lies what is termed the *design core* (Pugh, 1991). This model is strikingly similar to that of Pahl and Beitz and French in structure with the key difference being evident in the stages detailed. Where French and Pahl and Beitz define the main stages related to the design activity (Need, Concept design, Embodiment design and Detailed design), Pugh's design core emulates what he terms as the design flow- the activities necessary to get the design from user need through to product usage, including the manufacturing of the design and the sales activity. Pugh argues that all of these stages influence the overall design of the product and therefore design iterations may occur throughout each stage due to changing objectives.

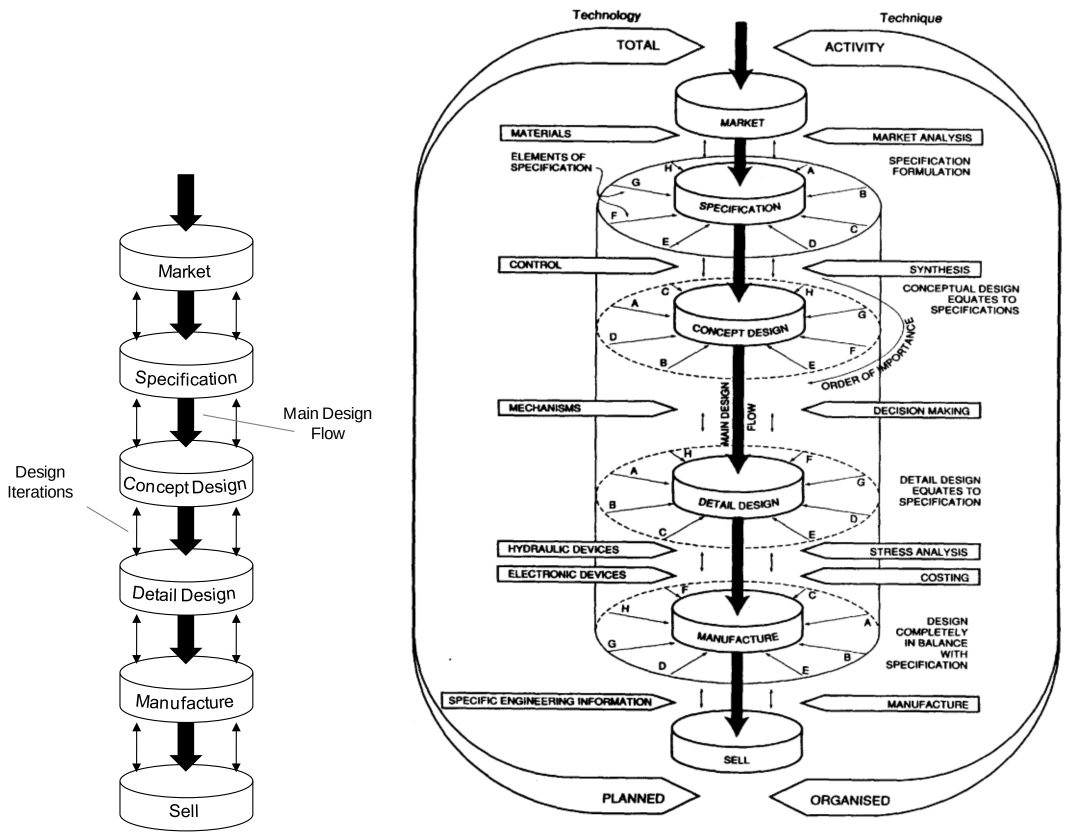


Figure 3.5 Design Core and Total Design process models (Pugh 1991)

3.1.1.4 A summative model of the design process

At this juncture of the research, the key existing models of the design process have been identified and the need to define the stages of design recognised. However, what has become apparent is that there is no summative model which adequately represents the key elements, methods and stages which can be gleaned from the analysis of these key pieces of work. Such a model of the design process would provide a platform upon which to structure studies of engineering design activities. Therefore to allow this thesis to progress, and the research to be of the most value, the selection of a specific existing model would not suffice: instead, a summative model was developed for this expressed purpose.

From reviewing the commonly cited and adopted models of design, and the extensive literature studies undertaken by Cross (2000), Wynn and Clarkson (2005), O'Donovan et al. (2005) and Huet (2006) it becomes possible to extract the core generic stages of the design process and create a model for use within this thesis. This simplified model consists of five stages, *Define*- encompassing the definition of the user need and problem specification, *Create*- the initial conceptual design work undertaken, *Refine* – the embodiment and detailing elements of the design activity, *Optimise*- the evaluation and optimisation of the design and finally *Produce* – encompassing the manufacturing and distribution of the final solution to meet the demand.

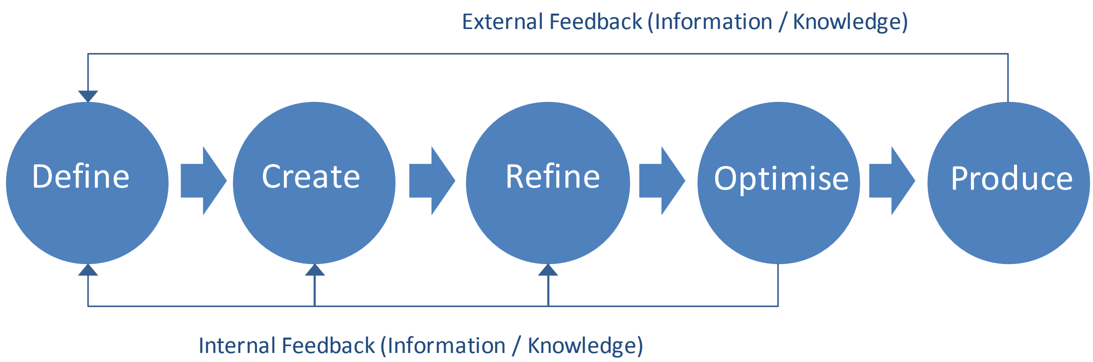


Figure 3.6 A summative model of the design process

The model above follows the structure proposed by French, Pahl & Beitz and other design models in that it is stage based, procedural and problem oriented; focusing on how the design will evolve from initial inception through to production. Now that a general picture of the design process has been constructed, the focus of this thesis turns to defining the information and knowledge elements being generated throughout and gaining a better understanding of the impact these elements have on the overall design activity.

PART B: DESCRIPTION

3.1.2 *Knowledge and Information Use within the Design Process*

As is evident from existing design models, the flow of information and knowledge generated on the design is a key component in the overall design activity. These elements help the design activity to progress through feeding back information and knowledge on how the design is performing at each stage and thus if modifications are required. In the summative model presented in Figure 3.6, the feedback occurs at two levels, conscribing to Dym and Little's view that there are *internal* feedback loops which occur throughout the design process and help progress the design and an *external* feedback loop which occurs when the product reaches its intended market (or in the case above, the production phase) and provides validation of the design (Dym and Little 2009). Throughout the first four stages, information and knowledge is fed back through the *internal* loops allowing iteration and evolution of the design to occur. However when the design activity reaches the *Produce* stage it becomes increasingly difficult and costly to modify the design, therefore it is recognised that design iterations should not occur unless absolutely essential. Instead, the product information and knowledge generated at this stage is fed back through the *external* loop to the initial definition stages to ensure that any issues highlighted during the production or in service phase will not be encountered in subsequent designs.

Pahl and Beitz (1996), identify that during the design process the information flows and linkages between the different elements of the process are essential and that the production and assembly in particular depend fundamentally on the information and knowledge gained from product planning, design and development. They also allude to the fact that the design and development activities are highly influenced by the knowledge and experience accrued throughout production and assembly activities: therefore highlighting that information can be said to be critical throughout the entire design process. By way of illustration, Pahl and Beitz created a model of the information flow within design (Figure 3.7) highlighting the complexity and interdependencies between the product evolution and the creation and usage of information and knowledge.

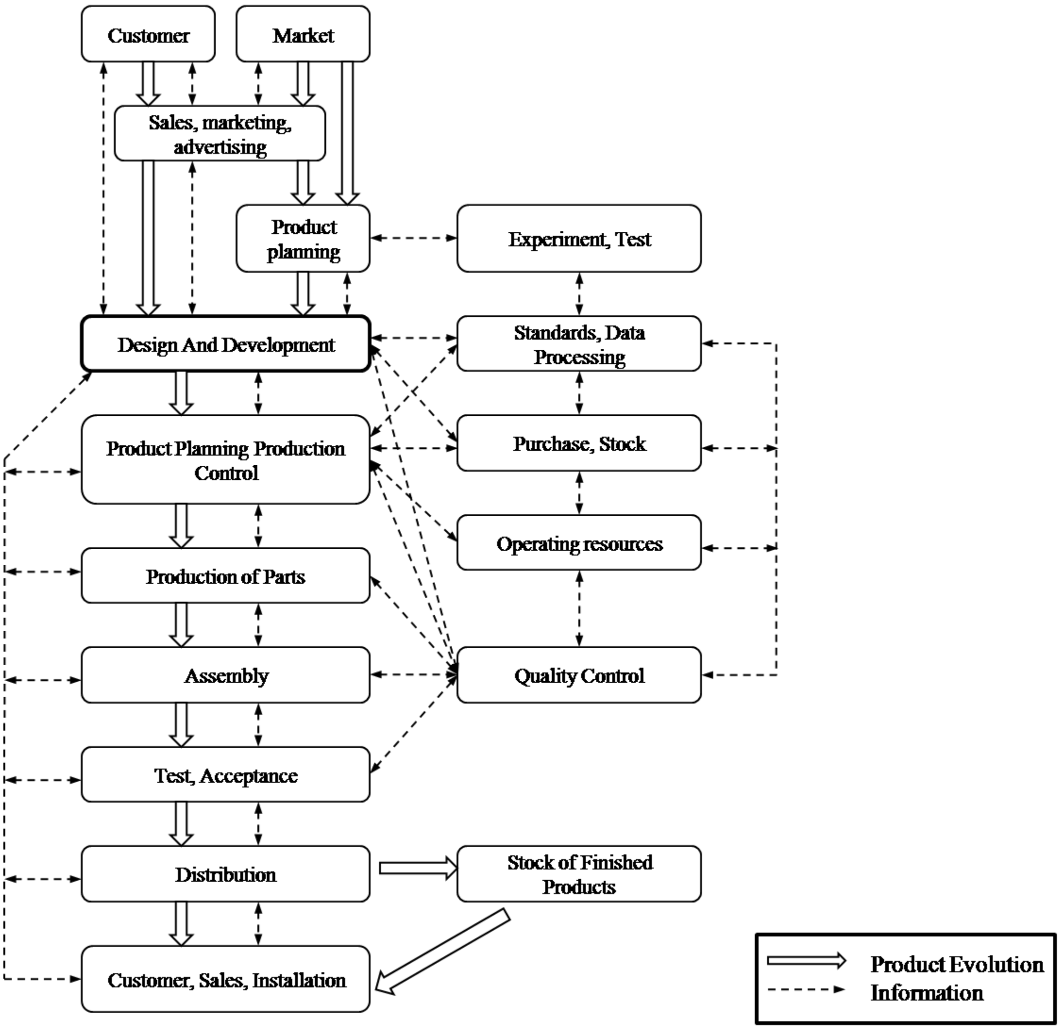


Figure 3.7 Product Information flow within the design process (Pahl and Beitz 1996)

To conclude, it is apparent that information and knowledge are critical components in creating successful product designs. The model above serves to highlight the importance of knowledge and information throughout the design process, demonstrating that without the flow of information between stages, the process of achieving a successful design becomes increasingly difficult. However, the literature models reviewed for this thesis take a fairly simplistic view of information and knowledge and do not address a key question: *what types of information and knowledge are generated and used in the design process?*

3.2 *Engineering Information Typology*

As discussed in the previous section, information within the design process has many different uses and at various stages within the design process. This section will now focus on identifying the types of information generated and how these essential commodities can be best utilised.

3.2.1 *Formal & Informal Information*

Information is widely regarded as being either formal or informal (Yang, Wood et al. 2005). Formal information is defined as being explicit and definite and that which takes the form of reports, finalised documents, Computer Aided Design (CAD) drawings, and any other information communicated in a predefined form (Pearshall 1998). Informal information therefore does not have a recognised or prescribed form and is valuable to designers as it can reflect many important aspects of the design process not found in formal documentation (Bellotti and Bly 1996). During the design and development of an object, the designer or design teams will rely on experience gained from past projects and similar tasks to aid them when making decisions and progressing through the development activity (Court, Culley et al. 1996). There is some ambiguity as to where exactly the split occurs between formal and informal information and how to identify the relevant information types. In an attempt to clarify the relationship between formal and informal information, Yang et al. (2005) proposed the Formality Spectrum of Design Information (Figure 3.8).

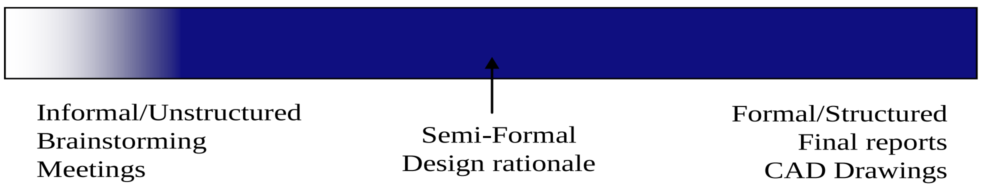


Figure 3.8 Design Information Formality Spectrum (Yang, Wood et al. 2005)

Although Yang et al's proposal gives a clear indication of the split between formal and informal information, it can be said that what they have proposed as examples of informal information may in fact be activities. For example, brainstorming is not informal information, it is an activity, which may or may not produce informal information. The same could be said regarding design meeting episodes, the meetings themselves are not information but *activities* which may create informal or formal information in the form of spoken word, sketches etc. However, Yang et al's formality spectrum can be useful as a platform upon which research can be built.

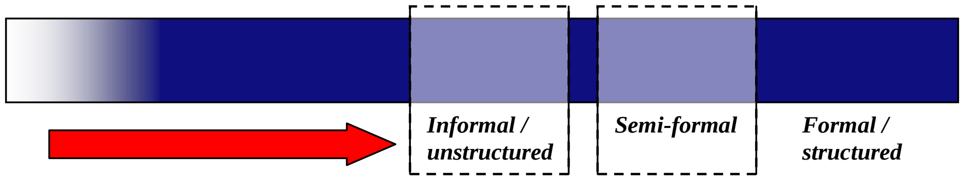


Figure 3.9 Formality Spectrum of Design Information - capture activity, adapted from (Yang, Wood et al. 2005)

If an information or knowledge object which lies at the informal or semi-formal end of the spectrum can be captured, then the capture process would in effect give structure to these objects, imparting formality and allowing for subsequent re-use. However, to achieve this it is critical to first identify the knowledge and information objects which currently go undocumented and develop methods of progressing these informal, unstructured elements along the formality spectrum, as illustrated in Figure 3.9.

Information can be further categorised into three groups which crossover with informal and formal design information; tacit, implicit and explicit. The Oxford English Dictionary (1998) defines tacit information as that which is unspoken or not communicated and usually resides within the designer's head. Tacit design information is entirely informal and encompasses design capacity, expertise, intuitive understanding and professional insight formed as a result of design experience. Throughout the lifecycle of a design project, the designer relies heavily on tacit design knowledge to support design decisions. Implicit information is implied though not plainly expressed; information which is capable of being inferred from something else. Implicit information can take the form of sketches and also oral communication and generally implicit information can be expressed through either informal or formal information. Explicit information encompasses all data and information recorded in a clear and unambiguous format.

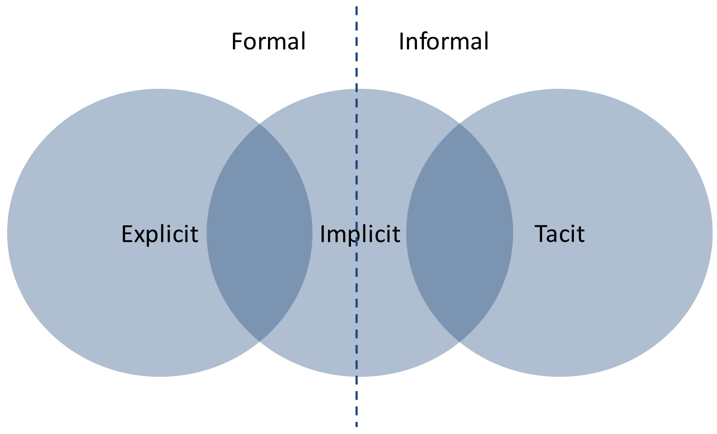


Figure 3.10 Relationship between tacit, implicit and explicit information

Explicit information can take the form of completed layout drawings, CAD models and any information medium which prescribes to a pre-defined form. In essence explicit information is formal in nature, however, in some cases this explicit information can be considered within contexts for which it has not been created, therefore becoming implicit. As stated above, tacit knowledge is regarded as being entirely informal and located within the head of the designer. This means that when this information and knowledge is communicated via <u>any</u> medium it can no longer be classed as tacit but instead it will be either implicit or explicit. The relationship and crossover between tacit, implicit, explicit information with regards to the informal and formal nature of information is demonstrated in Figure 3.10.

To address the issue of capturing the informal and sometimes implicit information and knowledge many solutions utilise tools such as video and media capture, adopting the belief that if you capture all information then you will not miss anything. However, this creates another problem. Not all the information captured will be useful, therefore how can you distinguish the information that is useful from information that is not? It is essential that before any design information capture solution can capture information, it must first establish exactly what information should be captured and its format. To enable this, the types of information generated throughout the design process must first be identified.

3.2.2 *Design Rationale*

One of the most widely identified and researched elements of knowledge and information is design rationale. Design Rationale (DR) can be defined as the reasoning behind or explanation of why an artefact or some part of an artefact was designed the way it was (Richter, Schuchhard et al. 1999). From this general definition it is possible to further explore design rationale as drawing on the designer's experiences, background knowledge and assumptions and encompasses the reasoning, trade-offs and decisions made throughout the development of the design. The subject of DR capture is a well documented issue and as such, much research activity has been structured around this. The difficulty with DR capture is seen to lie with developing methods and tools which enable its capture effectively and easily. To allow a deeper understanding of rationale capture and explore the associated complexities, Regli et al (2000) propose that the capture of design rationale can be divided into two methods, a) user-intervention based capture and b) automatic rationale capture.

3.2.2.1 User Intervention Based Rationale Capture

User intervention based rationale capture has often been approached by the documentation method (Regli, Hu et al. 2000). In general, the documentation found in user-intervention-based capture is graphical, text or a mixture of both and frequently is written by individual designers performing the design activities. The issue therefore is that much of the documentation tends to be created after the design activity and merely records the decisions thus failing to capture much of the designer's thinking processes that led to it.

Over the last decade there has been ongoing development on a number of Issue Based Information Systems, which map out the decision processes and issues encountered throughout the design activities. Notable developments on rationale capture include the development of software such as Compendium (Conklin 2006), Design Rationale Editor (DRed) (Bracewell, Ahmed et al. 2004) and Garcia's Augmenting Design Documentation (ADD) (Garcia and Howard 1992). Garcia's ADD is an integrated computational model for assisting designers in documenting projects during the design process. The system captures rationale by effectively using the computer as a 'design assistant', corresponding to Mann and Coons' theory of utilising computers as *"partners in the creative process"* (Mann and Coons 1965). Using a predefined set of relationships between various design parameters, the system expects certain values for the design parameters and if these 'expectations' are not met, the user is prompted to justify the difference. The explanation, provided by the designer, is recorded in the system's database alongside the unexpected value thus creating an effective method of rationale capture.

The DRed and Compendium software tools are very similar in structure in that they use nodes and connectors to map out the relationships between decisions of individuals and groups of designers and present these relationships in an easily followed graphical format. However, as with all user intervention based software, they require the designer to physically input all their decisions and create the relationships between them, generating additional work for the designers. To the designers and the design team, the recording of design rationale can appear to be both uninteresting and less than valuable. It is those who study the design at a later stage who will benefit from this information, hence there is little motivation for designers to record the thinking and reasoning behind their design decisions.

3.2.2.2 Automated Rationale Capture

To counter the issue of generating more work for the designer, research has been performed on developing automated rationale capture tools. Systems such as the Rationale Construction Framework (RCF) developed by Myers, Zumel, and Garcia (Myers, Zumel et al. 1999) and the COSTAR (Cable Organisation System Through Alternative Reality) platform (Robinson, Ritchie et al. 2007; Ritchie, Sung et al. 2008) propose seamless design rationale capture systems that acquire rationale information for the detailed design process without disrupting a designer's normal activities. Other notable research studies into the capture of design information have resulted in the emergence of rationale capture tools such as the RCF, The Hyper Object Substrate (HOS) system (Regli, Hu et al. 2000) and Design Rationale for the Information phase of Value Engineering (DRIVE) (Garza and Alcantara 1997). Their underlying approach involves monitoring designer interactions with commercial

CAD tools to produce a rich process history and interpret the intentions through the use of representation schemas. This means that the designers are not required to do anything more than pursue their usual design activities. However, the crux of these tools are integrated within computer software packages such as CAD packages, therefore much of the valuable informal information generated through sketches and other media are lost.

Overall, it can be said that design rationale is hard to capture, mainly because the capture process is very intrusive. In addition, its value may not be immediately obvious to the designer, as until now, retrieval of design rationale after the completion of the development cycle has been its main use. Only altruistic and cooperative designers will spend lots of effort with no obvious reward. However, if approaches could be developed whereby when rationale is recorded and captured as it was generated; it could provide immediate feedback and past examples of similar designs, which may increase the motivation for the designer to supply the rationale.

3.2.3 *Summary of key findings*

Within the literature, information is widely regarded as being either *formal* or *informal*. Where formal information can take the form of reports, finalised documents and CAD drawings, informal information can take the form of oral communication, body language, images and sketches. Information and knowledge can also be classified as either *tacit, implicit* or *explicit*, conforming to a sliding scale of formality, with tacit being informal and explicit being formal. Historically, formal information such as reports and specifications were widely regarded as being adequate for providing records of the design process, however, recently it has been recognised that informal and especially tacit and implicit design information which constitutes the *design rationale* can be extremely valuable. In some instances this can be more valuable than formal information, as it reflects many important aspects of the design process that describe the rationale behind decisions. It is worth noting that the very nature of informal and formal information is dynamic in that by capturing informal information it can be transformed into formal information. This then presents the ideal scenario where this transformation from informal to formal occurs without generating additional work for the individual(s) engaged in the design problem.

It is well documented that during the design and development of an object, the designer or design teams will rely on experience gained from past projects and similar tasks to aid them when making decisions and progressing through the development activity. If the information, knowledge and rationale behind these decisions can somehow be recorded throughout the design process, then these elements will be of utmost value to organisations who can reuse this knowledge in future projects. Owing to a paradigm shift in the engineering sectors (such as marine, aerospace, power generation) towards providing through-life support, organisations are placing a greater emphasis on constructing complete and accurate records of design activities. Thus, the capture and retention of knowledge and information becomes critical to aid the creation and through-life support of large, complex engineering products.

3.3 *The Through-life Knowledge and Information Management Paradigm*

In the current global environment, organisations supplying large made-to-order products are undergoing significant change from product delivery to through-life service support (Ding, Ball et al. 2007). To remain competitive in the global market, organisations are increasingly required to supply products and to provide support services throughout the product lifetime, which can encompass 5, 15 or even 30 years into the future, (Davies 2003; Oliva and Kallenberg 2003). The implementation of service support is becoming more common place within engineering as organisations in the UK and Europe adopt Product-Service Systems (PSS) in an attempt to remain competitive within the engineering and manufacturing industries (Baines, Lightfoot et al. 2007).

3.3.1 *Product-Service Systems*

The concept of PSS is one which has evolved from the UK and European manufacturing industry’s need to establish and maintain sustainability in fluctuating economic climates (Baines, Lightfoot et al. 2007). A PSS can be thought of as a business focus that extends the traditional functionality of a product by incorporating services and service plans into the product's purchase contract. Essentially this results in the customer purchasing the *use* of a product, rather than the product itself and so benefits from a restructuring of the risks, responsibilities, and costs traditionally associated with ownership (Shehab, Evans et al. 2008). In the traditional manufacturing sense, products are considered to be entirely separate from services; however in the context of a PSS, they are inextricably linked. Products may be serviced, upgraded, remanufactured and used for different purposes through their extended life (Goh and McMahon 2009). For organisations who both design and manufacture their products this shift towards PSS businesses provides greater access to valuable in-service information and knowledge which in turn can be fed back through the design process (Ward and Graves 2006). This is in direct contrast to the traditional model where products may be designed and manufactured but often, maintained and serviced by different companies resulting in disparate and often limited in service information being available (Goh and McMahon 2009). With many product oriented manufacturing organisations finding themselves challenged by countries with a low-cost labour base, the realisation is that to ensure longevity their business focus must shift from product delivery to knowledge intensive products and services (Hewitt 2002). The integration of products and service as a business model has occurred over recent years where the *servitisation* of products and the *productisation* of services have become more prevalent (Morelli 2003). *Servitisation* according to Vandermerwe and Rada (1998) is the process of adding value to products through an increase in the additional services offered as part of a package, whilst *productisation*, represents the evolution of services to include a product or products as part of the service offering. Ultimately, both approaches converge towards creating a Product-Service System (PSS) as demonstrated in Figure 3.11.

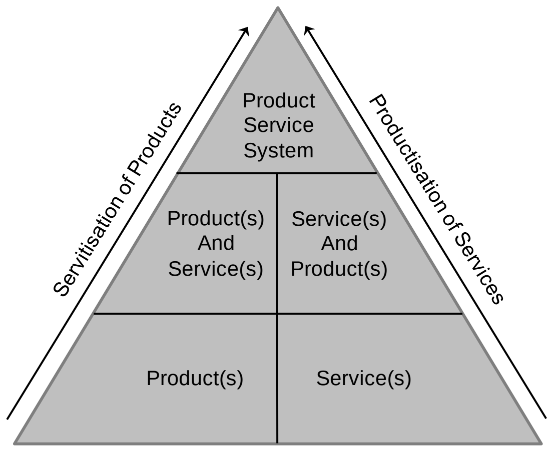


Figure 3.11 Evolution of the Product Service System (PSS) (Baines, Lightfoot et al. 2007)

Examples of this shift are present across the literature with a number of high-profile companies such as Xerox, Canon, IBM and Rolls-Royce quoted as having adopted the PSS model (Baines, Lightfoot et al. 2007; Goh and McMahon 2009) with the latter being the example most widely quoted. Referred to as "Power by the Hour" (PBH) in the private sector (Baines, Lightfoot et al. 2007; Kim, Cohen et al. 2007) Rolls-Royce’s Performance-based Logistics (PBL) scheme undertakes to provide the operator with a fixed engine maintenance cost over an extended period of time. This ensures that operators receive an accurate cost projection and avoid the costs associated with breakdowns. Thus the manufacturer must ensure documentation and designs for all parts of the products are continually reviewed and kept up to date to make certain that the company fulfils its contractual requirements, prompting a significant move away from the traditional product delivery practices within this sector.

With a major change in working practices comes the need for the development and application of business, operational and information system models for these extended lifetimes (Morelli 2003; Prencipe 2003). By way of example, engineering design organisations wishing to adopt the through-life knowledge management paradigm would be required to modify or adopt a design process which extended the process with stages such as modify/repair/servicing and recycling/disposal of the product. To illustrate this further, the summative model of the engineering design process proposed in Section 3.1.1.4 can be extended to incorporate such stages and the feedback stages modified accordingly.

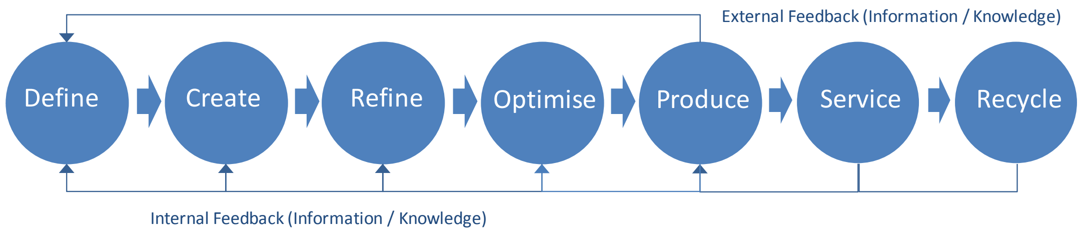


Figure 3.12 Extended summative model of the engineering design process

The change to a product-service model is believed to have substantial benefits as it encourages greater efficiency and more sustainable approaches to engineering by improving the scope for supply-side innovation. However, in aerospace the emergence of business models such as "power by the hour" as described previously has challenged traditional engine suppliers to rethink their technology offering – which in turn can lead to a revision of the design rules developed over the past 30 years (McMahon, Giess et al. 2005). That said one of the prime drivers behind the use of such approaches is that they present a significant opportunity to integrate the knowledge and information generated within the design and manufacture process.

In the PSS literature, a number of studies have been conducted looking at the feedback of in-service information and knowledge into the development process of high-volume consumer products (Goh and McMahon 2009). For example, Busby (1998) presents a study of five large commercial organisations looking at the extent to which design organisations learned from experience. To achieve this, the study assessed how well engineering designers were informed about the consequences of their activity and how this information affected their working behaviour. From this study, Busby made the following observations; feedback to designers was often unreliable, delayed, negative and sometimes missing altogether, designers failed to learn from the feedback that was available, developing plans that were at odds with past outcomes and repeating previous errors (Busby 1998). A latter study conducted by Chalmers University of Technology sought to analyse three Swedish manufacturing companies. This study noted that although the organisations observed had in place a systematic method of addressing customer issues and capturing feedback, none had adopted a formal structure to *transfer* the customer feedback to new product developments (Fundin and Bergman 2003). In a similar exercise, Sander and Brombacher (2000) conducted interviews within a design and manufacturing organisation and observed that although feedback loops were present between operations and development, they were *reactive* and not *pro-active* loops (Sander and Brombacher 2000) leading to limited application of the knowledge gained from the operations or in-service phases. These key observations demonstrate the criticality of adequate feedback from in-service stages of the product lifecycle. If adequate feedback methods / processes are incorporated in combination with a move to PSS working, then organisations have the potential to strengthen the development of subsequent generations of, or new products. If an organisation's feedback methods / processes are inadequate at utilising or even capturing vital information and knowledge then they increase the risk of producing ineffective products and or services. As design becomes an increasingly collaborative and knowledge-intensive activity, the need for computer-based frameworks to support the communication, representation, and use of knowledge and information within all stages of the development process becomes critical. The task many companies face is how to quickly and easily capture this information and knowledge along with its context, for re-use within the lifecycle of the project or for future projects without inhibiting either the designer or the design process.

3.3.2 *Knowledge and information needs throughout the product lifecycle*

In 2005, the Engineering and Physical Sciences Research Council (EPSRC) and the Economic and Social Research Council (ESRC) funded a research investigation into knowledge and information issues throughout the lifecycle of large made to order products. The "Knowledge and Information Management (KIM) Through-Life Grand Challenge Project" (McMahon, Burt et al. 2006) brought together a team of some 70 academics and researchers from 11 UK based universities to look at the knowledge management challenges associated with a move towards through-life product support.

A key output from this large research project was a UK survey conducted to establish the knowledge and information requirements of managers and engineers involved in design and service roles within organisations. The survey aimed to gather requirements regarding the needs for retrieval of previous designs and the needs to capture knowledge and information from current designs to support future engineering tasks (Heisig, Caldwell et al. 2010). Conducted using responses from 137 engineers the survey presents a good cross section of pre-defined industry sectors including: Aerospace, Engineering, Consulting services and Construction. The two key questions asked within the survey are of particular relevance and interest to this thesis.

The first question; *"Describe the information and knowledge* ***you would like to retrieve*** *from previous products/services"* (Heisig, Caldwell et al. 2010) was geared towards establishing the wants and needs of the respondents without taking into account the information and knowledge which they already can utilise. In the context of this thesis this question becomes interesting on two fronts. Firstly and most explicitly, the question responses can be used to structure a cross section of the information and knowledge needs and wants of staff engaged in design related activities. Secondly, and importantly for this thesis, the question does not account for the information and knowledge objects which ***were available*** to the respondents. This question generated notable results including the variety of information needs, unexpected absences of information and low frequency of information categories (Heisig, Caldwell et al. 2010).

The second question *"Describe the information and knowledge you think* ***should be captured*** *to assist future engineering tasks"* also provided notable results including the expectation of practitioners that tomorrow's needs will be similar to today's, the apparent failure to satisfy those needs and suggestions from respondents for improvements (Heisig, Caldwell et al. 2010).

The survey notes that of the 825 individual answers given to the first question, 67 categories of knowledge and information needs were defined (Heisig, Caldwell et al. 2010). Of these 67 categories the most common information and knowledge requirements identified by the engineers were as follows; design rationale (34.9%), component / part information (30.2%), changes / modifications (25.6%), drawings (23.3%), service information (20.2%) and design descriptions (21.7%). These responses correlate well with the current literature (Oliva and Kallenberg 2003; McMahon, Giess et al. 2005; Ding, Ball et al. 2007; Kim, Cohen et al. 2007) which are in agreement of the increasing need to provide engineers with such information and knowledge objects throughout the product lifecycle. However, what is particularly striking from the responses to the first question is that the engineers identified elements such as design *drawings*, *descriptions* and *changes/modifications* as being what they ***would like*** to have access to, implicitly stating that these valuable information objects are not available. This response illustrates that adequate methods of identifying and subsequently capturing knowledge and information objects which may be of use throughout the latter stages of design does not currently occur. As stated previously it should be noted that the question was not designed to elicit responses which detail the information and knowledge objects which were available to the respondents. However, to fully understand the usage and criticality of knowledge and information throughout the engineering product lifecycle, the availability of such objects must be investigated further.

Heisig, Caldwell et al's (2010) second survey question *"Describe the information and knowledge you think* ***should be captured*** *to assist future engineering tasks"* resulted in 60 categories which the respondents identified as being required, from a total of 414 individual answers. Again as with question one, Heisig et al phrased this question in such a way as to gather responses which identified information and knowledge not currently being captured within the organisation, not necessarily those objects which were. The most interesting result from this question was that many practitioners' expectations of that future knowledge and information needs were deemed to be *"same as today"* with 42.5% of the responses (Heisig, Caldwell et al. 2010). This would indicate that the knowledge and information needs identified in question one (such as design rationale, modifications etc) are not only what current design practitioners wish to have access to but what they consider as being critical for future projects and needs.

Overall, the study performed by Heisig, Caldwell et al (2010) and also previous similar studies (Kuffner and Ullman 1991; Court, Culley et al. 1993; Rodgers and Clarkson 1998) have shown that there is an increasing need to identify and capture product and process information and knowledge throughout the engineering product lifecycle. What is also evident is that organisations are increasingly required to ensure that engineers have the adequate and necessary information and knowledge at their disposal throughout each stage of the product lifecycle and particularly throughout stages such as design, manufacture, service, and disposal (McMahon, Giess et al. 2005).

3.4 *Conclusions from the Literature*

The research challenge which this thesis addresses is aligned with the current paradigm shift from product delivery to through-life service support within the engineering industry. Many companies are now faced with the challenge of creating accurate and reusable documents of design activities in order to support their products through life (McMahon, Giess et al. 2005). This exploratory review has served to highlight a key aspect of this challenge: the need to create richer and more accurate records of design activities. The aim of this exploratory review was to answer the following research question:

1. *Does the identification and retention of product and process information impact upon the engineering lifecycle?*

The answer to this question is now apparent. The identification, capture, and retention of product and process information and knowledge *do* impact upon the engineering lifecycle. Information and knowledge play a key role in ensuring that the development of the product meets the necessary criteria. As is explicitly shown in Figure 3.6, Pahl & Beitz demonstrate that the flow of information throughout the design process is a complex and critical element directly leading to the successful conclusion of the design activity (Pahl and Beitz 1996).What is also evident from the literature is that with the shift in focus from product delivery to product service comes a need to retain product and process information for extended product lifetimes, which can be some 10, 20 or 30 years. The need therefore is to assist design engineers to record more information than traditionally documented, providing a much richer product history and allowing the design process to be revisited and subsequently reused if and when necessary. If design engineers are to capture information and knowledge with a view to re-use at later stages in the product lifecycle then the focus must be on developing rapid, effective methods of capturing both formal and informal information at the point at which it is generated rather than through retrospective analysis.

The literature reviewed for this exploratory element of the research has provided a good understanding of the theoretical models of the importance of knowledge and information utilisation throughout engineering projects. However what is not present in the literature is whether there are specific stages of the engineering lifecycle, where the utilisation of information and knowledge is particularly prevalent, and subsequently, how efficient the current capture and utilisation mechanisms are at supporting this need. To address this issue, the second of the research questions was developed:

2. *Are there specific stages within the engineering design process where knowledge and information capture is inefficient?*

The literature study performed as part of this chapter has given an indication that knowledge and information capture is inefficient *throughout* the engineering design process rather than at specific stages. In addition, studies such as those summarised in Section 3.3.1 have provided a solid literature base upon which the information and knowledge needs and wants of engineering designers can be explored. However, to explore this research question further and establish first-hand if the literature is representative of industrial practice, an exploratory study was devised and undertaken within Company A.

3.5 *Exploratory Study I: Knowledge and Information in the Extended Engineering Lifecycle*

In the quest to establish what information is critical to the success of long-term projects, it is recognised that undertaking studies on the information types and occurrences during long-term and reactivated design projects would be of great benefit. Such projects may provide a clearer understanding of the information required during the latter stages of a project and therefore indicate steps which can enhance the capture of this critical information for reuse. Through existing contacts within Company A, located in Glasgow UK, there was opportunity to undertake interviews with the staff working on long-term design projects. As part of their ongoing process review activities Company A recognised that there were specific instances and areas within their business where knowledge and information capture was not optimal. To gain a better viewpoint and to establish whether knowledge management processes should be developed to remedy these issues, the company were supportive of the undertaking of this study, primarily as the results could be used to prioritise areas for improvement within the business.

3.5.1 *Company profile*

Company A is a ship repair, maintenance and engineering company. The business provides complete through life naval capability to support all aspects of UK and export warship provision. Currently operating out of three main sites in Glasgow, Portsmouth and Bristol, Company A employs over four thousand people and is involved in designing, building and supporting large 'made to order' Naval vessels such as Destroyer, Landing Ship Dock and Aircraft Carrier programmes for the UK MoD. In addition, Company A undertakes work for export customers such as Malaysia, Romania and Chile.

Initial informal studies highlighted interesting areas and issues relating to information availability during the reactivation of a number of warships for overseas customers. Company A was engaged to reactivate a number of products which had been decommissioned by their current owner in preparation for their onward sale. In most instances these products were some 10 – 20 years into their in-service life but had not been operational for some time. The reactivation activities required in these cases primarily involved the usage of dormant machinery and in some cases some structural modifications. One such modification included structural changes to the product to fit a large item of equipment and some strength calculations in the affected area. The project team was able to readily obtain engineering drawings for the affected structure; however, less readily available were the original design rationale and design calculations. In this instance, the project team was able to identify that a significant number of the original designers were still working in the company. Engaging with these employees to understand the rationale and decisions behind the original calculations of the structure allowed the project team to readily design and then subsequently undertake this modification. Whilst the engagement of members of the original design team provided an effective solution in this example, Company A recognise that this is not sustainable approach to solving the problem. Staff turnover and retirement coupled with long product lifecycles present a significant degree of risk to relying on such an approach. The general indication both from literature and initial studies is that companies typically retain product definition knowledge required for manufacture such as engineering drawings but are less ready to retain informal information such as design rationale and experience. The aim of this study was to establish the elements of information recorded, available and required throughout the engineering lifecycle of large engineering products such as naval ships. The study was designed to produce an accurate a viewpoint on how organisations developing and redeveloping such products rely on design knowledge and information.

3.5.2 *Semi-structured Interview Protocol*

Using Company A as a case study, semi structured interviews were conducted with staff currently working at various stages of the engineering product lifecycle. The focus was to establish:

- What information was required during these projects?
- What information was available during these projects?
- What information is missing during these projects?
- What information is recorded at each stage in the projects?

Four interview sessions were organised with three groups of employees; staff working on the design phase of projects, staff working in the production phase of projects and staff working on the re-activation and servicing of projects. By discussing and highlighting the information usage patterns at the different stages in the undertaking of projects, it becomes possible to identify where common gaps occur in the information usage and also identify what information is deemed critical by the people who are actually using it. Through the interviews it was possible to gain a representative view of the information which engineering teams require for a product throughout its life in service.

Using the four key questions identified above and also knowledge gained from the literature and initial informal studies conducted within Company A, a set of questions were developed which the semi structured interview could cover. These questions were:

- What information is being used?
    - Where/when was this information generated?
    - What form does it take?
    - Are decisions, rationale, alternate solutions, avenues previously explored useful?
    - Has it been necessary to contact previous engineers to find solutions to particular problems?
        - What happens if these personnel are not available?
        - Do these personnel provide answers where documentation does not?
        - What type of situation warrants the contact of personnel
        - Is this a "last attempt" solution?
- What information do staff require to work on projects?
    - What information would be expected as a minimum requirement to fulfil tasks?
- What information is available?
    - What form does this information take? Reports, drawings, data sheets etc.
    - Where is this information held? Stored locally, digital storage etc.

- What information is missing?
    - What type of information?
    - When and where was this information generated?
- What information is recorded?
    - What type of information product process?
    - What form does this information take?
    - Where is this information stored?

As discussed in methodology section 2.2.2.1.1, the adoption of semi structured interviews meant that the questions above formed an interview guide which was used to help the interviewer cover all necessary areas without imposing a formalised structure to the interview. This also ensured that the interviews were reliable and repeatable (Yin 2009).

3.5.2.1Transcription Methodology

As described in section 2.2.2.3, for this thesis, transcription methods were adopted within the undertaking of case studies and experimental activities. Using audio or video recordings to capture the interview, the subsequent transcription provides the researcher with an accurate record of the study for it removes the possibility of the researcher misinterpreting the response to a particular question. In his PhD thesis, Huet (2006) presents a basic transcription protocol (explained previously in section 2.2.2.3.1, page 25), and although developed for use in engineering meetings, this approach is equally applicable to interview situations and was subsequently adapted for this study. As is shown in Figure 3.13, the basic transcript consists of three columns: Speaker – identity of the person speaking (represented as initials); Transcript – the transcribed audio, and Time – the instance at which the intervention took place, relative to the start of the meeting. In addition to these, specific conventions were applied within the transcript. For example, three full stops (…) represents a pause of 10 seconds or less and the speaker ID enclosed in square brackets represents that some or part of the intervention from this speaker was not transcribed along with the reason given. The full conventions used in the transcript are detailed in Figure 3.13. For reasons of brevity one sample transcript from the interview sessions is included as Appendix A. The remaining seven transcripts are available for analysis upon request.

Speaker	Transcript	Time
DL	Yeah we will look at four or five different options and say “well this is the gun that you should be looking at or one with this calibre, and this range” …. and we also, the other thing we do we look at futuristic ideas, what the ships of 2030 should be looking like	02.11
AC	So when the…you said that the customer comes to you with a kind of spec	02.32
DL	Yeah	02.35
AC	You mentioned that it could be an A4 page or it could be books and books, what kind of information do they give you or is it just a case of here’s our requirements, go ahead	02.36

Legend

- Speaker - Identity of the speaker (initials);
- Transcript - Text transcribing speech;
- Time - Time when the intervention began (minutes: seconds);

Text conventions

- Words in italics are approximately transcribed
- … In the text marks a pause of 10 seconds or less
- (…) In the text marks a pause of more than 10 seconds
- […] In the text marks a pause of more than 30 seconds

Specific speaker conventions

- [ID] some or part of the intervention from this speaker was not transcribed and the reason given in the transcript encased in [ ]
- ID = X, the identity of the speaker was not recognised

Figure 3.13 Transcript conventions used within study

3.5.2.2Analysis Method

As the semi structured interview technique was applied in this study, it was not possible to apply statistical data analysis techniques to the transcripts. Instead, a method was required to aid in both the collation and also visualisation of the data gathered. This resulted in a simple matrix upon which the information objects which were documented could be mapped against the relevant stages in the design process (Figure 3.14). To analyse the information types used at each stage it was first necessary to select a process model which could be applied to the case study.

		Concept	Assessment	Demonstration	Manufacture	In-Service	Disposal
Information Used	**Process Information**						
	Decisions						
	Rationale						
	Lessons Learned						
	Feedback						
	Experience						
	Product Information						
	Formal Design Information						
	Informal Design Information						
	Lessons Learned						
	Supplier information						
	Costing information						
	Feedback						
	Experience						

- ● Strong relationship
- ◎ Moderate relatonship
- ▲ Weak relationship

Figure 3.14 Analysis Matrix

For this study, the Ministry of Defence (MOD)'s CADMID (Concept Assessment Demonstration Manufacture In-Service Disposal) acquisition model (Figure 3.15) was selected. This was selected for two reasons. Firstly as the study was conducted within and the results used by Company A, it was imperative that a design process which the company is familiar with was selected. Secondly the CADMID model is characterised by a number of stages through which the design must pass, as indicated in Figure 3.15, thus is comparable to the stage based engineering design process models presented in Section 3.1.

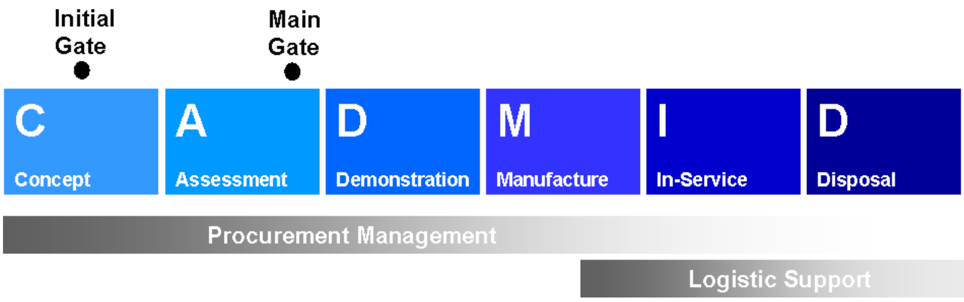


Figure 3.15 CADMID Model (Great Britain Ministry of Defence 2007)

This process is regarded as the standard project or product lifecycle for use in any MOD related project and as such, large product manufacturers such as Company A adopt this model as their general design process. As is highlighted in Figure 3.16, the CADMID model is directly comparable to the extended summative design process model developed as part of this study and both models align well with the through-life knowledge management paradigm discussed in Section 3.3.The adoption of a process model allows the information types (either product or process) to be mapped against each phase of the lifecycle.

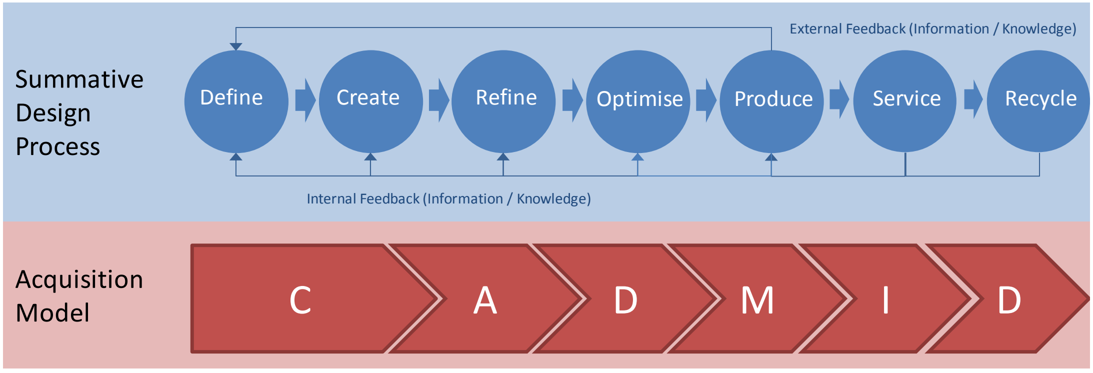


Figure 3.16 Extended summative design process and the CADMID acquisition lifecycle process

In many cases the information types were identified by staff as being available, used or recorded to different degrees within the stages of the engineering lifecycle. To ensure that these differences are recorded and analysed within the study, a rating scale was required. To represent the different degrees of availability, use and recording within the analysis, a three-level relationship scale was developed whereby the interviewer would retrospectively analyse the response from the staff member and identify the relationship rating accordingly. When the interviewee responded that a particular information object was ***explicitly*** available, used or recorded then this was identified as a ***strong*** relationship within the relevant stage of the engineering lifecycle. If the interviewee responded that an information object was available, used or recorded ***only upon request*** then this was identified as a ***medium*** relationship within that stage of the engineering lifecycle. Finally if the interviewee identified an information object as ***not*** available, used or recorded, this was identified as having a ***weak*** relationship with that particular stage within the engineering lifecycle.

3.5.3 *Case Study*

The study was undertaken within Company A located in Glasgow. As indicated previously, the interviews were aimed at staff working on projects across the lifecycle and across a variety of projects.

An indication of the lifecycle phases covered can be seen in the table below which shows where each interviewee's project can be deemed to be placed relative to the MoD CADMID lifecycle. The table also gives an indication of the variety of employees interviewed including an Engineering Managers, Change Manager, data Manager, Engineer and Naval Architects covering a variety of projects including the Type 45 destroyer (T45), Future Carrier (CVF) Royal Fleet Auxiliary Wave Knight Class tankers (RFA) and Export Ships.

Table 3.3 Interviewees and their role within the company

C	A	D	M	I	D
Senior Principal Combat Systems Engineer (Export Ships)	Engineering Manager (Carrier)	Data Manager (Carrier)	Change Manager (Destroyer)	Engineering Manager (Export Ships)	
System Design Manager (Naval Architect) (Export and Landing Ships)		Detail Design Manager (Export Ships)	Test & Commissioning Manager (Destroyer and Export Ships)		

In co-operation with representatives from the company, four interview sessions were arranged on separate dates, each session consisting of two one-hour long interviews with members of staff. The sessions were as follows:

Session 1 - 03/12/07

- Engineering Manager (Carrier)
- Change Manager (Destroyer)

Session 2 - 24/01/08

- Detail Design Manager (Export Ships)
- Senior Principal Combat Systems Engineer (Export Ships)

Session 3 - 29/01/08

- Data Manager (Carrier)
- System Design Manager (Naval Architect) (Export and Landing Ships)

Session 4 - 18/02/08

- Test & Commissioning Manager (Destroyer and Export Ships)
- Engineering Manager (Export Ships)

Each of the interview sessions was conducted onsite at Company A. The participants were briefed on the purpose of the study and permission sought to create audio recordings of the interviews.

3.5.4 *Analysis / Results*

The transcripts from the interviews were analysed against the semi-structured questions used in the interviews and the results compiled into the analysis table (Figure 3.17). The following sections detail the responses to the questions and demonstrate how these are represented on the analysis table.

			Concept	Assessment	Demonstration	Manufacture	In-Service	Disposal
1	Information Used	**Process Information**						
2		Decisions	●	●	●	●	●	
3		Rationale	◎	●	●	▲	●	
4		Lessons Learned	●	◎	◎	▲	●	
5		Feedback	●	▲	▲	◎	◎	
6		Experience	◎	●	◎	◎	●	
7		**Product Information**						
8		Formal Design Information	●	●	●	●	●	
9		Informal Design Information	◎	◎	◎	▲	●	
10		Lessons Learned	●	◎	◎	▲	◎	
11		Supplier information	●	●	◎	◎	◎	
12		Costing information	●	●	◎	◎	●	
13		Feedback	●	▲	▲	▲	◎	
14		Experience	◎	●	◎	◎	●	
15	Information Available	**Process Information**						
16		Decisions	●	●	●	◎	◎	
17		Rationale	●	▲	◎	◎	▲	
18		Lessons Learned	▲	◎	▲	▲	◎	
19		Feedback	●	▲	▲	▲	◎	
20		Experience	◎	▲	◎	◎	▲	
21		**Product Information**						
22		Formal Design Information	●	●	●	●	◎	
23		Informal Design Information	●	▲	▲	◎	▲	
24		Lessons Learned	▲	▲	▲	▲	▲	
25		Supplier information	●	◎	◎	●	◎	
26		Costing information	●	◎	◎	●	◎	
27		Feedback	●	▲	◎	▲	▲	
28		Experience	◎	▲	◎	◎	▲	
29	Information Recorded	**Process Information**						
30		Decisions	●	●	●	●	●	
31		Rationale	●	◎	◎	▲	◎	
32		Lessons Learned	●	▲	●	◎	●	
33		Feedback	●	▲	▲	▲	●	
34		Experience	▲	▲	▲	▲	▲	
35		**Product Information**						
36		Formal Design Information	●	●	●	●	●	
37		Informal Design Information	◎	◎	◎	◎	◎	
38		Lessons Learned	●	▲	●	▲	●	
39		Supplier information	●	●	◎	◎	●	
40		Costing information	●	●	◎	◎	●	
41		Feedback	●	▲	▲	▲	●	
42		Experience	▲	▲	▲	▲	▲	

●	Strong relationship
◎	Moderate relatonship
▲	Weak relationship

Figure 3.17 Transcript analysis

3.5.4.1 What information is currently being used?

As is evident from lines 2 and 8 of the results matrix (Figure 3.17), information objects such as *Decisions* and *Formal design information* were identified as those which were explicitly used across all stages of the design process. This is unsurprising in that many of the documents which respondents used in their tasks were found to be customer specifications and requirements documents along with formal CAD drawings and detailed reports. In many cases it was indicated that at the end of each stage Datum Packs containing such formalised information were created which would then be passed to the next phase ensuring that such information was made available for use. In addition, in the early phases of the lifecycle such as the bid and design stages it was noted that documents and information from previous bids (successful and unsuccessful) were useful sources of information. In many cases the bids would be for projects with a customer who had previously either accepted or rejected bid proposals in the past and as such, these documents were useful as indicators of what the customer would want or not want as part of the bid document.

As well as formal information, in the early (Concept, Assessment) and also latter stages (In-Service, Disposal) of the CADMID cycle, informal information and rationale were identified as information which was used when and if available (lines 3 and 9). In many cases, this information was derived from reports or meeting minutes and not explicitly from rationale or informal information documents. It is worth noting however that in the middle stages such as Manufacture and Demonstration, informal information and rationale was not deemed to be used to a significant degree.

A significant form of informal information mentioned during the course of the study was the application and use of experience within projects. Although difficult to quantify, and in some instances recognise, many of the participants indicated than at some stage they have consulted or sought out advice from colleagues on the best approach to tackling or proceeding with certain aspects of their work. Indications from the respondents were that in many cases this would be the easiest route to finding a solution or finding information about a certain aspect of a ship element or system design. Many of the engineers and designers who worked on past projects were still with the company and therefore could give first hand advice. In most cases this would be via informal verbal communication within episodes such as review meetings or social interaction, and subsequently complete and accurate digital or physical records of these would not comprise part of the design record.

3.5.4.2 What information is available?

Line 22 within the analysis matrix demonstrates that the information most readily available throughout the entire lifecycle appears to be formal information. That is report documents, drawings, spreadsheets, CAD models, supplier information, costing information, testing and evaluation report forms. A common issue which was highlighted was that of storing CAD models. The CAD software systems employed within Company A tend to be ship-specific systems, such as the SENER FORAN system which is was specifically developed for the development of naval ships (SENER 2010). These systems are utilised more to verify the integration of systems and components in the overall ship layout rather than to design and model each individual system. Owing to ever advancing technology and higher costs associated with maintaining and updating CAD models throughout the lifecycle, updates are made mostly to paper copies of drawings rather than soft copies.

Informal information was recognised as not being explicitly available, that is much of the intent, rationale and reasoning can be found through either talking to the engineers within the company or derived from the formal documentation such as reports but informal documentation sketches, drawings or sometimes calculations are not commonly captured or made available throughout the lifecycle.

Storage of information and data captured throughout the projects was indicated to be via one of four methods:

1. electronically on individual computer hard disk drives;
2. electronically in Product Data Management (PDM) systems (Destroyer, Carrier class);
3. paper documents kept in local storage (either departmentally or individually);
4. paper, microfiche or other means within the Archive Department.

Much of the legacy data for earlier ships (destroyer class) was identified as being held on Microfiche and stored within the archive. It was indicated that this format was considered suitable for long-term preservation and in many cases was the preferred storage method over electronic formats as it was not ‘system dependent’ and was more robust than paper. However, it was also indicated that the company’s Archive Department was not first choice for storage of records, as the task of retrieving information from the archive is a time consuming process. In many cases, engineers keep copies of documentation at their desk and archive additional copies, thus ensuring that if and when they required the documentation they are able to access it quickly and easily. The archive department is mostly used for storage of documents and records for projects no longer considered to be active. In the case of recent projects such as the Destroyer and Carrier, PDM systems such as Windchill® (2008) are employed and utilised to store much of the data virtually, although due to suboptimal set up of the system, navigating and searching the system has been identified as problematic.

A key observation from this section is that although much of the *informal* information is not explicitly captured during the design process, in many cases this can be derived from within the *formal* information which is available. The issue which Company A faces is that the methods and locations currently being employed to store this information are not standardised across the departments and therefore for individuals to identify and locate required knowledge and information requires significant effort not accounted for within the project plans. The result is that retrieval of information in ten or 20 years may prove difficult for Company A as the process for storing and locating information at the moment is ill defined and in many cases reliant on tacit knowledge within the person responsible for its creation, which is recognised as not a sustainable approach.

3.5.4.3What information is recorded?

Each stage in the CADMID lifecycle focuses on a very different aspect of work within the project and thus it is difficult to list, analyse and compare all types of information recorded at each stage. However, through the course of this study, commonalities were found between the information recorded at each stage. As is evident in lines 30, 36 and to a lesser degree 37 within the analysis matrix (Figure 3.17) the information which is recorded appears to be that which is predominantly formal in nature and that which performs specific functions within the lifecycle, i.e. to document an activity or a decision made. The following sub-sections highlight the three main categories of information which arose from the interview sessions undertaken:

- retrospective documentation;
- meeting documentation;
- lessons learned.

3.5.4.3.1 *Retrospective Documentation*

The main form of capturing and communicating information was indicated to be via retrospective reporting documentation such as design reports, activity reports, calculations and spreadsheets, focusing on setting out how the activities were performed compared with those which were planned. Very little is captured on *why* things are done, instead these documents are more focused on what was done: rationale and reasoning is not explicitly captured although could possibly be derived from reports or review documents. In many cases, these reports will go to a delegated design authority (DDA) whose role is to check and sign off that the information contained in the report(s) is correct and satisfies the relevant requirements for the project.

3.5.4.3.2 *Meeting Documentation*

Owing to a well controlled and corporate enforced culture, other formalised documentation captured throughout the CADMID cycle includes formal meeting minutes and records of stage gate reviews. Design Review meetings, Change Management Review meetings and other formal meeting scenarios are held at various stages throughout the lifecycle and also at differing levels. The agreed minutes from the formal record of these meetings are documented and stored for reference throughout the project lifecycle and beyond. In many cases these meeting records are seen as the formal documentation proving that the activities which were performed, reviewed and subsequently approved were done in accordance with relevant process instructions and parameters. However, the value placed on minutes from less formal meetings is lesser and as such these records do not tend to make up the datum pack for the project.

3.5.4.3.3 *Lessons learned*

An interesting and somewhat surprising aspect of information being recorded was the incorporation of a Lessons Learned (LL) database into many stages of the project lifecycle. From the study it is apparent that the company has recognised the value in capturing lessons learned from previous working and projects and has gone some way to creating a storage area for this information. However, it also is apparent that there are very different levels of capture for lessons learned; dependent on the department and also the staff members therein. It appears that staff working in the earlier and latter stages of the CADMID cycle place a much higher value on recording lessons learned than those involved in other central stages, which can in turn affect the quality and value of the information within the database. It also appeared that there was no current centralised storage process for LL capture and that many of the engineers would keep such data in localised storage spaces such as hard copies in filing cabinets, local network drives or indeed on personal computer drives.

The results from analysing the information recorded are unsurprising in that what is being recorded is essentially what is needed to perform and validate actions taken throughout the project lifecycle. However, what has also become apparent is that there is value being placed on less formal information such as lessons learned, rationale and design intent. The data which can be extracted and reused from this less formal information can be valuable to a company moving from product delivery to through-life maintenance and management. With this move to a more through-life oriented service comes the need to not only understand what was performed during the design, manufacture and in-service stages but also why these activities were performed and what impact they have had. It appears to a certain degree that Company A. have recognised this need and have encouraged the use of lessons learned as a means to understanding the process undertaken and the successes and failures associated with these; however, this process needs to be formalised and structured in a way that is applied at a consistent level across all aspects of the lifecycle if the initiative is to be of any benefit to the company.

3.5.4.4 What information is missing?

From analysis of the information used, available and recorded at each stage of the CADMID cycle it becomes possible to identify types and instances of information that are not currently being captured fully but may be of value and provide benefit to projects ongoing, future projects and the company as a whole. The following sections discuss these information objects further.

3.5.4.4.1 *Rationale / Experience*

Rationale is the reasoning behind or explanation of why a system or some part of a system was designed the way it was. This study has highlighted that although the rationale and reasoning behind many decisions are currently being captured, they are limited records and do not form an explicit part of the formal documentation processes employed by the company. Instead these elements of information have to be extracted from reports and other documentation. The primary reason appears to be resolving issues out with formal processes and therefore the resultant documentation will reflect the decision but not the rationale behind it. If Company A is moving from product delivery to through-life provider, then there may be justification for extracting and retaining design rationale over the entire in-service life, which in the case of ships can be 30 years or more. As is demonstrated in 3.5.4.1 such information objects are currently being utilised within the design and manufacture of current ships. Therefore based upon this evidence and what is known from the literature (Section 3.2.1) it is possible to conclude that the explicit documentation and retention of such objects would allow more informed decisions to be made at future stages where the original designers and those involved in the project may no longer be available.

3.5.4.4.2 *Feedback*

During the early design and bid phases of the CADMID cycle customer feedback has significant value in helping to make decisions on how to approach bids and create designs. However, it is also recognised that feeding information about each stage back into the CADMID cycle would also be of benefit. In the course of this study, many individuals identified feedback from latter stages, such as manufacturing or in-service, as valuable information which they could utilise especially in the context of repeat orders or future projects with similar requirements or specifications. The implementation of feedback processes or sessions into each stage of a project could allow more informed decisions to be taken throughout the project and thus reduce the risk of errors or problems being repeated.

3.5.5 *Conclusions*

Projects and work being undertaken within Company A are increasingly complex, long duration projects across multiple sites. With these large projects, 'alliances' with other organisations are becoming more commonplace and thus more complex splits of responsibilities are required. Information management represents a significant part of a design process at a high level. A designer receives input data; this data is then processed to produce a set of information or knowledge outputs. Information management is intrinsically bound up with engineering design. Current data management processes employed can be said to be strongly influenced by Information Technology solutions available and thus with multiple partners across multiple sites, data consistency in organisations such as Company A is a key challenge.

With knowledge and information management becoming more prevalent in business, Information Technology (IT) is advancing rapidly. To some extent, a design process is defined by the tools (e.g. CAD) which the designer uses. Should these tools allow – or even demand – data management then it will become embedded in the design process. During the course of this study, this issue was highlighted numerous times. Many of the interviewees attested that they had encountered, first hand, problems in retrieving data and information from software files which were either out of date or unreadable due to software changes. In many cases this resulted in soft copies being transferred to other more robust storage formats such as microfiche or simply paper copies for archiving. Given the length and complexity of the projects and products Company A are involved in, greater emphasis must be placed on ensuring the longevity of electronic formats throughout product in-service lifetimes. For example, a ship may have a five year design and build lifetime followed by a twenty year in-service life. There are ships in service today (2011) which were designed in the 1970s and early 1980s. It can readily be seen that there have been significant changes in IT over this time period. When updating and choosing IT software, consideration must be given to version compatibility and the ability to retrieve data from files created on previously used software.

Preservation of information is generally undertaken using two methods:

1. Storing files locally in computer hard drives, shared network drives (on a project by project basis) and in filing cabinets or desks.

2. Archiving copies of documents in the centralised company archive.

In general, the first method of storing information locally was indicated to be the most frequently used simply because many respondents did not have full confidence in the archive department being able to quickly and easily locate the necessary files. Company A has recently greatly improved its company archive and to highlight the department's capabilities, demonstrations of using the system and the benefits need to be given to staff. A dedicated storage location exists which has been properly equipped as an archive with shelving and cabinets. A professional archivist has been employed and processes set up to manage the archive. Implementation of a centrally located and easily accessed electronic archive is a recognised need within the business and following the publication of a corporate policy on data management from Company A, there is now a greater emphasis on this topic across the company. Projects and departments now typically have dedicated and structured networked electronic storage areas.

A significant finding within this study was the low level of information reuse occurring within and also across projects. This was surprising in that Lessons Learned activities were repeatedly identified as part of the formal process undertaken by each stage in the project lifecycle. However, indications are that the information being fed in to the lesson learned database was simply not being used. In general, the most significant reuse of information occurred in both the early bid stages of the project or in the latter in-service and disposal stages. As indicated previously, feedback from previous stages, bids, projects has significant value in helping to make decisions on how to approach bids and create designs and. In the course of this study, many individuals identified feedback from latter stages, such as manufacturing or in-service, as valuable information which they could utilise especially in the context of repeat orders or future projects with similar requirements or specifications.

With Company A moving from shipbuilder to shipbuilder/in-service design authority, there is a greater need to retain process knowledge and information such as design rationale over the entire in-service life. However, with industries such as gas and oil seeking individuals with a similar skill set, and offering more competitive salaries, there is a real possibility that the number of staff remaining within the organisation for 10 years or more will fall significantly. Therefore, methods and processes of capturing this valuable knowledge and rationale from staff should be implemented to ensure that this information is not lost if employees were to leave the organisation. Capturing this information would also be of value as it would enhance the knowledge learning process for new staff and ultimately help them to become more familiar with projects and able to deal with problems more effectively.

Overall this study has highlighted a key consideration for this research; the ineffective capture of information and knowledge is not bound to one particular stage of the engineering design process. From the evidence presented in the literature (Section 3.2 & 3.3), this study performed within Company A is symptomatic of many large multinational engineering product manufacturers. What is apparent from both the literature and also this study is that the problems facing these organisations cannot simply be solved through the implementation of software tools or ‘quick fix’ solutions. Instead, the key to creating an organisation whose management of engineering design knowledge and information is truly effective, must come from implementing processes and methods into the engineering design process. Effective processes and methodologies, in addition to the necessary tools and mechanisms, will present engineering organisations with the necessary capability to undertake effective knowledge and information management.

3.6 *Chapter summary*

As is evident both in the literature, and through the industrial case study described, many engineering companies are now faced with the challenge of creating accurate and reusable documents of design activities in order to support their products through life. The aim of this chapter was to provide an exploratory review of the use of information and knowledge within the engineering lifecycle and answer the following research question:

1. *Does the identification and retention of product and process information impact upon the engineering lifecycle?*

The identification, capture, and retention of product and process information and knowledge can have an impact upon the engineering lifecycle. As is explicitly shown in the literature, the flow of information throughout the design process is a complex and critical element directly leading to the successful conclusion of the design activity. What is also evident from the literature is that with the shift in focus from product delivery to product service comes a need to retain product and process information for extended product lifetimes. The aim therefore is to assist design engineers to record more information than traditionally documented, providing a much richer product history and allowing the design process to be revisited and subsequently reused if and when necessary. The literature reviewed for this exploratory element of the research has provided a good understanding of the theoretical models of knowledge and information utilisation throughout engineering projects. However what is not present in the literature is evidence of which stage of the engineering lifecycle these modes of information are most widely generated, recorded, and required. To address this problem, a second research question was tackled:

2. *Are there specific stages within the engineering design process where knowledge and information capture is inefficient?*

An exploratory study conducted within a large multinational engineering organisation provided an exemplary overview of the elements of information which organisations record, are available and are required throughout the engineering lifecycle of large made-to-order engineering products, in this case naval ships. Through the undertaking of semi-structured interviews, this study highlighted the types and instances of information used and required at each stage of the Ministry of Defence's (MOD) CADMID process model. The study highlighted a key consideration for furthering the research within this study; the ineffective capture of information and knowledge is not bound to one particular stage of the engineering design process but rather can be deemed to be a by-product of the processes employed. These findings are in line with the exploratory literature study performed within this chapter. That is, the key to creating an organisation whose management of engineering design knowledge and information is truly effective is to implement effective processes and methods into the overall engineering design process in addition to the necessary tools and mechanisms.

At this juncture in the research it has become apparent that information and knowledge usage is prevalent within the engineering design process. It has also become apparent that there are no particular stages of the process within which the use and generation of knowledge and information is more critical than other stages. Therefore this research must now delve deeper into engineering design and try to understand if any particular activities which engineers encounter or participate in have a direct link to the knowledge and information objects utilised and captured throughout the design process.

Chapter 4: Focused Literature Review: Synchronous Engineering Design Episodes

Establishing the answers to research questions 1 and 2 within the previous chapter has provided insights and understanding of the differences between information and knowledge, and the importance of capturing these commodities for usage at stages throughout the engineering product lifecycle. From the review of literature and also the exploratory study performed within Company A it was established that information and knowledge are generated and utilised throughout the various stages of the engineering product lifecycle. Therefore this research must now narrow the focus of study to particular activities which engineers encounter or participate in where the capture of information and knowledge is of paramount importance to creating an accurate record of the activities performed.

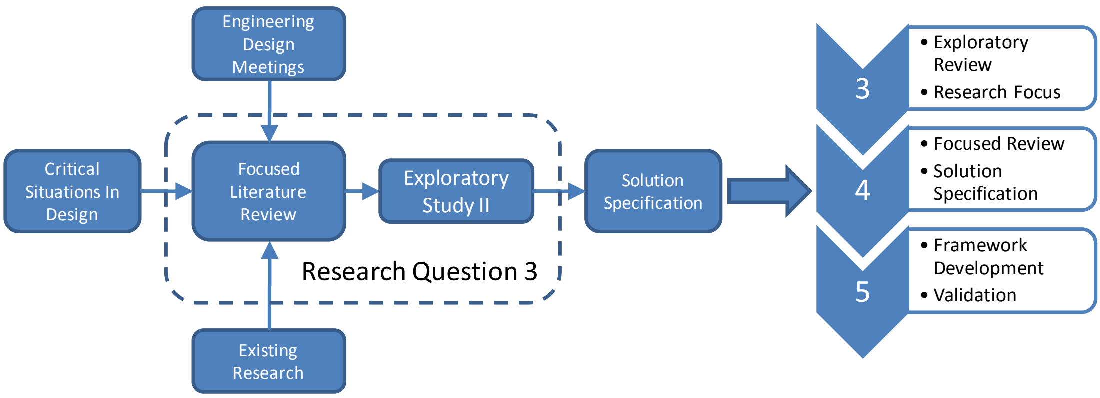


Figure 4.1 Chapter Structure

As demonstrated through Figure 4.1 above, this chapter presents an overview of the different modes of working in design and through review of literature, previous research and a second exploratory study provides the answer to the third research question:

3. *Are there specific activities employed within the engineering design process where knowledge and information capture is inefficient?*

4.1 *Synchronous and Asynchronous Modes of Working*

Design is a collaborative process involving communication, negotiation and team learning (Ion, Wodehouse et al. 2004). That is, the majority of communication in the design process can be said to be of an *asynchronous* nature with information being relayed between design partners in a sequential manner, for example utilising communication mechanisms such as email (Wasiak, Hicks et al. 2009). However, for certain activities within design, such as design development, brainstorming or indeed critical analysis, *synchronous* communication becomes more crucial. When undertaking large collaborative engineering design projects, the effective use and understanding of both synchronous and asynchronous modes of working becomes critical to the success of the project (Conway, Giess et al. 2008). This is also true of smaller, co-located projects as during these, both modes of working will be utilised.

In engineering design, working synchronously involves individual designers and/or team members working on the same activity at the same time. Activities such as design related meetings are prime examples of social and collaborative instances where valuable information and knowledge can be communicated through channels such as speech, body language and even gesturing, which can be extremely difficult to both recognise and document. In many cases subsequent decisions can be linked to this tacit or implicit knowledge and information, therefore much of the rationale behind these decisions are lost.

When working asynchronously, an engineer focuses individually on a given problem. The specific approach that they may take, the methods that they use and the assumptions that influence their course of action are not generally recorded and the electronic files that they may manipulate do not expressly indicate the processes followed or where supporting information was obtained. As such, it is difficult to revisit previous design activities either to reuse in similar situations or to reassess and potentially update the design activity in the light of new understanding.

With the ubiquity of computational tools in the design process, much of the information that an engineer will encounter during the course of their working will be computational and by seeking to capture these manipulations performed on the information and the interdependencies between different information resources, it becomes possible to build up a view of the processes followed in both synchronous and asynchronous working.

4.1.1 *Synchronous Modes of Working*

In the past decade, a significant body of work has been undertaken on aiding the capture of information within synchronous engineering design episodes. This body of work can be categorised as either conforming to the *record everything and analyse later* method or *analyse and document at the time* method. The latter of these approaches utilises emerging technology such as Issue-Based Information Systems (IBIS) as described in Section 3.2.2.1, documenting the decisions made and the issues resolved using structured argumentations in real-time. However, the IBIS approach fails to record much of the critical dialogue which precedes decisions being taken and thus valuable information goes undocumented. A key element within current live capture approaches is the structuring of the information in a way which can be easily visualised and followed by the users, as it occurs in real time (Conklin 2003). This is the area in which most IBIS based tools excel (Bracewell, Ahmed et al. 2004; Conklin 2006; Bracewell, Gourtovaia et al. 2007). The structuring of information according to the argumentation effectively provides a 'road map' to the design episode, allowing users to follow the development process and understand how the design evolved to the final state, including the right and wrong 'turns' which were discussed throughout. However, the real-time display of this information throughout a synchronous design episode could also 'steer' the discussion, thus IBIS technologies can be considered to be much more than simply documentation tools, they could be considered as tools which aid the actual development process and influence the direction in which the episode progresses.

Similarly, effort has been focused on developing systems which simply record everything using multimodal technology such as video and audio. Systems such as Informedia (Hauptmann 1995; Hauptmann, Thornton et al. 2001), Convera and Ferret Browser (Lalanne, Lisowska et al. 2005), possess the ability to capture information using video / audio capture and speech recognition. However, this approach results in masses of information being captured, some of which can be regarded simply as noise, resulting in extensive post processing time. Rather than storing everything and attempting to subsequently split the information into smaller subsets, it is proposed that it is more effective to be selective in the capture of information during the design activity. However, as Moran, Palen et al. (1997) and Huet (2006) highlight during various studies of engineering meetings, the use of multimodal technologies are the most effective method of ensuring that accurate, transparent records are created.

The key issue therefore presents itself as the need to bridge the gap between current 'live capture' and 'post processing' systems by utilising a combination of principles from both. The metadata which can be extracted from various elements of multimodal information such as audio, video, word processor documents images etc. can provide a defined and easily traceable structure which can be displayed within software systems. In addition, the ability to upload and view media such as video and audio associated with the meeting at a later date enhances the overall record of the meeting and draws on the principle employed by systems focused on 'post processing', where the key factor is that a complete and accurate record of the meeting can be captured using video and audio.

4.1.2 *Asynchronous Modes of Working*

As described above, synchronous modes of working generate much of the discursive or argumentative activities through discussions and use of the external information resources to support or otherwise inform such argumentation. As such, the subsequent documentary practices aim to provide a description of how information was manipulated within a discursive activity. Conversely, asynchronous working involves individuals interacting with information objects and generating decisions based upon both their own knowledge and information, and that which is made available to them. Engineers utilise technologies such as email, shared repositories and secured file transfer systems to exchange these information objects and as such, research into this area of knowledge capture is increasing (Wasiak, Hicks et al. 2009). For example a number of studies have been conducted to explore the effectiveness of email in terms of employee time and in comparison to alternative means of communication (Wilson 2002; Jackson, Burgess et al. 2006).

However, the documentary practices of asynchronous working is not dissimilar to that of synchronous, as the key goal is to identify where external information is utilised within a specific activity and the mechanisms by which it is manipulated or otherwise utilised to generate further information. However, where synchronous working is heavily reliant upon cognitive processes, those within an asynchronous activity tend to be more explicit in the utilisation and manipulation of the information objects (Giess, Conway et al. 2008). Through mechanisms employed to document the manipulation of the information and how these manipulations are deployed in the course of the activity, theoretically it becomes possible to construct an accurate record of the processes followed within an asynchronous activity.

In general, current documentary practices have been identified as sub-optimal, failing to capture activities and decisions in their entirety and providing insufficient detail. There are other approaches which consider design processes from a modelling perspective including those based on Petri-nets (McMahon and Meng 1996), Decision Structure Matrices (Steward 1981) and other more business-oriented process modelling approaches such as Business Process Modelling (White 2004). In general, these tend to be implemented at a high level, where they are well-suited to partitioning the design process into distinct areas of activity and indicating some form of precedence. These approaches are not generally applied at a more detailed level and hence do not capture the interactions with information conducted by an individual designer.

It is argued that generating a literal, low-level record of asynchronous activities allows for greater re-use of previous design work, both in terms of the activities necessary to develop a design through to completion but also in what considerations were addressed and what specific information guided this development process. It becomes possible to revisit a previous design, both to apply the design process to a new problem (if sufficient context of the design is understood and it can be seen to be applicable in a new application) and to update the existing design to take account of new understanding of any aspect of the design, for example of new analytical methods, improved materials, customer requirements etc.

In addition to the distinction between synchronous and asynchronous activities, it is worth noting that a second distinction (that applies especially in asynchronous working) exists between 'transaction' and 'learning' activities. In transaction activities some specific information manipulation is carried out to produce new information and the relationship between this input and output information and the manipulation mechanism may be recorded explicitly. The manipulation mechanism may be used repeatedly over multiple transformations. A learning activity, by contrast, is carried out to produce new knowledge or understanding which may be built upon by subsequent activities addressing the same issue.

4.2 *Critical Situations in Design*

A critical situation in the context of design scenarios can be defined as any situation which impacts directly or indirectly upon the direction or development of the design activity being undertaken (Badke-Schaub, Frankenberger et al. 1997). Critical situations therefore by definition can occur during synchronous or asynchronous design development activities. Previous work in this area has focused on distinguishing the critical situations from what is termed *routine work* (Badke-Schaub, Frankenberger et al. 1997) performed during the design activity. The idea of distinguishing critical instances is by no means a new phenomenon with similar work performed on *novel design decisions* by Akin and Lin (Akin and Lin 1996) and work on *critical incidents* by Flanagan during the 1950s (Flanagan 1954). However, Badke-Schaub et al's work on critical situations is of particular relevance to the design activity as they proposed identifying criteria based upon the general problem solving process as shown in Figure 4.2.

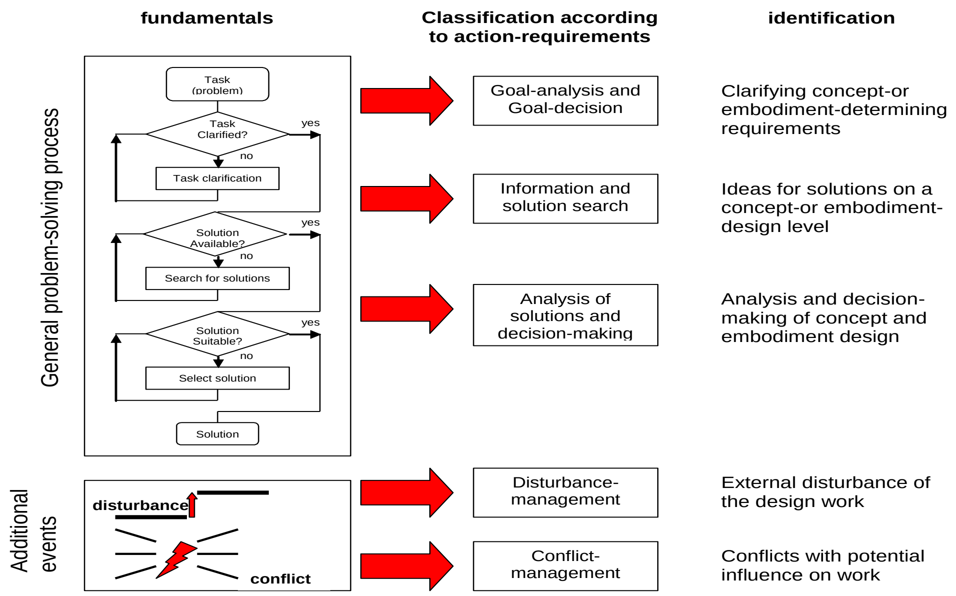


Figure 4.2 Division of 'critical situations' according to the general problem-solving process (Badke-Schaub, Frankenberger et al. 1997)

Badke-Schaub et al's work stems from two methods of data compilation, direct and indirect. They determine direct compilation as being *"the continuous non-participating observation of the design work"* (Badke-Schaub, Frankenberger et al. 1997) page 383, in which they employed two independent observers to observe the design process, a mechanical engineer to monitor the technical aspects of the design process and a psychologist to monitor the social and collaborative aspects of the design work. They also employed methods such as video recording, audio recording and the like to ensure that all interactions were observed. The indirect data compilation methods were post-experiment analysis through the distribution of diary sheets, questionnaires and also post experiment interviews. Through a combination of the indirect and direct data compilation, Badke-Schaub et al gained a comprehensive record of the design process from which they could use to distinguish the critical situations from the routine work. Figure 4.2 shows the protocol used to identify the critical situations. Badke-Schaub et al categorise critical situations into five variations: goal analysis, solution analysis, solution search, and additionally disturbing or conflict management (Badke-Schaub, Frankenberger et al. 1997). From this analysis of the design activities they were able to model the design process dependencies based on the identified critical situations.

Badke-Schaub's work is of particular relevance to this thesis as the study focuses on the examination of engineering design teams engaged in design activities. However, Badke-Schaub et al define critical situations as occurring only when engineers *"come together to make decisions and to discuss options"* which may impose limiting factors on the scope of the activities under study. Within this doctoral research study it is wholly acknowledged that the majority of design decisions and critical situations occur within social or collaborative *synchronous* situations, when designers come together. However, it is also acknowledged that decisions will be made during *asynchronous* individual working, some of which may fit within Badke-Schaub's proposed identification criteria. In this respect, the criteria proposed, although strongly influencing this work, can be used only as the basis for *indicating* the occurrence of critical situations in design and not as a robust identification mechanism. The examination of critical situations in design does however strengthen the argument that working synchronously is critical to design, with many of the design and goal decisions being taken when designers work collaboratively, whether globally or temporally displaced.

4.3 *Virtual and distributed modes of working*

Globalisation and displacement of design teams into virtual environments has meant the design of complex engineering products has increasingly become a collaborative task among designers or design teams that are physically, geographically, and temporally distributed (Szykman, Sriram et al. 2000). The increased complexity of modern products has seen industry invest in multidisciplinary product design and development teams co-located in offices around the world, the implementation of which has lead to a shorter product development cycles, lower development costs, and increased quality.

As a result, companies are increasingly retaining only their core competencies in-house and are relying on partner firms to provide complementary design knowledge and expertise needed for a complete product. In fact, designers are no longer merely exchanging geometric data but more general knowledge about design and design process, including specifications, design rules, constraints and rationale (Szykman, Sriram et al. 2000). Collaboration occurs over the network using e-mail, shared files or in some cases explicitly designed groupware. While design becomes an increasingly collaborative and knowledge-intensive activity, the need for computer-based design frameworks to support the communication, representation, and use of knowledge and information among distributed designers becomes more critical.

With the explosive growth of the Internet and associated information infrastructure, the use of the Internet and the World Wide Web as a medium for communications and information transfer is increasing (Szykman, Sriram et al. 2000). Many of these interactions are conducted using currently available tools to support Computer Supported Collaborative Working (CSCW) and include technologies such as email, video conferencing, instant messaging and various Product Data Management systems. In traditional group collaboration environments, the interactions, collaboration and information capture and exchange would occur from many resources such as paper, whiteboards, computers, physical models, etc. These environments have the advantage of the users being able to use these resources simultaneously and move among them flexibly and quickly. The challenge here is how to replicate these environments within the digital domain, enabling users to interact and collaborate using similar technologies whilst embracing new digital technology. Recently, work has been conducted on the development of Virtual and Automated capture environments, whereby the design activity is supported within a distributed environment, facilitating the use of many traditional styled resources to capture and share information. The most notable developments being the iRoom and iLoft projects conducted at Stanford University along with the I-LAND project conducted by the German National Research Centre for Information Technology (GMD) and Integrated Publication and Information Systems Institute (IPSI). These will be discussed in more detail in the sections following.

4.3.1 *Virtual Capture Environments*

The use of virtual computational tools is not new within engineering design. It is a well documented fact that virtual computation tools such as computer aided design (CAD) systems benefit the design process through improved visibility of components and quality through modelling (Ye, Campbell et al. 2006; Robinson, Ritchie et al. 2007). This has led to significant research effort being directed to use various virtual and augmented reality environments using computational based visualisations and interface technologies as alternatives to more traditional design process methods (Ye, Campbell et al. 2006). However a key benefit of developing virtual computer *environments* lies in the ability for organisations to manage and capture product and process related design knowledge and information within global and distributed design team working (MacGregor 2002). If designers can perform their design activities synchronously, in virtual environments using the latest technologies available to them, then this provides an opportunity for organisations to capture the knowledge and information from the designer's workings in digital form, which in turn will aid storage and retrieval. The creation of such environments came to fruition in the late 1990s and early 2000s coinciding with the use of the internet as a means to aid communication within design. In fact since 1999, work at institutions such as Stanford University's Centre for Design Research (CDR) have focused on developing seemingly unobtrusive methods of information and knowledge collection during the design activity (Johanson, Fox et al. 2002). A pioneering solution developed at the CDR was the Design Observatory, which provided an engineering design environment consisting of video and audio recording technology to record the designer's interactions, supporting video integration analysis and verbal protocol analysis (Milne and Winograd 2003; Johanson, Fox et al. 2010). This environment however was found to remove the designer from the natural design environment thus inhibiting the design activity. Another issue was the size limitations imposed by the Design Observatory; it could only support up to six members of the design team at any one time, therefore for larger groups of designers or for large review meetings, the observatory became obsolete.

However, the development of the Design Observatory laid the foundations for the iSpace program; a partnership between Stanford University and The Royal Institute of Technology (KTH-Stockholm) to develop new forms of human computer interfaces specifically suited to engineering design and to study the ways in which designers use these new tools (Milne and Winograd 2003; Johanson, Fox et al. 2004). The iSpace program saw the development of interactive workspaces, each of which uses a common software system infrastructure called the Interactive Room Operating System (iROS) (Milne and Winograd 2003). The iROS software was developed to support advanced user interfaces such as the PointRight system, allowing users to control any of several computers connected to projected displays, switching between computers by merely moving the mouse off the edge of one onto another.

The first prototype environment developed within the program was the iRoom, an interactive meeting room. The iRoom consisted of three touch sensitive white-board displays, and a custom-built 9 megapixel, 6-foot diagonal display with pen interaction called the interactive mural (Johanson, Fox et al. 2002). In addition, the iRoom was fitted with an interactive table with a built in 3-foot by 4-foot display custom designed to look like a conference room table. The room was also fitted with cameras, microphones, wireless LAN support, and a variety of wireless interaction devices. This ensured that through the use of mobile technology such as PDAs and laptops, users could connect to the Event Heap server and share information wirelessly from anywhere in the room. The server was designed to be accessible through web-based interfaces enhancing integration between the existing room hardware such as tables and displays with the mobile devices. Essentially the iRoom was deemed to be successful as it provided a platform for which designers could communicate and interact digitally. However, the iRoom was designed as a static environment that could not be re-configured to suit different design activities; hence it was limited in its uses.

To address this fundamental issue, Stanford's CDR began development of the iLoft; a further development of the iRoom designed to be a *"highly flexible physical space that incorporates new forms public and personal technologies that augment patterns of work in which design engage."* (Milne and Winograd 2003) The researchers working on the project were aware of the need to change the way in which new and emerging digital technology interacted with the physical design workspace, essentially matching it to patterns of work exhibited by designers. The improved physical flexibility of the space, e.g. mobile interactive displays, wireless laptops and PDAs, coupled with information mobility across devices served as the main improvements over the previous iRoom intended to address these issues. The major components of the iLoft configuration were as follows (Milne and Winograd 2003):

- LightBox – a mobile interactive rear-projection system working in conjunction with the PointRight and MultiBrowse components of iROS.

- GroupBoard – a sketching system for distributed design teams using a single iSpace enabled pen input to write on real paper, select between multiple views of other designers' sketches, and issue commands.

- CurveBoards – moveable whiteboard surfaces that are slightly curved and can be rolled around the iLoft as needed. Each of these whiteboards is fitted with a pen capture system, enabling them to record any pen strokes marked on their surface and later make them available for retrieval.

- TableBoards – round, collapsible tables that incorporate whiteboard material on their table top in support of unplanned discussion sessions.

- Videoconferencing system – basic connection between the iLoft and other sites. Future plans include integrating this device with the iROS infrastructure so that it can receive commands through the EventHeap.

Although Stanford University are recognised as pioneering the work on virtual design environments they were not the only institutions working in this area. The i-LAND Interactive landscape was developed through a joint project conducted by the German National Research Centre for Information Technology (GMD) and Integrated Publication and Information Systems Institute (IPSI) (Streitz, Geißler et al. 1999). Streitz et al proposed that with the advent of new information technology, information is created, stored and communicated by means of computers resulting in the creation of virtual information spaces (Streitz, Geißler et al. 1999). The i-LAND system was designed to integrate these virtual information spaces with real architectural spaces through the implementation of what Streitz et al term 'roomware' components; computer augmented objects resulting from the integration of physical room elements such as walls, doors and furniture with computer-based devices (Streitz, Geißler et al. 1999). Three roomware components were developed and incorporated into the i-LAND environment; the DynaWall, InteracTable and the CommChairs.

- The DynaWall is touch sensitive software, projected onto the walls of a room allowing two or more people to collaborate. The DynaWall operates with BEACH software, which enables the users to interact with information structures. The DynaWall also has features such as “take and put” which enables the users to cut and paste information from one surface to the other without the need for continuous contact with the surface, and the “shuffle” feature which allows users to pass objects from one surface to another (Streitz, Geißler et al. 1999).

- The InteracTable is an interactive table-top display which uses an LCD beamer to project high resolution images to the top of the table unit providing a horizontal touch sensitive display of 65cm x 58cm (Streitz, Geißler et al. 1999). The table unit can be moved around the room and is large enough for collaboration with up to six people. The surface of the tabletop provides an interactive surface upon which people can write, draw and move objects and input txt using a wireless keyboard. The objects within the display can also be moved and rotated allowing all users located round the table to interact with them.

- The CommChairs are interactive armchair styles seats, which incorporate docking facilities for laptop computers and integrated pen-based computers built into the fold up desk surfaces. Using wireless networks, the CommChairs interact with the DynaWall and InteracTable and allow users to share information between the devices. The cooperative functionality is facilitated through the BEACH software.

The software developed to facilitate the co-operative working within the project is called BEACH, constructed from a layered architecture (Streitz, Nexroth et al. 1998). The lowest level of the architecture is COAST framework, which provides the functionality to distribute, replicate and synchronise information objects. The next level of the architecture facilitates the interaction of the user with the roomware components and the third level provides the mechanisms to structure the collaboration. Streiz et al’s “Roomware for Cooperative Buildings: Integrated Design of Architectural Spaces and Information Spaces" (Streitz, Nexroth et al. 1998) gives a detailed review of the BEACH software and the architecture.

The concept of virtual environments for designers to perform activities was in effect proven as a method of providing communication in a digital form; however the effectiveness of the rooms in aiding design activities were never examined. Essentially much of the developments made by Stanford University's CDR and the GMD focused on providing environments and tools for designers to perform design activities, whilst not addressing a fundamental question: ***do these environments and tools provide an enhancement to the design process?***

From the literature reviewed for this thesis the answer is not apparent. Many of the developments detailed are highly interesting and as a student of engineering design are exciting; however there is no evidence of significant gains in adopting the technologies. For the designer to use the proposed tools and technologies effectively means removing them from their natural working environment. This in turn can lead to development of new design protocols and processes to fit with the technology, all of which will have significant costs associated. This is perhaps why much of the research performed in parallel to the virtual capture environment work, focused not on developing *virtual* capture environments, but on environments which *automatically* captured the workings of designers as and when they performed their design activities.

4.3.2 *Automated Capture Environments*

Automated capture environments are attractive options for organisations wishing to capture their activities as they can accurately document design episodes, allowing humans to attend to, synthesise, and understand the context of the episode unfolding (Richter and Abowd 1999). Ubiquitous capture of design knowledge within automated capture environments has several benefits over traditional rationale capture techniques. The capture process is largely unobtrusive and where possible undetectable to the participants, requiring no additional effort to be spent and no required deviation from the design episode, for example to clarify what is being recorded. There is also issue with this approach; while it is recognised that by not imposing structure to the information as it is being documented the full richness of design information can be achieved (Richter and Abowd 1999), the challenge then becomes how to process this raw data to understand how designers can access and reuse the information recorded.

Innovative research developments undertaken within Heriot-Watt University's Scottish Manufacturing Institute has looked to capture the application of individual designer's knowledge and information throughout design activities, automatically and unobtrusively, through the use of virtual reality tools and environments (Ritchie, Sung et al. 2008). Work on the COSTAR (Cable Organisation System Through Alternative Reality) platform utilises a head mounted display and 'pinch' glove to allow the user to interact with parts of a design within a 3D CAD environment as demonstrated in figure 4.3

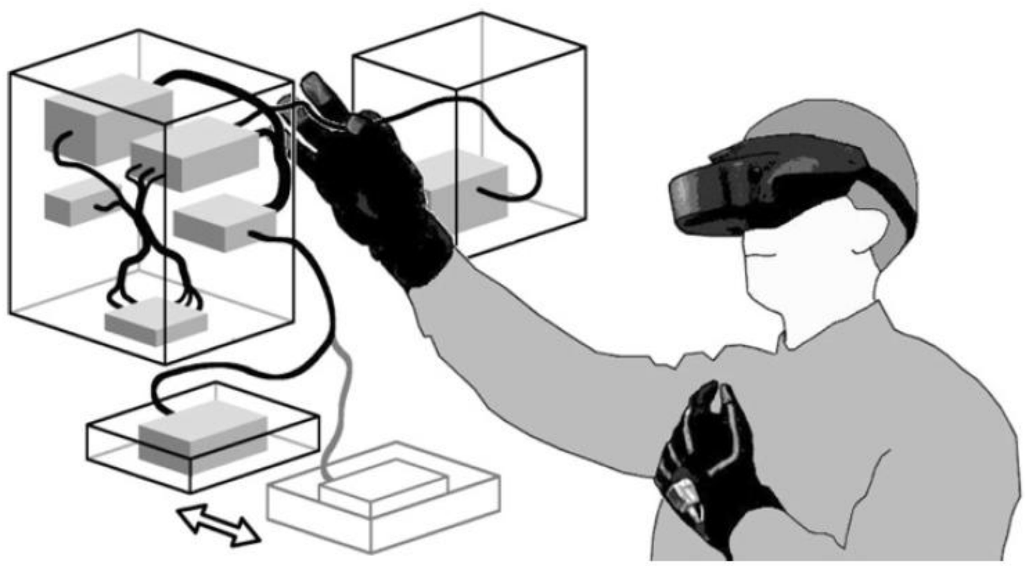


Figure 4.3 COSTAR Cable harness design system (Robinson, Ritchie et al. 2007)

The premise of this work is to automatically generate xml and textual records of a designer's movements within the system which then can be interpreted and represented using IDEF0 diagrams (Sung, Ritchie et al. 2008). Essentially, the key output from the COSTAR system is a method of recording an individual designer's rationale for much of the design activity, and as such is comparable to the research on design rationale capture presented in Section 3.2.2. However, whilst the potential for capturing rationale within the 3D virtual environments is great with respect to designers working individually (asynchronous modes of working), this work is not directly applicable to synchronous based design working, shown through the literature to be critical to the overall design process.

An industrial project conducted by the Exploration & Production (E&P) Division of the Italian petroleum company Eni, developed a web-based collaborative environment where technical know-how can be easily captured and reused along all phases of an in-house project (Piantanida, Volpi et al. 2003). The environment named *The Technical Know How Portal* provides the functionality needed to access the different types of technical data and information relevant to the phases of an E&P project, and quickly combines the results and transforms them into company knowledge. In the initial phase of the project, the focus is on finding all relevant information and data available. The environment has facilities to retrieve reports and project databases from previous studies, updated seismic interpretation models and data stored within the company's Electronic Document Management System (EDMS) (Piantanida, Volpi et al. 2003). In latter phases, the environment provides tools to access the best available 'professional knowledge' to carry out the work necessary within the project. This is achieved through collaborative work sessions with geographically distributed experts and by using semantic search tools to find out the best approaches used in previous studies. During the final phase of the project the environment automatically captures and indexes the generated interpretation data and reporting documents for later reuse. The underlying structure of the environment is made up from the following; a web-based workspace environment which provides the database access and invokes the applications when required; a collaborative document management system (IBM Lotus Domino) and synchronous collaboration tool (IBM Lotus Same time); and a workflow-oriented knowledge environment (Accenture E and P Online) which binds all the elements together (Piantanida, Volpi et al. 2003).

The eClass project (formerly known as Classroom 2000) developed at the Georgia Institute of Technology was an attempt to study the impact of ubiquitous computing on education. The project developed a prototype classroom environment along with software to seamlessly capture the interactions occurring in everyday lectures. The aim of the project was to revolutionise the classroom experience through the introduction of a capture, integration and access service. Activity on the whiteboards were captured using a Java applet called ZenPad (Richter and Abowd 1999). This program allowed the lecturer to write on a blank electronic whiteboard or on top of prepared slides and these electronic annotations, audio, video, and web browser activity, are automatically recorded and time-stamped. After each lecture, ZenPad automatically merges the captured events together, thereby creating standard HTML Web pages. The user interface for the system includes a timeline providing an index to the video, slides, and visited web pages. This feature enables students to click on annotations made by the lecturer on the slides, and replay the audio and video created during the lecture; a powerful method for gaining a greater understanding of how the activity unfolded and what sources of information were presented throughout.

4.3.3 *Project Memories*

At the University of Strathclyde recent research has focused on the development of project memories; essentially records of product and process knowledge and information stored during design process at the organisational or project level (Conklin 2006). To support the creation of such memories researchers within the Design Manufacture and Engineering Management (DMEM) department have developed web-based design project environments based on wiki technologies. The system, known as LauLima was developed as part of the Digital Libraries for Global Distributed Innovative Design, Education and Teamwork (DIDET) project (Breslin, Juster et al. 2003-2007). The aim of LauLima was to provide an environment which would allow students to rapidly capture and share information and promote the capture and retention of knowledge and information which was unstructured and informal in nature. The wiki-based system has a granular permissions system incorporated, which allows supervisors to monitor their project teams' progress and work via the wiki sites and thus were able to retain much of the informal notes, sketches and decision making information which was traditionally not recorded during the project. The system however was not designed simply as a source of information for supervisors to monitor and retain, but rather as an environment which would allow the students to have access to their project knowledge and information and work synchronously. Students noted that through the use of team wiki sites they were able to organise and manage their project work; were more aware of events in the project's development; could share project development more easily; and were able to reflect on stored information and learn from their experiences (Breslin, Nicol et al. 2007). However, several teams found the sites to be time consuming to maintain and the information difficult to navigate, providing barriers for the students to use the system effectively. Nevertheless, as a means of storing and sharing project information, the system was found to be very effective.

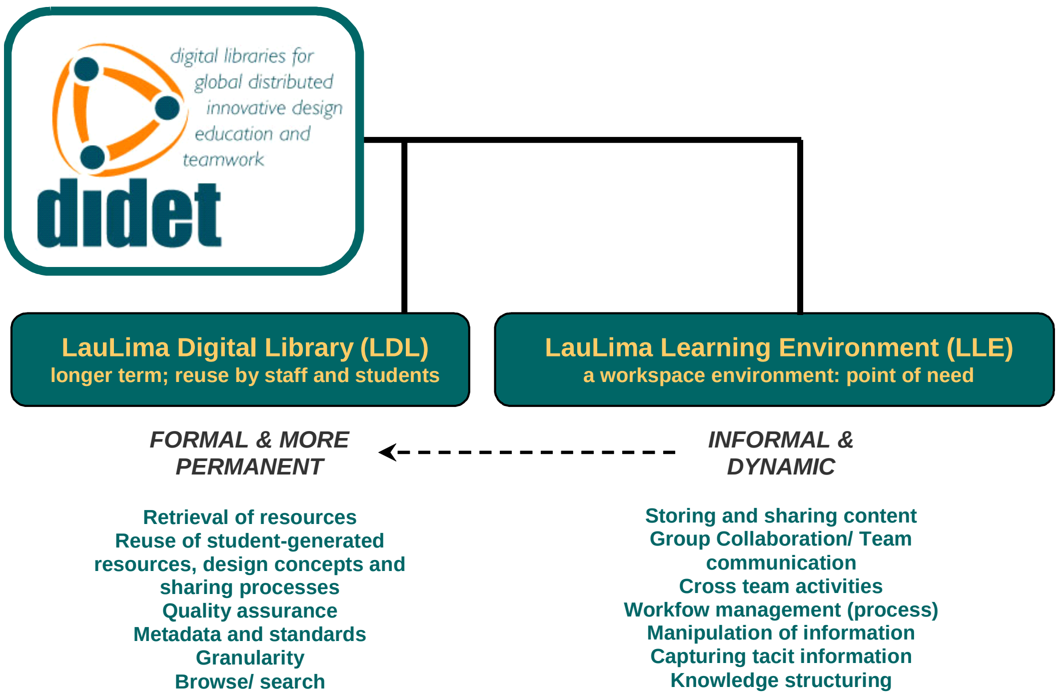


Figure 4.4 LauLima System Architecture (Breslin, Juster et al. 2003-2007)

As can be seen in Figure 4.4, the LauLima system was divided into two main components; the LauLima Learning Environment (LLE) and the LauLima Digital Library (LDL). The LLE is the working area of the system allowing material to be created, shared and modified by providing access to, e.g. wiki pages, file galleries (online folders) and various communications tools (email, shout box, forums, blogs). Users can control who can read and modify their material. Additionally they can provide links to files stored within the file galleries allowing them to be shared. The

LDL is a digital repository used to store digital items (eventually wiki pages and wiki sites) for longer-term use. The LDL incorporates search and browse functionality allowing the users to locate wiki-based documents of interest. These documents are retrieved based on user determined page viewing choices. The database retrieves the appropriate raw data; it is parsed and displayed to the user.

Work on LauLima has provided an effective means of retrieving information but at the same time has revealed the difficulty of capturing information without generating additional workload - all files stored on the system require an element of metadata to be attached to it. The system provides functionality for storing, retrieving and communicating information effectively but not capturing. Essentially LauLima creates a sifting process, which through the use of the LLE can visualise and identify useful information stored within wiki pages; however, it requires human resources to transfer this information to the LDL for longer-term storage. The intention of both the DIDET project and indeed the LauLima system was to develop effective means of creating project memories, something which can be been argued was achieved, however, the system also presented many challenges for users and thus would require further development. In essence if a system is to become effective at providing project memories then it must not challenge the users, it must be intuitive to use and fit seamlessly into the existing design processes.

4.4 *Research Focus*

Building upon what has been established from the literature thus far and analysing synchronous and asynchronous modes of working, design activities such as engineering design meetings present themselves as a key aspect of the engineering design process. As alluded to by Badke-Schaub et al, synchronous activities such as meetings can be classed as critical to the design process as these episodes include discussion, reasoning and decision making activities influenced strongly by both product and process information and knowledge. This is supported by the wealth of research developments focused on aiding designers to identify, capture and share engineering design knowledge and information. At the beginning of this chapter the following question was posed;

3. *Are there specific activities employed within the engineering design process where knowledge and information capture is inefficient?*

The focus of this question can now be narrowed. Synchronous situations such as engineering design meetings can be identified as one specific activity which is necessary to the engineering design process and yet the effectiveness of such activities in terms of capturing knowledge and information is not explicit. In addition, engineering design meetings are regarded as synchronous episodes which are conducted throughout all stages of the design process and indeed the product lifecycle, allowing a broader view of knowledge and information usage to be established. The following sections will focus on understanding engineering design meetings; their purpose, structure, and application within the engineering design process and establish the effectiveness of knowledge and information capture within such activities.

4.4.1 *Engineering Design Meetings*

In the literature it is recognised that synchronous activities, such as meetings, are part of a cyclic process (Figure 4.5) in that they are preceded and followed by asynchronous work such as the execution of activities arising during the activity, distribution of the results from the activity and commencement of the next activity (Post, Mirjam et al. 2008).

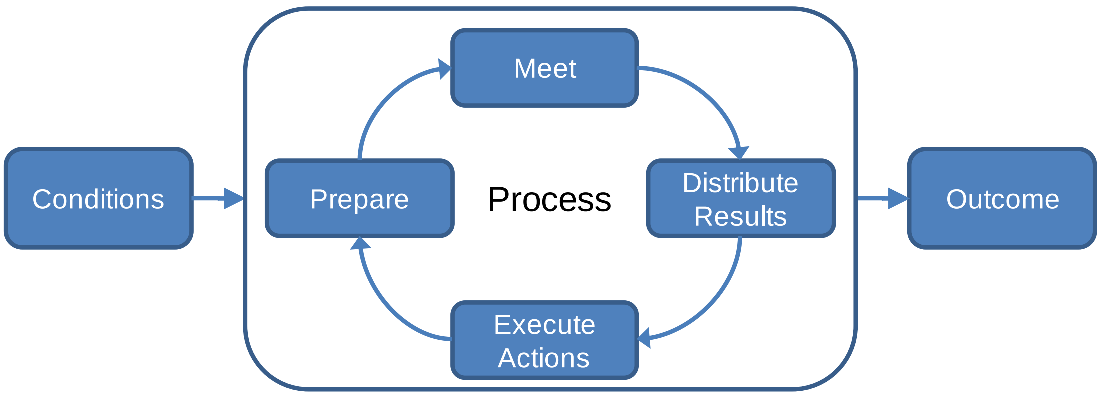


Figure 4.5 Meeting cycle (Post, Mirjam et al. 2008)

By way of example, if we take the summative design model established in Chapter 3 of this thesis (Figures 3.6 and 3.12), it becomes clear that the cyclic process proposed by Post et al. is one which is repeated throughout the individual stages of the design process and ultimately, the combination of both synchronous and asynchronous activities contribute to achieving the overall project aim. From this understanding, it is also recognised that the meeting cycle will impact upon the information / knowledge feedback loops, both at the internal and external level. Essentially meetings are critical elements of the design process and specific instances where much of the information and knowledge (both product and process) is generated. To understand how these activities can be utilised to the greatest effect within the engineering design process we must analyse the various structures and key elements of meetings.

4.4.1.1The Structure of Meetings

Meetings serve many different purposes within engineering design, such as problem solving, progress evaluation or review, task clarification, and as a consequence the structure and formality of meetings varies depending upon the purpose or task the meeting aims to address, the individuals involved, and the desired outcomes.

Adapting the previously defined definitions of formal and informal information, *formal* meetings can be defined as those which are explicit and definite and adhere to predetermined rules and procedures, such as executive board meetings, working groups and technical committees. *Informal* meetings tend to have less structure and are not predetermined, for example discussions between two or more individuals with common interests, idea generation or brainstorming sessions. The degree of formality of meetings and the level of adoption by organisations is likely to be determined by the organisational culture. For example, in aerospace and defence organisations such as BAE Systems and Airbus, highly formal, predetermined meetings such as Design Reviews are an integral part of the design process (Huet 2006). The definition of a Design Review is given as a *"formal, documented, comprehensive and systematic examinations of a design to evaluate the design requirements and the capability of the design to meet these requirements."* (HB05/04 2002-2005)

4.4.1.1.1 *Categorising meetings*

In the literature there are a number of authors who look to identify and categorise meetings (O'Sullivan 2000; Burger, MacLaren et al. 2002; Huet 2006). However, as discussed previously, the different types and categories of meetings are entirely subjective depending on the organisation undertaking them and/or the context of the meeting itself. Therefore a broader, more generic categorisation is required.

In their work on analysing the usability of PDAs (Personal Digital Assistants or Palmtop computers) within engineering design meetings, Zurita, Antunes et al (2006) give a broad definition of the different meeting scenarios and associated functionalities as is shown in Table 4.1 below.

Table 4.1 Meeting Scenarios adapted from (Zurita, Antunes et al. 2006)

Meeting	Major goals	Meeting Input	Meeting process	Meeting Output
Ritual	Social interaction, progress evaluation.	None	Simple, conducted by the facilitator.	Group formation, intangible information, limited documentation
Deliberate	Problem solving Decision making Information integration	Attached documents, agenda, attendees list	Highly structured, conducted by the facilitator.	Report and other formal meeting elements
Creative/design	Brainstorming Brain-sketching Collaborative design	On-site gathered material (e.g. building snapshot)	Unstructured with free collaboration.	New ideas and sketches
Ad hoc	Opportunistic decision making	None	Simple, unstructured.	Individual notes
Learning	Brainstorming and brain-sketching Collaborative writing Problem solving Developing social skills	Class planning, Pedagogical practices and materials (e.g. reading documents)	Structured, conducted by the facilitator.	Report. Pedagogical achievements: new ideas and solutions (individual or group writing)

Zurita, Antunes et al define six categories of meetings; Ritual, Deliberate, Meeting ecosystem, Creative/design, Ad-hoc and Learning. This thesis will disregard Meeting ecosystem as a separate categorisation, for as indicated within the paper, these meetings may be regarded as an aggregate of sub-meetings with different goals

(Zurita, Antunes et al. 2006). This leaves five categories of meetings which are defined as follows (adapted from Zurita, Antunes et al 2006):

- *Ritual meetings* focus on socialising and communicating across the organisation. The reasons for holding such meetings vary but can include team building and group cohesiveness, and progress evaluation or communication. Meetings of this type generally require a human facilitator / chairperson responsible for conducting the meeting process (Antunes and Ho 2001). The meeting outcomes are mostly intangible (satisfaction, sense of belonging, knowledge about others, etc.) and as such documented information and knowledge outputs are limited.

- *Deliberate meetings* are mostly related to problem solving and decision making. Deliberate meetings usually adopt highly structured processes, with a chairperson or facilitator organising and regulating the participants' interventions. This type of meeting requires advance preparation, either because the decision is likely to have a severe organisational impact or the issue is complex. The meeting participants are carefully selected and previously informed about the meeting agenda. Therefore, this scenario integrates various asynchronous activities accomplished prior to meetings, such as agenda preparation, document sharing and preliminary discussion adhering to the theory of meeting cycles (Post, Mirjam et al. 2008).

- *Creative/design meeting* – In general, creative/design meetings focus mostly on the generation of ideas and conceptual solutions. The creativity aspect may be supported using techniques such as brainstorming (Zurita, Antunes et al. 2006), while design builds upon creativity with discussion, assessment, decision-making and planning. Creative / design meetings tend to be less structured than deliberate or ritual meetings and as such in many instances self governance is employed rather than utilising meeting facilitators or chairpersons.

- *Ad hoc meeting* – The Oxford English Dictionary gives the definition of ad hoc as *"Improvised and often impromptu; formed or done for a particular* *purpose only."* (Pearshall 1998) On this basis, ad hoc meetings can be defined as unscheduled, spontaneous, lacking an agenda, and with an opportunistic selection of participants (Romano and Nunamaker 2001). This type of meeting can occur anywhere and anytime and as a consequence the meeting records can vary significantly. Much of the key outcomes (decisions, actions, and deadlines) will exist only in private notebooks (Fruchter 1996) leading to discrepancies and inaccuracies in the account of the meeting.

- *Learning meeting* - Learning meetings are very different from other types of meetings as they focus on communicating information and knowledge to participants rather than reach consensus and decisions on issues. Learning meetings will often incorporate a facilitator with responsibility for structuring the episode and in many cases reporting on the achievements of the participants and the session as a whole.

Although the broad categories described above cover many scenarios and meetings instances which occur, they categorise meetings by type, thus allowing for discrepancies and misalignment within these categories. An alternative approach would be to categorise meetings by their level of formality (i.e. from informal to formal) ensuring many more types of meetings could be categorised without fear of misalignment. For this thesis, a five point novel formality scale is proposed where 1= informal and 5= formal. Table 4.2 provides an overview of the five formality levels of meetings, citing indicators, exemplar scenarios and how these levels compare with the view from the literature (Antunes and Ho 2001; Romano and Nunamaker 2001; Zurita, Antunes et al. 2006).

Table 4.2 Meeting formality

Formality Level (1=informal, 5 = formal)	**Indicator(s)**	**Meeting Category** (From literature)	**Examples**
1	Unstructured, no defined agenda, collaborative, no meeting record.	Creative /Design	Brainstorming session, ideas generation.
2	Unstructured, no agenda, opportunistic, limited meeting records	Ad Hoc	"Coffee room" meeting, corridor meetings, after event discussions.
3	Structured, flexible agenda,	Ritual	Weekly project

	meeting facilitator /scribe		progress meeting, Monthly update / catch up meetings.
4	Structured, defined agenda, meeting facilitator / scribe	Learning	In-house training/ dissemination seminar.
5	Structured, pre-approved agenda, predefined participants, meeting facilitator/chairperson, meeting scribe	Deliberate	Design review, project review, client presentation.

4.4.1.1.2 *Meeting governance*

In order to ensure that meetings are successful in achieving their aim, a degree of governance is required. In the case of informal, unstructured meetings such as brainstorming and idea generating sessions or ad hoc meetings which can occur in any location, governance does not play a significant role simply because these meetings are informal in nature and often do not have a pre defined agenda. However, as is evident from the literature, structured, semi-formal and formal meetings require an element of governance to ensure that the meeting runs according to the agenda. In many cases this governance is provided through the appointment of a chairperson or facilitator (Huet 2006). Meeting facilitation can be defined as the process in which a person (who is acceptable to all members of the group) intervenes to help improve the way the participants identify and solve problems and make decisions (Schwarz 1994). Nunamaker et al. (1997) further this definition by proposing that the human facilitator executes four key functions within meetings:

1. Provides technical support by initiating and concluding the use of specific software tools.

2. Chairs the meeting, maintaining and updating the agenda.

3. Assists in agenda planning and participant identification.

4. Provides organisational continuity, setting rules and maintaining and/or directing the meeting record.

In the case of engineering design review meetings, Huet defines the facilitation role as one undertaken by a chairperson, responsible for nominating the secretary (scribe) and review team, chairing the meeting and facilitating the dialogue between the review team and the project team (Huet 2006). From these definitions it is possible to gain an aggregate view of the role of the meeting chairperson. The chairperson can be said to be the individual responsible for setting the meeting agenda, ensuring that the correct participants are invited to attend, facilitating the meeting in accordance with the agenda and producing or approving the record of the meeting activities. This view of the meeting chairperson also extends to include what is seen as a critical element of effective meeting governance; that the chairperson appoints a meeting scribe or secretary whose responsibility is to provide an objective view of the meeting. To ensure that a balanced viewpoint and accurate representation of the meeting is produced; the scribe *must not interact with and engage* in the discussions and/or decision making process (Moran, Palen et al. 1997; Whittaker, Laban et al. 2005; Huet 2006).

Table 4.3 Meeting governance

Formality Level (1=informal, 5 = formal)	**Indicator(s)**	**Meeting Category** (From literature)	**Governance**	
			Facilitation	**Documentation**
1	Unstructured, no defined agenda, collaborative, no meeting record.	Creative /Design	Participants	Participants
2	Unstructured, no agenda, opportunistic, limited meeting records	Ad Hoc	Chairperson	Participants
3	Structured, flexible agenda, meeting facilitator, meeting record	Ritual	Chairperson	Chairperson
4	Structured, defined agenda, meeting facilitator / scribe	Learning	Chairperson	Chairperson / Scribe
5	Structured, pre-approved agenda, predefined participants, meeting facilitator/chairperson, meeting scribe	Deliberate	Chairperson	Scribe

Building upon the description of meeting formalities proposed in Section 4.4.1.1.1, Table 4.3 above proposes the different governance structures required for each formality level of meetings with respect to facilitation and the documentation activities. To summarise, the governance of meetings is directly proportional to the level of formality at which the meeting will occur. The formality and subsequent structure applied to meeting will define the level of governance required to effectively undertake the meeting.

4.4.1.1.3 ***Meeting documentation***

Efficient communication is critical to achieving better co-operation and co-ordination among members of a design team (Ion, Wodehouse et al. 2004) and thus creating accurate and reusable records of decisions and activities occurring during episodes such as meetings become fundamental. During the undertaking of design and development activities, greater emphasis must be placed upon capturing the design activities in their entirety, allowing richer, more accurate records to be constructed. Fruchter makes the following observations on conventional synchronous design activity records;

> *"Individual notebooks (are used), recording background information and results of reasoning and calculations. Notebooks are private documents and are not shared among team members"* (Fruchter 1999) page 261.

> *"Even when knowledge capture does take place, it is limited to formal knowledge (e.g. documents).Contextual or informal knowledge, such as the rationale behind design decisions, or the interaction between team members on a design team, is often lost, rendering the captured knowledge not reusable, as is often the case in current industry documentation practices."* (Fruchter and Demian 2002) page 1.

As highlighted by Fruchter, a large quantity of information and data is generated, not only on the object being designed but on the decisions, the rationale, the reasoning and also the application of past experience and much of this goes undocumented. This issue is highlighted further in a study of the contents of engineer's logbooks and journals (McAlpine, Hicks et al. 2006). From this study, various information types were identified and categorised, showing the wealth of information and knowledge engineers will utilise throughout activities (Table 4.4). Of particular relevance is the identification of design reasoning and calculations used as part of the decision making process. As alluded to by Fruchter, these rich sources of information and knowledge simply are not recorded in standard records of synchronous activities and as such are lost.

Table 4.4 Engineer's journal content (McAlpine, Hicks et al. 2006)

Type	Class	Description
Textual	Hand written notes	Personal notes taken during individual or collaborative work.
	Meeting notes	Notes taken during a meeting.
	Contact details	Names, phone numbers, e-mail, addresses.
	Hand calculations	Simple or complex hand calculations used for evaluation of a situation.
	Tables and figures	Hand drawn or printed.
	Completed forms	Copy of official document.
Graphical	Sketch	Hand drawn, from pencil sketch to high quality rendering.
	Graphics and diagrams	Hand drawn
	CAD drawings	Printed and inserted in the journal.
Graphical and textual	External documents	Report sections, product information, pictures inserted in the journal.
	Annotated external documents	As above with manual notes added
	Annotated CAD drawings	Manual add-ons to existing drawings
	Memorandums	Post-it notes, highlighted notes, memory aids

The traditional method of recording and communicating the outcomes of synchronous episodes such as meetings are through the distribution of meeting minutes. The dictionary definition of minutes, in the context of a meeting, is *"a brief summary of the proceedings at a meeting."* (Pearshall 1998) Essentially, meeting minutes are an abstract record of attendees, group decisions, past actions and future commitments. In many instances they also document whether previous commitments and actions by group members have been carried out and thus can, and often are, used as a checklist for progress of certain activities.

It can be said that the structure and content of meeting minutes are entirely organisationally subjective; that is, there is no internationally recognised or prescribed form in which meeting activities should be documented. This is in part due to the variance in meeting formality, structure and indeed objectives as highlighted previously (Sections 4.4.1.1.1 and 4.4.1.1.2) and also an indicator of the richness of approaches taken to solve problems (McAlpine, Hicks et al. 2006). However, in general, meeting minutes can be said to consist of four key elements of information; *meeting metadata* (including but not limited to: date, time, location, attendees, meeting reference number, agenda); *exploration activities* (discussions, reasoning, debating); *decisions* (conclusions or judgments reached or pronounced in agreement); and *actions* (defined activities to accomplish an objective or objectives). In practice, meeting minutes tend to give a high level overview of activities: they document all major decisions and actions, rather than focusing on specific aspects of the meeting. As indicated previously meeting minutes may incorporate elements of exploration such as reasoning and discussion directly related to decisions or actions, but this is entirely dependent upon three factors: the structure of the minutes; the content of the minutes and the experience; and the ability of the meeting scribe constructing the minutes.

4.4.1.2 Role of the meeting agenda

Within the context of meetings, the meeting agenda can be defined as a programme of things to be done; specifically, a list of things to be dealt with at the meeting (Niederman and Volkema 1999). In practice, most formal and deliberate meetings will distribute an agenda prior to the meeting being held, as this determines the sequence of major activities to be discussed and indeed the participants required to attend (Jain, Kim et al. 2003).

In the literature, the agenda is seen as critical element to successfully manage meetings since much of the resulting actions and outcomes are structured around it (Niederman and Volkema 1996; Romano and Nunamaker 2001; Jain, Kim et al. 2003). However, in a subsequent publication, Niederman and Volkema present an interesting alternative theory on the role of agenda use within meetings. They reason that:

> *"Laying out a particular series of steps, perhaps even discussing and agreeing to them will generate more commitment to adhere to these steps during the meeting resulting in fewer diversions and more focus on addressing content issues. By advanced distribution of the agenda, the facilitator or sponsor may be signalling the importance of the meeting creating both more preparation prior to the meeting and more concentration on content issues during the meeting. The creation of an agenda may also be a way for the facilitator, the sponsor, and/or the group to signal what issues will not be considered during the meeting thus*

creating a boundary between activities within and outside the meeting framework." (Niederman and Volkema 1999) Page 54

This presents an interesting take on the multiple roles of the agenda. For instance, Niederman and Volkema argue that the agenda not only identifies the topics which are intended to be discussed and/or resolved at the meeting but also provides direction to the participants as to what will *not* be discussed. The role of the chairperson becomes critical in ensuring that the meeting does not deviate from the prescribed agenda.

4.4.2 *Previous Research Projects*

It is recognised that the study of engineering design meetings and their associated technologies is a widely researched subject. Studies such as the Delft Protocol Studies (Cross, Christiaans et al. 1996), and the latter symposia on Descriptive Models of Design (Cross 1997), Design Representation (Porter and Goldschmidt 2001) and Expertise in Design (Cross 2004) have been instrumental in directing research activities towards improving the record of design activities performed in synchronous situations such as meetings (McDonnell and Lloyd 2009). Many of these research endeavours have focused on prescribing tools and techniques which automate the documentation process as much as possible with particular focus on elements such as information capture, information reuse, distributed working and software development.

In addition to the information and knowledge capture mechanisms discussed at the beginning of this chapter, several research projects have focused their efforts directly on developing tools, techniques and methods for conducting engineering design related meetings. This section presents eight research projects which were analysed with a view to establishing the state of the art and potential knowledge gap within this domain. For reasons of brevity, these eight projects are summarised as follows.

AMI: Augmented Multi-party Interaction

The AMI was a collaborative research project concerned primarily with new multimodal technologies to support human interaction, in the context of smart meeting rooms and remote meeting assistants. The project aimed to enhance the value of multimodal meeting recordings and to make human interaction more effective in real time.

The Meeting Recorder Project

The meeting recorder project was a joint research project undertaken by researchers at ICSI, UW, SRI, and IBM. The project was primarily focused on developing speech recognition and automatic transcription tools and techniques. The researcher sought to develop such tools through collating and analysing multimedia records of meetings.

Compendium Institute

The Compendium Institute is an open forum for the ongoing development and dissemination of the Compendium methodology and software tools. Compendium is about sharing ideas, creating artefacts, making things together, and breaking down the boundaries between dialogue, artefact, knowledge, and data.

Design Transaction Monitoring

The Design Transaction Monitoring was a doctorate research project, conducted in University of Bath in conjunction with Airbus UK, exploring how design experience and rationale can be captured from the discourse of design reviews. The project presents a novel information mapping technique to highlight the discrepancies between what is captured in the official design record (meeting minutes) and what is captured through transcription of the meeting audio. The findings are based on an industrial case study and a survey on the requirements of practicing engineers in leading aerospace companies.

Memetic: An Infrastructure for Meeting Memory

The Memetic project was a JISC funded collaborative research programme between The University of Manchester, The Open University, The University of Southampton and The University of Edinburgh. The goal of the Memetic project was to create a toolkit for meeting support. This included; developing tools to record all or selected video streams in a meeting; investigating the scope for automatically indexing the video stream timeline with multimedia elements to allow for enhanced search ability and reuse.

M4: Multi Modal Meeting Manager

The M4 project was a 3 year, EU funded research programme with the principle objective of developing and constructing a demonstration system which would enable structuring, browsing and querying of an archive of automatically analysed meetings. The project was a collaboration of nine Universities from across Europe and ran from 2002 till 2005.

Project-EIFFEL

EIFFEL was a French joint research project run by the INRIA (French National Institute for Research in Computer Science and Control) and CNAM (National Conservatory of Industrial Arts and Crafts). The objectives of the team were to model cognitive and cooperative processes involved in design activities and to assess and specify tools and methodologies that support design.

Project Nick

As part of the research Project Nick, the Design Interface Group within the Software Technology Program at the Microelectronics & Computer Technology Corporation (MCC) undertook research in the areas of meetings analysis and meetings augmentation. Project Nick developed techniques to apply automated facilities to the process, conduct, and semantic capture of design meetings. At the time of the project, MCC was one of the largest computer industry research and development consortia in the United States with members including NCR, Motorola, and the Lockheed corporation (Myers 1985).

The previous research projects identified above range from large collaborative multi organisational research projects to individual doctorate research studies and encompass many studies undertaken with industrial collaborators such as Airbus UK (Huet 2006) and MCC (Ellis, Gibbs et al. 1991). In order to understand the scope and range of activities covered by each of the previous research projects, analysis was performed looking to identify specific research themes present in the project descriptions and objectives. Essentially, these themes became the *metrics* against which the projects were measured, establishing the areas of research covered by the projects. These themes themselves were derived from the literature and experimental studies undertaken throughout the research activities of this thesis. They were as follows:

- *Meeting structure*: Analysing the effect which the overall structure of engineering meetings has on both the undertaking and documentation of the episode (derived from Section 4.4.1.1).

- *Meeting formality*: Definition of the different categories of meetings and their associated formalities. Studying the effect which meeting formality has on the structure and governance of the meeting (derived from Section 4.4.1.1.1).

- *Information capture*: Evaluation and/or development of techniques and tools to enhance the capture of meeting information (derived from Sections, 3.2, 3.5 and 4.3).

- *Information reuse*: Evaluation and/or development of techniques and tools to promote and study the reuse of meeting information (derived from Sections 4.1, 4.2 and 4.4.1)

- *Through-life support*: Analysis and development of techniques to support or promote the capture, retention and reuse of information throughout the entire life of a product or project (derived from Section 3.3).

- *Software development*: Research focusing on the development of software tools or architectures to aid in the structuring, undertaking and documentation of meetings (derived from Section 4.3).

Table 4.5 Analysis of previous research projects

			Research Themes					
Research Title	Lead Institution(s)	Research Focus	Meeting Structure	Meeting Formality	Information Capture	Information Reuse	Through-Life Support	Software Development
AMI: Augmented Multi-party Interaction	Idiap Research Institute (CH) / University of Edinburgh (UK)	Meeting browsers; tools that allow users to find the information that they want quickly from a recorded meeting.	●		●	●		●
The Meeting Recorder Project	International Computer Science Institute - ICSI (USA)	Automatic capture of meeting content and provide structured emthod of re-engagement with information.	●		●	●	●	●
Compendium Institute	Knowledge Media Institute (UK)	Development of tools and method of structuring arguments and dialogue conducted throughout synchronous design activities.	●	●	●	●	●	●
Design Transaction Monitoring (PhD)	University of Bath (UK)	Development of tools and methods to analyse information transactions during design.		●	●	●	●	●
Memetic: An Infrastructure for Meeting Memory	Knowledge Media Institute (UK)	Recording interactions conducted via internet video conferencing, and making these navigable and manipulable in linear and non-linear ways.	●	●	●	●		●
M4: MultiModal Meeting Manager	University of Sheffield (UK)	Software system to enable structuring, browsing and querying of an archive of automatically analysed meetings.	●		●	●	●	●
Project-EIFFEL	INRIA - Rocquencourt (FR)	Modelling cognitive and cooperative processes involved in design activities and to assess and specify tools and methodologies that support design.	●	●	●	●		●
Project Nick	Microelectronics and Computer Technology Corporation - MCC (USA)	Understanding and Improving the dynamics of meetings.	●	●	●	●		●

From the analysis of the previous research projects (Table 4.5), it is clear that significant effort has been focused on the creation of software based tools to better record the synchronous and asynchronous interactions that take place during the design process. This is demonstrated since all eight of the projects can be said to cross three key themes: *Information capture*, *Information reuse* and *Software development.* However, this highlights the gap in other areas of research such as the structure of meetings, the formality of meetings and also the process of undertaking meetings, as all of these factors have an effect on the ability to create accurate records. In fact, of the eight key research projects analysed only one can be said to address all six of the research themes identified. The identified project is that of the Compendium Institute, and even then, this project has a weak relationship with three of the key themes; *Meeting formality*, *information reuse* and *through-life support*.

This presents a significant gap in research into the development of methods, tools and models of engineering design meetings which can adequately address the need to develop systems and models which can adapt to different meeting structures and varying degrees of formality, whilst still providing effective information and knowledge capture mechanisms.

4.4.3 *Commercial meeting capture systems*

The issue of documenting meetings accurately is a well defined and researched topic and as a result, a multitude of commercially produced software systems are available which claim to fulfil this need. For reasons of brevity, this section will focus on the two key developments as seen by the author; Microsoft's Office OneNote system and the Quindi Corporation's Quindi Meeting Companion software.

OneNote is a software package integrated within Microsoft's (MS) Office suite of tools and is aimed at providing free-form information gathering and multi-user collaboration in the form of a digital notebook (Microsoft 2007). Core functionality of the system allows users to 'cut and paste' multimodal elements of information into a series of 'pages' allowing users to quickly record webpages, text, images and video currently in use. However, as the system is integrated within the MS Office suite, OneNote relies upon predefined meeting templates, which are not customisable, limiting the user’s ability to structure the information captured. In addition, the system is specific to Windows operating systems and thus cannot be used on non Windows machines, inhibiting the shareability and usability of the documents.

The Quindi Meeting Companion (Quindi 2008) is a dedicated meeting capture tool that has the ability to record and integrate audio, video, notes, and data, including PowerPoint slides, screenshots, and whiteboards into a meeting record file. The system can be configured to unobtrusively record meetings using a combination of video, audio and screen capture technologies, resulting in the creation of a single file automatically indexed by time. A key aspect of the Quindi application is its ability to capture and bookmark individual PowerPoint slides automatically and as the system uses timestamps to organise the data objects, the individual slides are coordinated with corresponding audio and video recordings. Quindi also has the ability to save meeting records as a web page allowing shareability through a standard web browser. However, as with OneNote, the application is specific to Windows operating systems, thus only users with a software license and access to the Quindi file for the meeting can edit make further annotations, hampering the usability.

4.5 *Conclusions from the Literature*

From the study of previous work it is apparent that the capture of design information, and design rationale in particular, is much sought after within industry. Current virtual environments provide significant support in the exchange of formal design information such as geometric data and specifications. However, over extended lifecycles, it may desirable to communicate informal information and knowledge about the design and design process, including design rules, constraints, rationale, etc (Szykman, Sriram et al. 2000), not all of which is currently captured. It is recognised that working synchronously in engineering teams and engaging in episodes such as engineering design meetings is critical to engineering design and such episodes generate significant informal knowledge and information elements. Current documentary approaches and systems (both commercial and research based) are not sufficient at providing the necessary flexibility for varying degrees of meeting formality and structure and thus the capture activities remain ineffective. From reviewing the literature and identifying the gaps in current research, it becomes possible to identify elements which can help define and develop the effectiveness of knowledge and information capture systems.

In order for an information capture system to be most effective within today's globally dispersed design and manufacturing organisations, it must facilitate distributed working. As highlighted previously in the literature there are a number of systems which support distributed working, however, these systems do not possess the necessary methods to quickly and easily capture information regardless of the situation and location.

The key difference must be the capturing of data as it being generated (i.e. in its raw and unaltered format) and the association of metadata with minimal additional effort on the part of the user. In order to allow for more effective data capture solutions, consideration must be given to the physical environment and the use of mobile devices such as PDAs, mobile phones, laptop computers, digital pens and paper along with desktop computers and various meeting room technologies.

To turn a repository or database into an effective project memory, a higher quantity of information and metadata is required than is normally captured. At present, most systems will automatically generate metadata such as date, time, user ID and file type but to be effective, further elements of metadata such as context, description and status should also be captured. In order to create more effective project memories which can be used beyond the lifetime of the project, the system must generate as much metadata as possible at the point of capture. By doing this, the system can create 'data objects' constructed from the data file and the associated metadata. These data objects can then be used to construct a comprehensive project memory, i.e. a representation of the activities undertaken throughout the duration of a project.

An essential factor in the creation of project memories is the retrieval and visualisation of the data. The use of object views within the system would allow for various methods of viewing the data. Any system developed must have the ability to query the database and retrieve data objects, thus a search or query environment must be incorporated. The system should allow project memories to be interrogated from multiple perspectives. For example, the use of timelines linking together sets of data objects would allow the user to view all activities captured between certain periods in the project.

The objective of the review of literature and previous research was to analyse collaborative design meeting scenarios to gain an insight into the various types of information and knowledge which are typically generated and communicated within synchronous situations. The overall aim of the review was to identify where improvements could be made in the recording of this sometimes tacit and implicit information and knowledge. Using video and audio recordings of meeting are satisfactory at capturing all interactions and informal and formal information and knowledge exchanges as they happen, however these method result in large quantities of data being stored, much of which can be dismissed as being unimportant routine work or ‘noise’. In contrast, traditional meeting records comprising minutes taken during the meeting fail to capture all of the critical situations as they occur as they may not be obvious at the time and thus many decision made during these instances may be lost. What this review has identified however runs deeper than just the capture mechanism. The overall structure of the meeting (governance, documentation and participation) must be accounted for, the meeting process must be modelled and the capture mechanism architecture designed to fit with these models. Only if all factors are considered in the solution will the capture of the critical knowledge and information become effective.

4.6 *Exploratory Study II: Engineering Design Meetings*

Within this section, experimental situations are described which were undertaken with a view to analyse synchronous, collaborative design meetings and gain first hand insights into the information and knowledge typically generated and communicated within such episodes. The experimental hypothesis is that current methods of recording synchronous situations such as design related meetings are not effective in capturing the necessary information and knowledge quickly and in forms which can be scrutinised at later dates.

4.6.1 *Methodology*

Through a combination of the techniques discussed previously (Sections 2.2 and 2.3) the critical situations were captured and retrospectively identified within various design meeting scenarios, subsequently identifying the critical decision points in the design processes and proposing techniques to improve the information and knowledge capture process. This analysis was based on a series of experiments conducted in controlled environments. The aim was to study and examine two basic elements of information activity within the design process:

1. *What information is generated?*
2. *What information is stored?*

By knowing what information is generated and what is actually stored it is possible to build a view of what should have been stored but was not (i.e. lessons learned).

In the first instance, face-to-face meeting scenarios were created whereby a group of five participants were given a simple design exercise and asked to complete the task within a limited time (30 mins). Only four of the participants were actively participating in the design process and comprise the design team, the fifth participant was nominated as chairperson and given an agenda which was to serve as the main driving force behind the meeting whilst also doubling as a document for which the meeting record can be documented. The design meeting scenarios were filmed using two digital video cameras; a table camera which monitored the face-to-face interactions between the group and an overhead camera which monitored the hand movements and gestures of the group during the meeting. This set up (Figure 4.6) gave complete coverage of the meeting and allowed unobtrusive monitoring of the meeting as is shown in Figure 4.7.

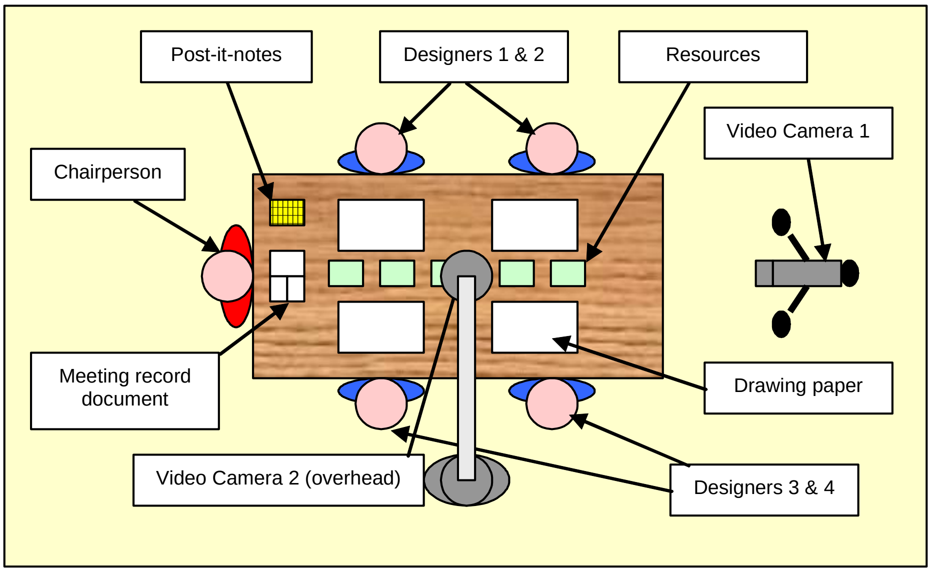


Figure 4.6 Experiment set up

Figure 4.7 Camera Views

The audio recordings from the meetings were transcribed and a combination of an adapted version of Huet's Transcript Coding Scheme (TCS) (Huet 2006), to document the interactions within meeting scenarios and Badke-Schaub et al's Critical Situation work (Badke-Schaub, Frankenberger et al. 1997) to interpret the results used. The basic structure of the TCS was kept the same as many of the categories developed by Huet were applicable to the analysis; however, additional categories were added to identify the critical situations. Through the application of the critical situation criteria proposed by Badke-Schaub et al (Badke-Schaub, Frankenberger et al. 1997) to the transcript of the meeting, it became possible to identify the critical situations as they occurred throughout the meeting transcript and it was subsequently possible to identify the critical decision points within these situations as is shown in Figure 4.8.

ID	Transcript	Time	Type	Role	IT	Item	Crit. Sit.	Crit. Dec.
LH	Maybe something that you slip down	28:22	S	DEB	PROD	2	**3**	
JH	Its like a lid thing	28:24	S					
MS	So you’ve decide that your making it as a modular design?	28:25	Q	CLA	PROC			
KM	yeah	28:27	A	DEC				
MS	A modular design	28:28	S	INF				

<u>Legend</u>

ID	Identity of the speaker (initials);
Transcript	Text transcribing speech;
Time	Time when the intervention ended (minutes: seconds);
Type	Intervention type (statement (S), question (Q), answer (A), or feeling/emotion (F));
Role	Exchange role (informing (INF), exploring (EXP), resolving problems (RES), managing (MAN), evaluating (EVA), debating (DEB), digressing (DIG), clarifying (CLA), or decision making (DEC));
IT	Information type (product (PROD.), process (PROC.) Resources (RES.), or external factors (EXT));
Item	Agenda Item
Crit. Sit.	Critical situations; 1 - Goal analysis and goal decision, 2 – Information and solution search, 3 – Analysis of solutions and decision-making, 4- Disturbance management, 5 - Conflict management
Crit Dec.	Critical decisions;

<u>Text conventions</u>
Words in *italics* are approximately transcribed
… In the text marks a pause of 10 seconds or less
(…) In the text marks a pause of more than 10 seconds
[…] In the text marks a pause of more than 30 seconds
<u>Underlined</u> words are those which overlap with the transcript following

<u>Specific speaker conventions</u>
[ID] some or part of the intervention from this speaker was not transcribed and the reason given in the transcript encased in [ ]
ID = X, the identity of the speaker was not recognised

Figure 4.8 Modified Transcript Coding Scheme (TCS)

For reasons of brevity a sample transcript from the experimental sessions is included as Appendix B. The remaining transcripts are available for further analysis upon request.

4.6.2 *Engineering Design Meeting Experiments*

The experiments were undertaken within the department of Design Manufacture and Engineering Management at the University of Strathclyde and focused on participants who had experience in design or engineering related problem solving. A design brief was created specifically for the experiments and this brief asked the participants to undertake the concept design and evaluation of a paper-based coffee cup holder. The design brief was loosely based on a class design project undertaken by third year undergraduate Product Design Engineering students within the department. It was felt that the level of difficulty of this task was such that it would not present any significant problems for the participants to complete within a short time-frame, whilst replicating a valid design exercise. Using this student project as a base also allowed the introduction of resources to the scenario such as existing concept sketches and models developed by the students as it was felt these resources would normally be present in real-life scenarios. Within the brief, it was made clear that there were three points which had to be covered within the time frame:

1. Identify the Unique Selling point of the design
2. Generate, concepts, combine and select three to take forward
3. Identify the final design

These three points provided an identifiable structure for the meeting and subsequently were incorporated as agenda items around which the chairperson was instructed to conduct the meeting around.

Initially two experiments were undertaken. In each experiment, a group of five people, each with a design or engineering background, were given a simple design task to perform within a design meeting setting and a chairperson was nominated from within the participants. A design brief was provided to each member of the team and the chairperson given sheets of paper with the three specified agenda items that the meeting was expected to cover within 30 minutes.

4.6.2.1Phase 1 Results

The audio recordings from both meetings were transcribed and analysed through the modified TCS and, using this as the datum, the accuracy of the meeting minutes were analysed with respect to: the number of decisions recorded and the number of *critical* decisions recorded as defined by Badke-Schaub et al. The results (presented in Table 4.6) showed that the depth of information contained in the minutes differed significantly from that of the transcript; with a minimum of 23% maximum of 50% accuracy in documentation of decisions. From the evaluation of the data from the first meeting it was observed that there were ten instances which, according to the TCS, came under the banner of a critical decision but which were not identified within the meeting minutes. From the analysis of the second meeting data set it was observed that there were twelve instances where critical decisions were highlighted by the TCS but failed to be recorded in the meeting minutes. A general observation was that in some cases the decision was recorded; however there was no rationale or background to which would give an indication of how the decision was reached. The following table summarises the results.

Table 4.6 Initial Experimentation Results

	Decisions		Accuracy	Critical Decisions		Accuracy
	Minutes	**TCS**	**(%)**	**Minutes**	**TCS**	**(%)**
Ex 1	5	22	**23**	5	15	**33**
Ex 2	17	34	**50**	9	21	**43**

Overall, the conclusion drawn from the initial experiments were that traditional minute taking activities are not sufficient to provide a rich history on the decisions made throughout design activities, especially if the intention is to reuse the information within the minutes at a later stage in the design process. It was also observed from the video footage that many decisions stemmed from informal information sources such as gestures and resources available in the meeting, thereby another problem was identified: *how can these physical gestures and interactions with resources be recorded in a way which would help provide detailed information on the decision points?* In fact it was observed that to adequately record what was happening in the scenarios, certain additional key pieces of information should be recorded.

4.6.2.2 'Enhanced' meeting record

In line with the literature presented within section 4.4.1.1.3, the following elements of information were proposed as a method of enhancing the structure of the meeting record:

- *Exploration* – information relating to or influencing the decision making process
- *Decision* – the agreed summation of the discussion point resulting in further action.
- *Action* – the agreed steps necessary to progress a decision.

It was proposed that these key pieces of information, if recorded, would provide a richer history of information on the decisions relating to both product and also the process information. The identification of these key pieces of information led to the development of a modified method of minute taking. From the evaluation of the traditional minutes it was observed that not enough information on the decisions was being recorded. It was felt that to solve this issue the chairperson or minute taker should employ an enhanced method of minute taking which would record not only the decisions taken during the meeting but also the key information which related to the rationale and background. If at the instance when the minute is being recorded, the minute taker was able to document not only what the decision or minute was but also where it stemmed from, i.e. if a decision was made based on a drawing which was made or even centred on the resources being used in the meeting, then these interactions would be considered valuable as it provides rationale behind the decision. This enhanced method of documenting activities was perceived as a step closer to achieving a richer information history.

4.6.2.2.1 *Modified experiment methodology*

Building upon the analysis and conclusions from the initial set of experiments and to evaluate the concept of an enhanced method of minute taking, the design meeting experiments were repeated. The chairperson was given three sets of colour-coded Post-It® notes, each colour representing a different information object (Yellow – Resources provided to the teams, Green – Sketches created within the meeting, Blue – Physical interactions and gestures between the design team). As well as documenting the decisions and actions as they arose from each member of the design team, the chairperson was responsible for adding the Post-It® notes to the written document, indicating the background to the decision i.e. where the decision stemmed from. This was done by attaching the appropriately coloured Post-It® note to the relevant point in the meeting minutes, as the minutes were being taken (Figure 4.9). To aid post meeting analysis, the resources which were made available in the meeting set-up were clearly labelled as is shown in Figure 4.10 and the chairperson asked to note the identifier of the resource on the Post-It® notes. Labelling the resources was also considered useful for the identification of the resources when analysing the videos retrospectively. To adequately identify and represent the user interactions with the resources, the previously used TCS document was modified. An additional column was added which documented the use of media such as the resources, the drawing paper (i.e. conveying ideas through sketching), text based communication and also physical gestures.

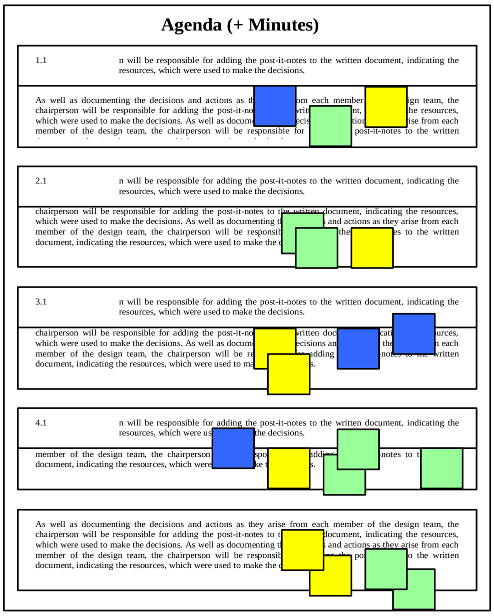


Figure 4.9 Enhanced Minute Concept

Figure 4.10 Labelled Resources

4.6.2.3Phase 2 Results

As with the initial experiments, the audio from both the third and fourth meeting scenarios was transcribed and analysed within the TCS document. The TCS was then used as the datum against which the meeting minutes were directly compared, thereby measuring the accuracy of decisions and critical decisions recorded.

Table 4.7 Experimentation Results Summary

	Decisions		**Accuracy**	**Critical Decisions**		**Accuracy**
	Minutes	**TCS**	**(%)**	**Minutes**	**TCS**	**(%)**
Ex 1	5	22	**23**	5	15	**33**
Ex 2	17	34	**50**	9	21	**43**
Ex 3	9	26	**35**	5	21	**24**
Ex 4	16	39	**41**	7	24	**29**
		Aggregate	***37***		***Aggregate***	***32***

As can be seen in Table 4.7 above, the results for experiments three and four again highlight a significant difference in the number of critical decisions identified through post meeting analysis compared with those identified within the minutes of the meeting. In fact by taking an aggregate view of the accuracy across the four experimental episodes it can be gleaned that traditional documentation techniques provide on average a level of accuracy of 37% in recording decisions and only 32% accuracy in recording decisions which can be deemed as critical to the design activity. This further strengthens the argument that traditional minute taking techniques are not sufficient to capture all important decisions as they are made. It should also be noted that, based on these results, it can be said that the concept of the ‘enhanced minute’ trialled throughout experiments three and four failed to aid the chairperson in increasing the number of decisions recorded; in fact it would appear that the introduction of the concept neither enhanced nor hindered the documentation accuracy. However, the use of the enhanced minute concept and the addition of coded Post-It® notes provided not only a record of the decisions but also gives indication of the rationale and the background to these decisions, something not present in traditional minute taking techniques.

From analysis of the Transcript Coding Schemes and minutes from the initial two experiments and the third and fourth experiments, it is apparent that although the enhanced minute concept does not actively aid the chairperson in recording design decisions, it does enhance the overall meeting record. The addition of the Post-It® notes provide some of the much sought after rationale which traditional minutes fail to record. Decisions which stem from sketches and the user's interactions with resources are made explicit through the addition of the Post-It® notes, ensuring that a more complete view of the meeting is achieved. These additions can improve the process of identifying the influencing factors on which many design decisions were undertaken and in many cases why. The overall gain achieved by enhancing the meeting record is such that employees or design team members who were not present at the time can potentially gain a more accurate perspective of the meeting and better understand the outcomes compared to traditional minuting techniques.

4.6.3 *Conclusions from the study*

Through a series of experiments, initial studies were undertaken to observe, identify and evaluate critical instances of information and knowledge generation amongst engineering design teams whilst performing conceptual design activities within synchronous design episodes. Using unobtrusive multi-media recording equipment and observation techniques, the study provided an insight into the decision making processes which engineering design teams typically follow during the course of a design exercise. Adopting proven transcription methods, the study highlights through experimentation that traditional minuting techniques fail to capture all decisions made throughout the course of design development. It was also found that many of these decisions stem from informal information sources and therefore the rationale and intent becomes difficult to identify and subsequently capture.

Overall, the undertaking of this study has provided a useful insight upon which further work can build. From analysis of the conceptual methods presented, it becomes clear that the development of enhanced documentation methods complimented with multi-media such as audio and video has the potential to improve the recording of informal information for reuse at latter instances. The aim is to assist design engineers to record more information than traditionally documented, providing a much richer product history and allowing the design process to be revisited at a later instance. If design engineers are to capture information and knowledge with a view to reuse at later stages in the product lifecycle then the focus must be on developing a rapid, effective method of capturing formal and informal information at the point at which it is generated rather than through retrospective analysis.

4.7 *Chapter Summary*

Through a focused review of the literature and a second exploratory study, this chapter has presented the key difference between synchronous and asynchronous modes of working in design and provided the answer to the third research question:

3. *Are there specific activities employed within the engineering design process where knowledge and information capture is ineffective?*

Building upon what has been established from the literature thus far and analysing synchronous and asynchronous modes of working, design activities such as engineering design meetings present themselves as a key aspect of the engineering design process. As alluded to by Badke-Schaub et al, synchronous activities such as meetings can be classed as critical to the design process as these episodes include discussion, reasoning and decision making activities influenced strongly by both product and process information and knowledge. This is supported by the wealth of research developments focused on aiding designers to identify, capture and share engineering design knowledge and information. Synchronous situations such as engineering design meetings therefore have been identified as one specific process which can be deemed as critical to the engineering design process and yet regarded as ineffective in capturing knowledge and information using traditional methods, techniques and tools. In addition, engineering design meetings are regarded as synchronous episodes which are conducted throughout all stages of the design process and indeed the product lifecycle, allowing a broader view of knowledge and information usage to be established.

From the study of previous work, and the plethora of tools and techniques found in the literature, it is apparent that the identification, capture and subsequent reuse of design knowledge and information are recognised as critical by much of the engineering design community. However, what is most apparent from the review is that for these techniques, tools and methods to be truly effective in capturing knowledge and information, there is a need to address more than just the capture mechanisms. From the literature reviewed and also exploratory studies undertaken, the structure and protocols adopted as part of engineering design meetings can be seen as key to providing a representative record of the activities. In many cases these protocols and structures are not adequately developed and implemented within organisations, leading to discrepancies in how records of design activities are constructed. The overall structure of the meeting (governance, documentation and participation) must be accounted for, the meeting process must be modelled and the capture mechanism architecture designed to fit with these models.

The overall aim of the research presented in this thesis is to assist design engineers to record more information than traditionally documented, providing a much richer product history and allowing the design process to be revisited at a later instance. With this in mind, the main challenge and fourth research question which this study will address is:

4. *Can a framework model be developed to enhance the practice of documenting design knowledge and information at the point of generation?*

The focus of this research is on engineering design meetings and social interactions, where traditional records can fall short of documenting many important design decisions as is evident from the review of literature. The challenge this research will address is how to best manage the capture and storage process in a way that is both simple and efficient, whilst remaining unobtrusive to the designers involved and without inhibiting the design activities.

PART C: PRESCRIPTION

Chapter 5: Framework Development

The literature analysis and initial experimentation activities undertaken throughout Chapters 3 and 4 have helped establish that easy and unobtrusive capture of information as it is being generated is the key to the construction of a comprehensive record of activities. This early work has also firmly established synchronous design activities, such as meetings, as activities which occur throughout the design process and during which much of the product and process decisions are made. In addition it is also evident that the organisational structure of meetings, plus a defined process, is fundamental to creating enhanced representations of the activities.

The aim of this work now is to develop a framework which if applied to synchronous situations would allow for enhanced capture of design process and/or product information without creating additional work for the users. The dictionary definition of *framework* is given as a particular set of rules, models or beliefs used to solve problems or prescribe work (1998). Using this definition as a basis, it becomes evident that there is a need to derive the individual models required to form the basis of an overall capture framework.

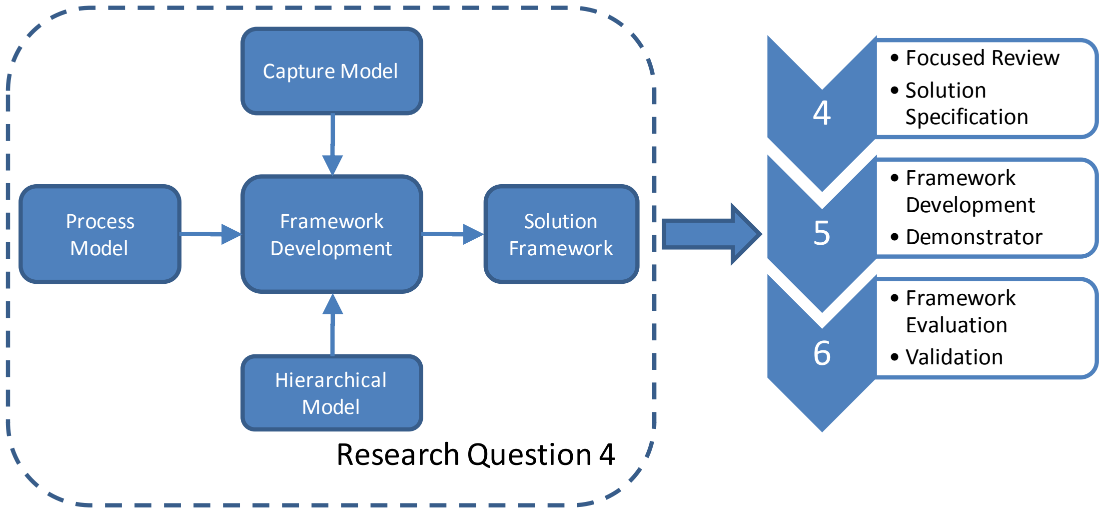


Figure 5.1 Chapter structure

This chapter charts the development of these models which combine to create the knowledge capture framework.

5.1 *Organisational model*

As discussed in Chapter 4, there are many different formalities and categories of meetings and as such, the governance and subsequently organisation of meetings is directly proportional to the level of formality at which the meeting will occur. That is, the formality and structure applied to meetings will define the level of governance required to effectively undertake the meeting. Building upon the description of meeting formalities proposed in Section 4.4.1.1, three organisational roles can be extracted;

1. *Facilitation* – organisation and structuring of the meeting;
2. *Documentation* – capturing and producing a record of meeting activities;
3. *Participation* – actively engaging in discussions and decision making process

In addition to these organisational roles, three categories of participants are present within meetings. These are as follows;

i. *Participant*– member of organisation involved in discussions and the decision making process within the activity;

ii. *Chair (chairperson)* – facilitator responsible for chairing the meeting, maintaining and updating the agenda, assists in agenda planning and participant identification;

iii. *Scribe* – member of organisation responsible for constructing an objective and unbiased record of activities or meeting minutes. Does not actively engage in discussions and the decision making process.

These definitions and the work performed in Chapter 4 present a platform upon which to model the organisational aspects of meetings in relation to their formality. As discussed in Section 4.4.1.1.1 and presented in Table 4.2, meetings can be categorised against a five point scale of formality (i.e. from informal to formal). The following sections present the organisational models for each of these five categories.

5.1.1 *Formality level 1*

Formality level 1 represents meetings which are unstructured with no defined chairperson or specific agenda to follow. Meetings of this formality tend to be highly collaborative, brainstorming and idea generating meetings (Zurita, Antunes et al. 2006). As a consequence, it is unlikely that agreed meeting minutes are produced; instead each of the participants is likely to have their own personal record of activities. In terms of organisational structure, as is shown in Figure 5.2, meetings which fall into this formality level can be deemed to have no or very little hierarchical structure underpinning the activities. As a direct consequence, each of the three organisational roles, facilitation, documentation and participation, are undertaken by all of the participants. The likely result from meetings such as these are outputs (i.e. decision, actions) with limited coherence and agreement.

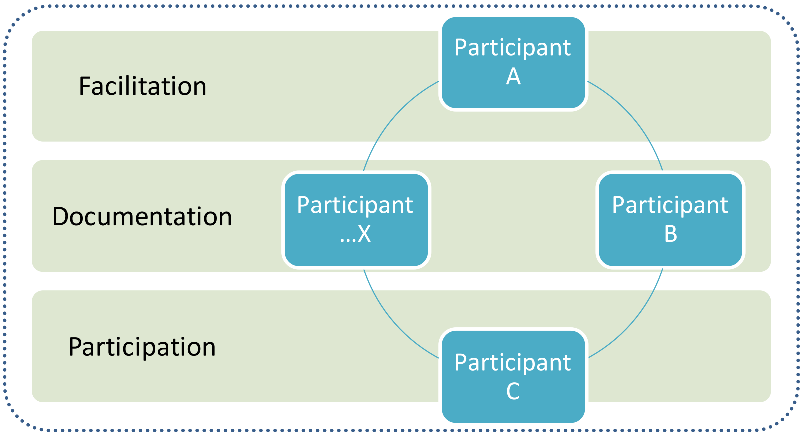


Figure 5.2 Organisational model: formality level 1

Meetings of this formality are highly advantageous for teams working collaboratively or brainstorming an idea since very little restriction or structure is imposed on the participants, allowing more collaborative freedom. However, the key disadvantage lies with the difficulty in producing an agreed output of the episode. With no defined governance in place, the resulting documented record of proceedings will have varying degrees of structure and include varied information, potentially leading to discrepancies between the participants’ recollections of events, discussions or decisions. A common result is that record of the activities are kept within personal computers or notebooks and not subsequently shared with other meeting participants (Fruchter and Demian 2002).

5.1.2 *Formality level 2*

Formality level 2 refers to unstructured meetings whereby there is no defined agenda, and no official documented record. However, unlike level 1, this level of formality incorporates a degree of facilitation or direction provided by an individual acting as the meeting chair as shown in Figure 5.3.

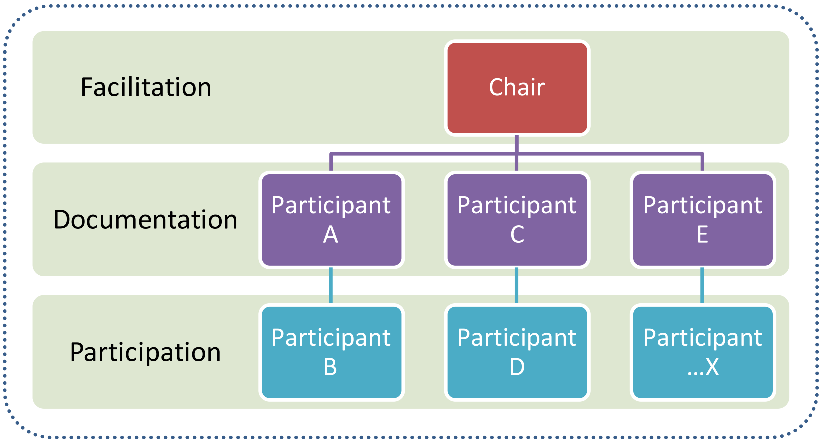


Figure 5.3 Organisational model: formality level 2

Formality level 2 meetings are similar to those within level 1. Due to their free-form nature they are advantageous for teams working collaboratively or brainstorming an idea. However, the incorporation of a defined facilitation role provides a degree of control and structure to the meeting, which the lower formality level meetings do not possess. This additional control and structure could potentially increase the level of accuracy of the documented record, as the variance in the structure of the record and the points covered may be reduced. However, with no ‘agreed’ or definitive record produced, the potential for different viewpoints on the actions, decisions and exploration activities may still lead to discrepancies between the attendee’s understandings of the episode.

5.1.3 *Formality level 3*

Meetings occurring within formality level 3 are particularly common within small to medium enterprises (SMEs) or within groups or teams working on or within a particular project (Zurita, Antunes et al. 2006). These meeting will have a structure associated with them but also allow for flexibility on the meeting agenda. As indicated by Zurita, Antunes et al. (2006) these meeting can be described as ritual and encompass activities such as progress updates, team building and cohesiveness.

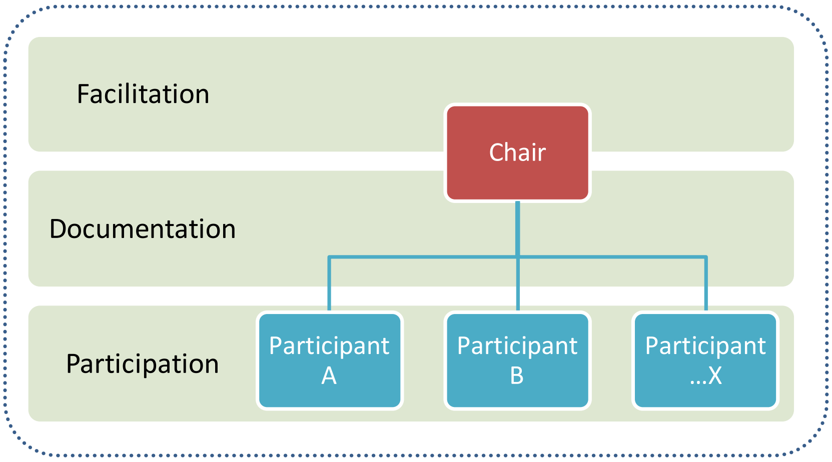


Figure 5.4 Organisational model: formality level 3

In this level of formality, it is common for a nominated person to assume the role of meeting chair as demonstrated in Figure 5.4. However in addition to facilitating the meeting, the chair will likely participate and may also act as the primary meeting scribe, producing minutes or some form of record of the activities. This structure provides advantage in consistency of the overall meeting governance and the outcomes agreed. However with a participant acting in the dual role of chairperson and also scribe there is the possibility some issues may be misconstrued or not documented accurately due to the requirements of fulfilling two roles. As Huet proposed throughout his studies, to achieve a truly objective record of the meeting outcomes a dedicated meeting scribe should be employed (Huet 2006).

5.1.4 *Formality level 4*

Meetings occurring at a formality level of 4 are possibly the most common within organisations. Facilitation of the meeting is conducted through the appointment of a meeting chair, whose responsibility it is to ensure that all of the action points are covered within the meeting timeframe. Level 4 meetings are structured through the preparation and prior distribution of a meeting agenda with specific attendees required to attend. Throughout the course of the meeting the documentation of decisions, actions, and exploration activities are performed by a meeting scribe.

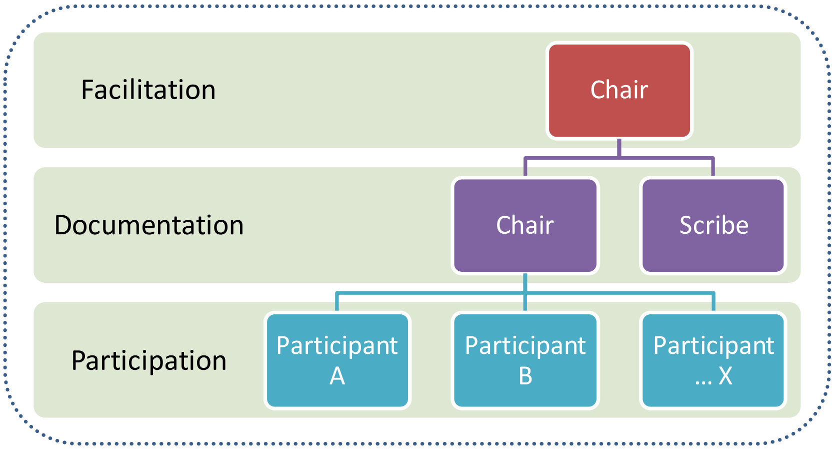


Figure 5.5 Organisational model: formality level 4

In many cases the scribe will be assisted by the meeting chairperson, whom throughout the proceedings may instruct or direct the scribe on the actions and documents which he or she feels necessary inclusions for the meeting record (Figure 5.5). This structure provides similar advantage to level 3 formality meetings whereby consistency of the overall meeting governance and the outcomes are agreed. However, unlike meetings occurring at a lower formality level, the addition of a dedicated meeting scribe ensures that a more objective record of the activities is produced.

5.1.5 *Formality level 5*

Meetings which fall into the formality level of 5 are entirely structured and regimented episodes. The meeting agenda and participants list will be produced and distributed in advance of the meeting and in many cases, advance views on meeting documentation (papers, presentation etc) may be given. These meetings will have a dedicated meeting chair who will not actively participate in the discussions or decision making process, and a dedicated meeting scribe or clerk whose sole responsibility is to provide an accurate and objective view of the meeting proceedings. Examples of meetings which may occur at this level of formality are official review panels, annual or bi-annual board meetings and legal reviews.

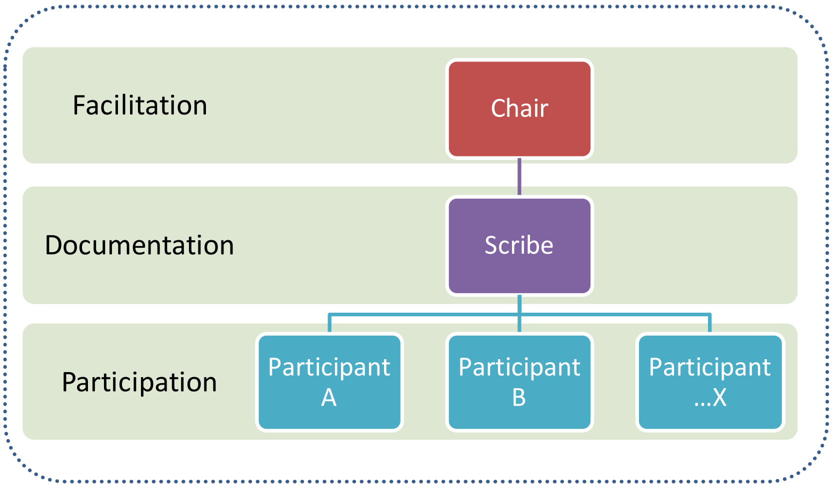


Figure 5.6 Organisational model: formality level 5

As is shown in Figure 5.6, each of the meeting attendees will have specific roles assigned to them and these will be notified well in advance of the meetings. This process of role assignment allows every attendee of the meeting to have sight of their and other attendee's roles, removing ambiguity of who is responsible for which element of the meeting. Highly structured, formal meetings such as those which occur within formality level 5 will provide a well structured record of the activities and often will be part of a series of meetings, such as six monthly or annual project reviews. In many cases predefined document templates will be used to present the proceedings of the activities, ensuring consistency in the documentation. However, where the inclusion of defined structure and roles contribute to providing a more defined record of activities, this enforced structure has potential to have a negative effect on the meeting in terms of group collaboration.

The organisational models presented within this section of the thesis provide useful mechanisms for researchers to structure and analyse synchronous activities such as meetings, allowing tools, techniques and processes to be measured within multiple formalities. However, for the models to provide the most benefit there is a need to understand and model the process within which the organisational structures are applied.

5.2 *Meeting Process Model*

As highlighted in Chapter 4, owing to the diversity and range of organisational structures and contexts within which they occur, there are no universally defined and accepted process models of the engineering design meeting found in the literature. However, what is indicated by much of the literature on meetings is that the agenda is recognised as the central structural element around which the meeting is conducted (Niederman and Volkema 1996; Romano and Nunamaker 2001; Jain, Kim et al. 2003). This therefore presents the meeting agenda at the core of the meeting process model.

Similarly, as documented in Section 4.4.1.1.3, general meeting documentation can be said to consist of four key elements of information; *exploration*, *decisions, actions* and the *meeting metadata*. Expanding upon these elements, it is possible to reason that in order to generate the necessary information outputs for documentation; four individual activities must be undertaken. These are: discussing, reasoning, and debating of the agenda item (*exploration*); conclusions or judgments reached or pronounced in agreement for the agenda item under discussion (*decisions*); defined courses of action to be undertaken (*actions*) and documentation of the exploration, actions and decisions in addition to meeting metadata, the agenda point under discussion and source data used to reach decisions or actions (*record*). If these four elements are structured against the meeting agenda, this in effect presents a cyclic model of the meeting process, whereby the agenda is the core central element and exploration, decision, action and recording activities are undertaken for each item on the meeting agenda (Figure 5.7).

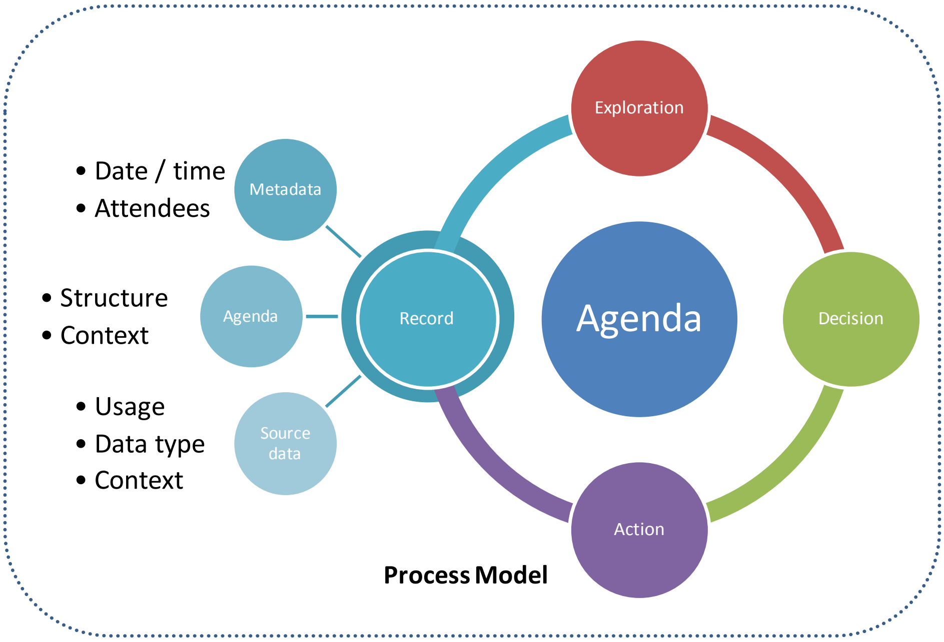


Figure 5.7 Meeting process model

For this model of the meeting process to be accurate there is an assumption that an underlying structure to the meeting is present. However, as highlighted by Zurita et al (2006), this is not always the case; many informal meetings will take place which are unstructured and without a predefined agenda to follow. In these instances activities such as exploration, decisions and indeed actions may still occur; however, without the core agenda element around which to structure the meeting, it may not be possible to accurately document the progression of the meeting.

5.3 *Information Capture Architecture*

The earlier literature analysis and experimentation activities have firmly established that enhancing the capture of information, through the use of multimodal information, is key to the creation of a comprehensive and usable project memory. The specific interest within this research is on the capture and storage of process information and context within synchronous episodes. The aim was to develop a system architecture which would enable the capture of design process and / or product information without creating additional work for the users. To this end, work has been performed on developing a system architecture which can act as a platform upon which software tools could be developed to enhance the capture of design knowledge and information at the point of generation.

5.3.1 *Architecture Requirements*

Following the review of technology and related work in the area of design knowledge and information capture as presented in Chapters 3 and 4, and stemming from the experimental activities performed throughout this doctoral study (Sections 3.5 and 4.6), a set of requirements have been drawn up which, if satisfied, would form the basis of an information capture system architecture for use within the context of synchronous episodes such as meetings. The following sections present the requirements as derived from the experimental studies and the literature reviews undertaken within this thesis (Chapters 3 and 4).

5.3.1.1 Facilitate Distributed Working

Advances made in the computing world, and in particular, the expansion of the Internet, have been key factors in the increased prevalence of distributed design teams in recent years. Another key factor has been the growth of the global market fuelled by demand for technologically advanced products. The knowledge and skills required to develop and manufacture products rarely resides within a single location, leading to the need to establish distributed and possibly global design teams. However, the implementation of distributed design teams means that the process of capturing the important information, knowledge and decisions undertaken throughout the development of products becomes increasingly difficult. In order for an information capture system to be most effective within today's globally dispersed design and manufacturing organisations, it must facilitate distributed working. As highlighted in Chapter 4.2 there are a number of systems which support distributed working, however, these systems do not possess the necessary methods to quickly and easily capture information regardless of the situation and location of the users. The knowledge and information capture architecture should be directly applicable to distributed working and to provide the most benefit to teams globally or temporally dispersed, generate online collaborative documents and storage facilities which are accessible by any web-enabled hardware device.

5.3.1.2 Capture of information & data

A key aspect of capturing knowledge and information relating to design activities lies in the ability to capture both formal and informal information and the unstructured and raw data. As demonstrated through the studies presented in Section 4.6 and also the supporting literature throughout this thesis, current knowledge information capture techniques are not efficient in accurately capturing knowledge and information. The key difference must be the capturing of information and data as it is being generated and the association of metadata with minimal additional effort on the part of the user. In order to allow for more effective data capture solutions, consideration must be given to documenting contextual information as well as the information objects themselves. Consideration must also be given to the physical environment and the importance of not removing the designer from their natural working environment. Ancillary devices such as laptop computers, digital cameras and mobile devices can provide the necessary mechanisms to record information and knowledge *as it is generated*, and *as they take place*; from the corridor meeting or sketching designs on the train, to the group discussions and design review meetings taking place in designated rooms. Although it is not possible to be prescriptive in identifying all of the technologies necessary to meet this need, the design of any solution must interface or take account of such factors.

5.3.1.3 Storage of Data Objects

To turn a repository or database into an effective project memory, a higher quantity of information and metadata is required than is normally captured. At present, most systems will automatically generate metadata such as date, time, user ID and file type but, to be effective, further elements of metadata such as context, description and status should also be captured. In order to create more effective project memories the system must generate as much metadata as possible at the point of capture. By doing this, the system can generate *data objects* generated from the data file and the associated metadata. These data objects can then be used to construct a comprehensive project memory, i.e. a representation of the activities undertaken throughout the duration of a project.

5.3.1.4 Creation and Retrieval of Object Views

An essential factor in the creation of design episodes is the retrieval and visualisation of the data. The use of object views within the system would allow for various methods of viewing the data. Any system developed must have the ability to query the database and retrieve information in the form of data objects, thus a search or query environment must be incorporated. The system architecture should allow project memories to be interrogated from multiple perspectives. For example, the use of timelines linking together sets of data objects would allow the user to view all information captured within certain stages of the project or product lifecycle.

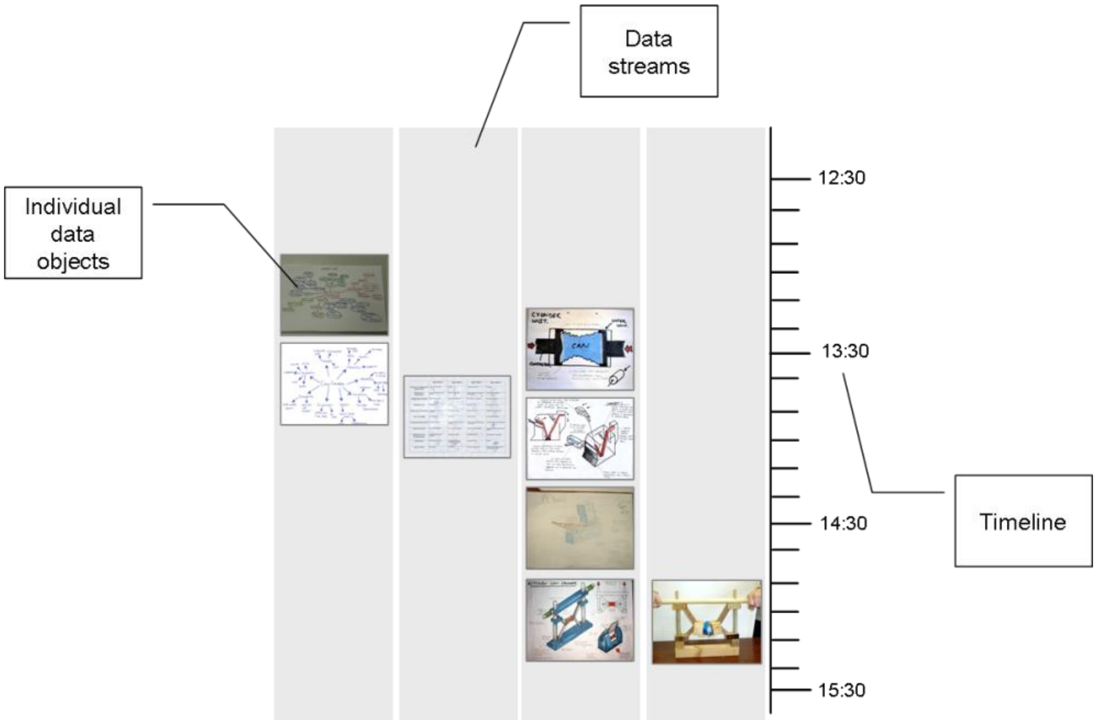


Figure 5.8 Object view of concept sketches

By way of illustration, an object view of concept sketches (Figure 5.8) generated within a certain period of time during a design project, would give a perspective on the range and scope of concept exploration undertaken by the design team at that point in time.

5.3.2 *Information Capture and Storage System Architecture*

The identification of requirements for an information capture and storage system has provided a basis for the development of a solution architecture. The system requirements can be grouped into two areas; a physical *engineering* workspace and a virtual *documentary* workspace.

The engineering workspace consists of the design team, web-enabled hardware and the input to the virtual documentary workspace. Due to the distributed nature of design, there is a need to cater for many different situations and therefore the system cannot be hardware specific. As previously stated, the engineering workspace should possess the functionality to allow designers (users) to access the system through a number of ancillary devices. To do this, an adequate user interface must be incorporated. There are various programming languages such as Java, PHP (Hypertext Pre-Processor) or C++, all of which could be used to adequately create this interface. By way of example, the web-based LauLima system (Breslin, Nicol et al. 2007) uses a PHP based interface as the input to the system. PHP is a widely-used general-purpose scripting language that is especially suited for web development as it can easily be embedded into HTML.

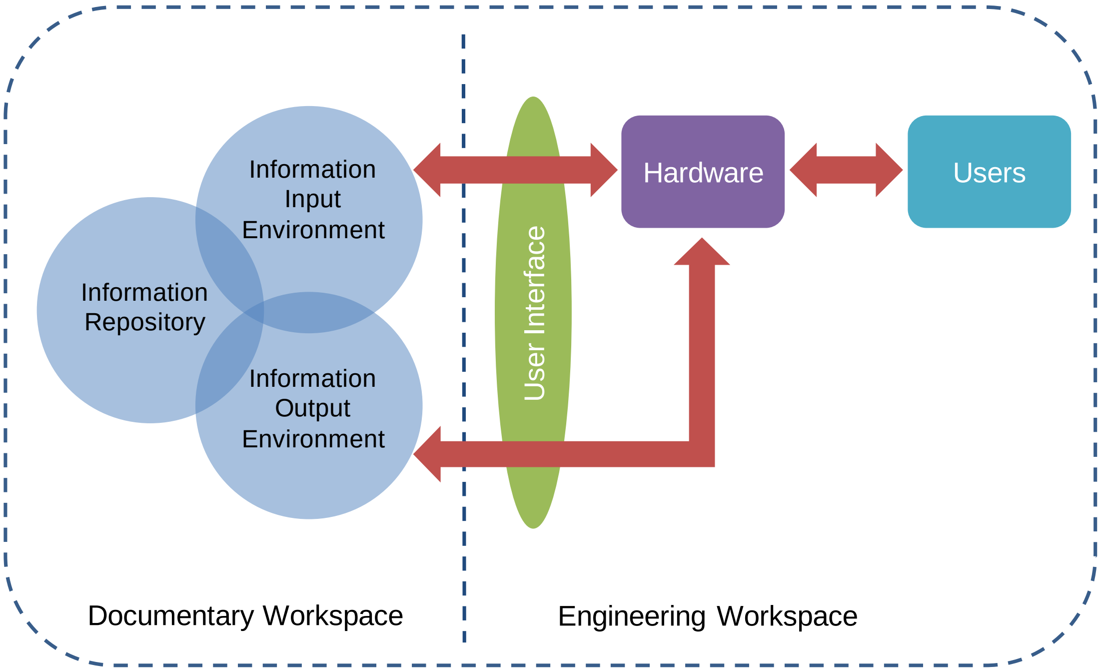


Figure 5.9 Information Capture and Storage System Architecture

The documentary workspace by contrast is entirely virtual consisting of an information capture environment, a search or query environment and a file repository or storage facility. The information capture environment is dynamic in nature in that it should allow the user to create and capture information and knowledge as and when it occurs in a 'live' environment and supports the editing and updating of the information at a later instance. Incorporated within the virtual environment is a file repository linked to a database. This repository enables the users to store and access their information irrespective of their location and provides the underlying basis for the system. In order for the user to search and retrieve data objects from the repository, a search and query environment must be included, bridging the gap between the user interface and the repository. The search environment also allow the users to return various views on the data objects contained in the repository, generating multiple perspectives on the data, whether it be by date, user id, title or any other associated metadata.

Utilising already available and prominent technologies, the system architecture proposed in Figure 5.9 meets the necessary system requirements as proposed in section 5.3.1. As well as proposing a viable solution to the problem, this architecture provides a model upon which future development can be performed, laying down the foundations for a potentially valuable information capture and storage system.

5.3.3 *Concept of an 'Enhanced' Meeting Record*

Within the exploratory study reported in Chapter 4.6 of this thesis, the concept of enhancing the documented record for design meetings was introduced. This stemmed from the realisation that traditional meeting documentary practices such as minutes do not provide a completely accurate record of the activity with much of the contextual information being lost. As discussed in section 4.6.2.2 and expanded upon further in Section 5.2, through the application of a structured process the engineering design meeting has the potential to aid the documenter to record an 'enhanced' record through the categorisation of information into specific categories; *Exploration* – information relating to or influencing the decision making process, *Decision* – the agreed summation of the discussion point resulting in further action, or *Action* – the agreed steps necessary to progress a decision. Further, the exploratory study (Section

4.6.2.2) demonstrated that the codification of supporting information objects using a simple colour coded Post-It® note technique has the potential to record more of the elusive contextual information. For example, where a decision was made based upon a drawing or image, not only would the decision be recorded but also the supporting object used to make the decision recorded using the relevant Post-It®, building upon the principle of object views as discussed previously in 5.3.1.4. The concept of codifying the information objects using contextual data is not a new approach to activity documentation, and previous work presented by authors such as Huet (2006), Conklin (2006) and Bracewell et al. (2004), Lalanne, et al. (2005) and Hauptmann, et al. (2001) employ similar techniques. However, it was recognised that this codification, coupled with the three key elements of information (decisions, actions and exploration), would provide a richer history of information on the decisions relating to both product and also the process information and as it was being generated. This is in contrast to retrospective analysis, which techniques proposed by Lalanne, et al. (2005) and Hauptmann, et al. (2001) employ. As described in Section 4.6.2.2, the identification of these key pieces of information and the codification techniques piloted throughout the study led to the development of an enhanced method of minute taking.

With requirements for the system architecture defined (Section 5.3.1) and the architecture itself structured (Section 5.3.2) a conceptual solution was explored further. As defined in the requirements, the solution should possess the ability to quickly and unobtrusively create richer representations of activities by displaying and organising the information objects recorded and also presented during the episode. This led to the design of a conceptual software based system which, using pre-defined structure templates and drag and drop file upload facilities, has the ability to record not only the decisions and actions specified during meetings, but also document the rationale and exploration which in effect led to the decisions and actions being taken.

The envisaged tool itself was in the form of computational web-based software interface linked to a storage repository, following the design of the system architecture described in Section 5.3.2 and presented in Figure 5.9. In essence this created two fundamental workspaces; the *engineering* workspace in which the team are physically located and performing the design activities and the *documentary* workspace in which the record of activities are documented using the software tool. As demonstrated in Figure 5.10 the interaction between the different workspaces would be facilitated using the software interface, with information objects being documented and reviewed through the use of a database repository, software interface and data convertors. As shown in figure 5.10, using the input stream (highlighted in red), information objects are uploaded to the documentary space through the software interface. These information objects are then converted into raw xml data format for storage in the system database. For retrieval and viewing of the data, the inverse of the process occurs (shown as the output stream). The user interface is used to request xml data from the database repository and which is converted into the correct format for display to the user.

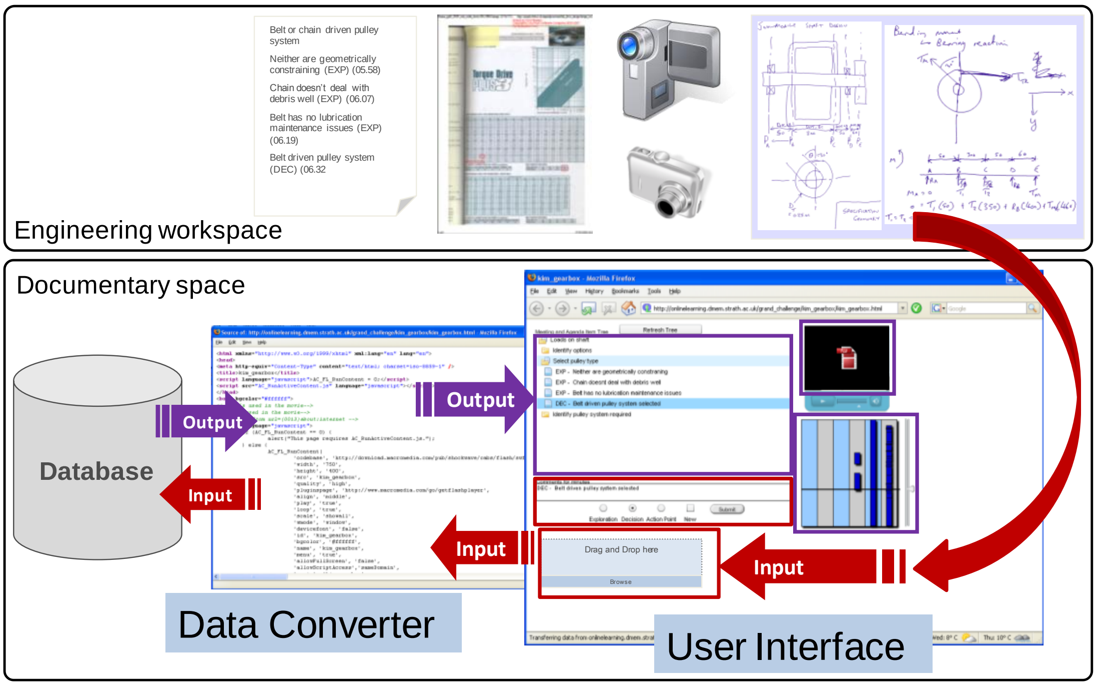


Figure 5.10 Interaction between Engineering and Documentary Workspaces

This structure enables the system to display the data objects in individual *'data streams'* customisable to the specific user's requirements, enabling multiple object views as proposed in Section 5.3.1.4. As shown in Figure 5.11, the conceptual design allows the display of the agenda and metadata for the meeting (time, date, attendees) and presents a *'live view'* of the meeting against the timeline, highlighting in the various streams, the data objects and notes recorded during the meeting. Post-meeting, media streams such as video and audio can be incorporated into the system and synchronised using the meeting timeline. These additional data streams, which are also displayed against the agenda points, are accessible and allow the user to revisit any part of the meeting record and view the data objects corresponding to a specific instance or occurrence during the meeting (Figure 5.12).

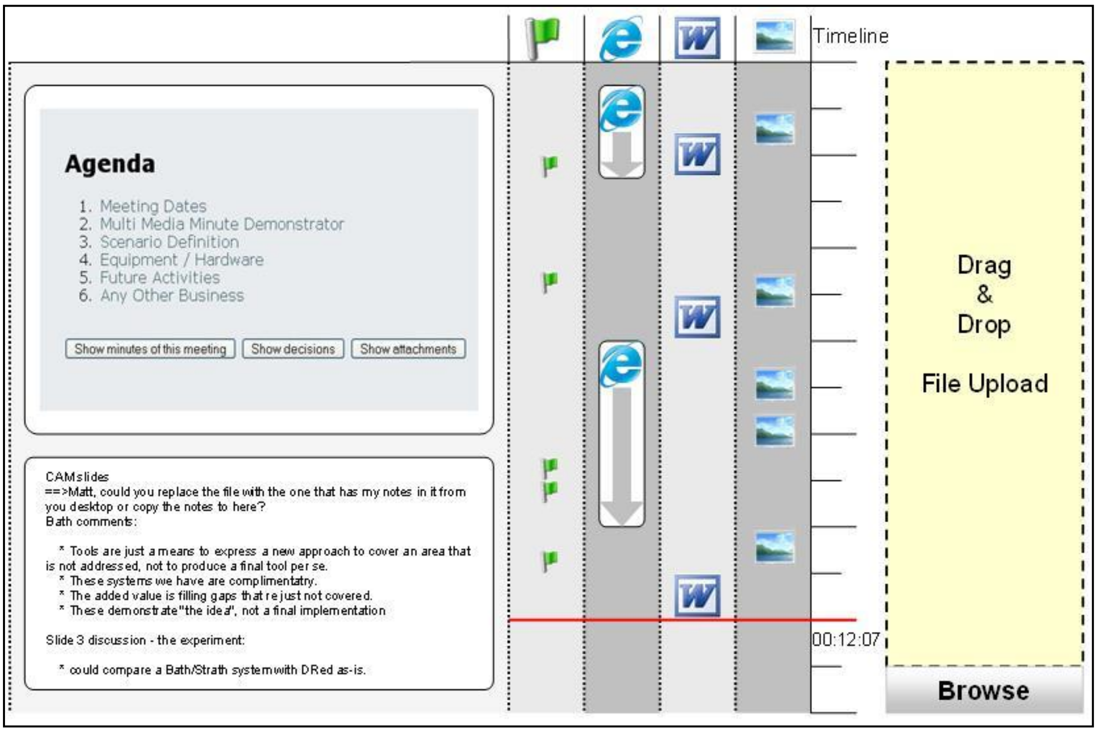


Figure 5.11 Conceptual System's 'Live' Meeting Display

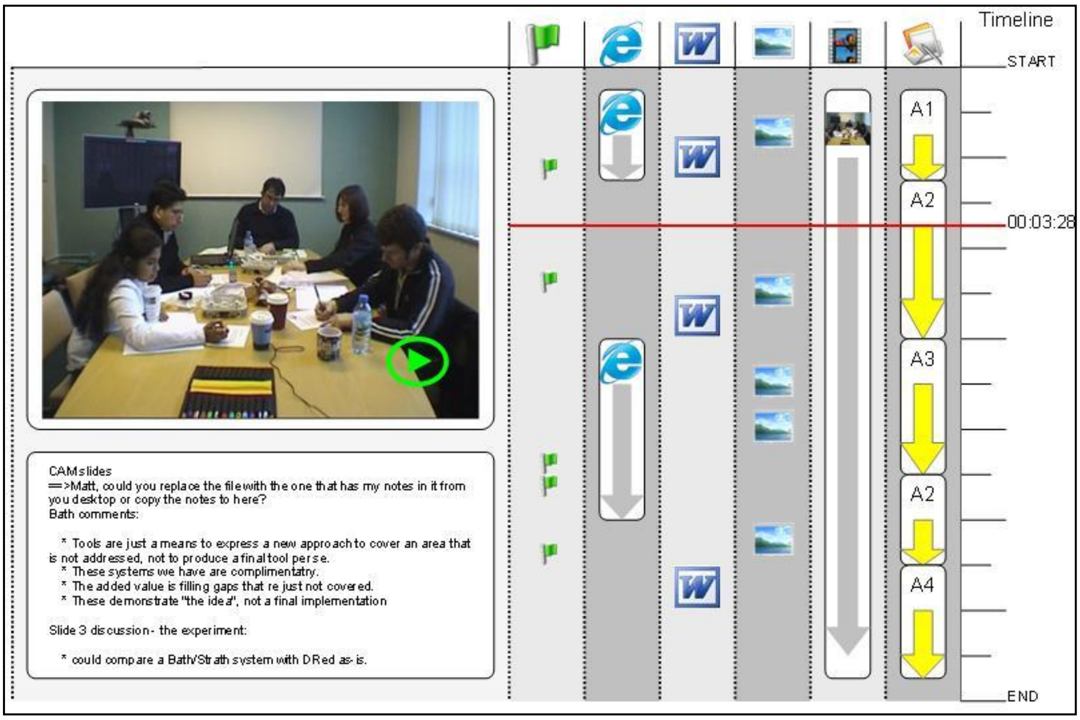


Figure 5.12 Conceptual System's 'Post Meeting' Display

5.3.4 *Knowledge Enhanced Notes Demonstrator*

The conceptual systems and the underlying architecture described thus far have been designed with the express purpose of enhancing the documentation activities of engineering episodes. In order to validate and demonstrate the potential of the architecture, it was necessary to create a system demonstrator based upon the design and requirements. To this end the development of a prototype software tool was commissioned based upon the requirements, concepts and architecture proposed in Sections 5.3.1 through 5.3.3. The following sections chart the development of the Knowledge Enhanced Notes (KEN) demonstrator tool.

5.3.4.1 Commissioning and development process

With a conceptual design for the software system created, requirements derived from the literature and exploratory studies, and the creation of an underlying architecture upon which the concepts were based, the author sought assistance in developing a software tool which could be used to validate and evaluate the proposed models. Owing to the researcher's lack of experience and ability in software development, a software developer from the department of DMEM at the University of Strathclyde was enlisted to help with the development activities.

The developer was provided with the specifications and conceptual sketches (figures 5.10 and 5.11) along with the underlying architecture (figure 5.9) and the feasibility of the design of such a system discussed. As the system required the development of database and web server, the coding of the KEN system was done on the Linux based Ubuntu operating system, allowing more flexibility in developing the functionality of the system due to its open source nature under the GNU public license.

The author worked with the software developer in generating a number of iterations of the demonstrator until the required functionality and appearance was present in the software. The outcome from this process was the development of the Knowledge Enhanced Notes (KEN) demonstrator software tool as presented in Figure 5.13.

5.3.4.2 KEN Software description

The KEN tool itself is web-based software linked to a repository, designed to allow the user to easily and rapidly create a record of the meeting in real time as opposed to creating digital or paper-based minutes retrospectively (Conway, Ion et al. 2009). Essentially the software has a three layered structure, an underlying relational database, hypertext pre-processor (PHP) scripts to interrogate the database and a Flash™ based user interface (UI) (Figure 5.13) to input, retrieve and display objects using the PHP scripts as the data translator.

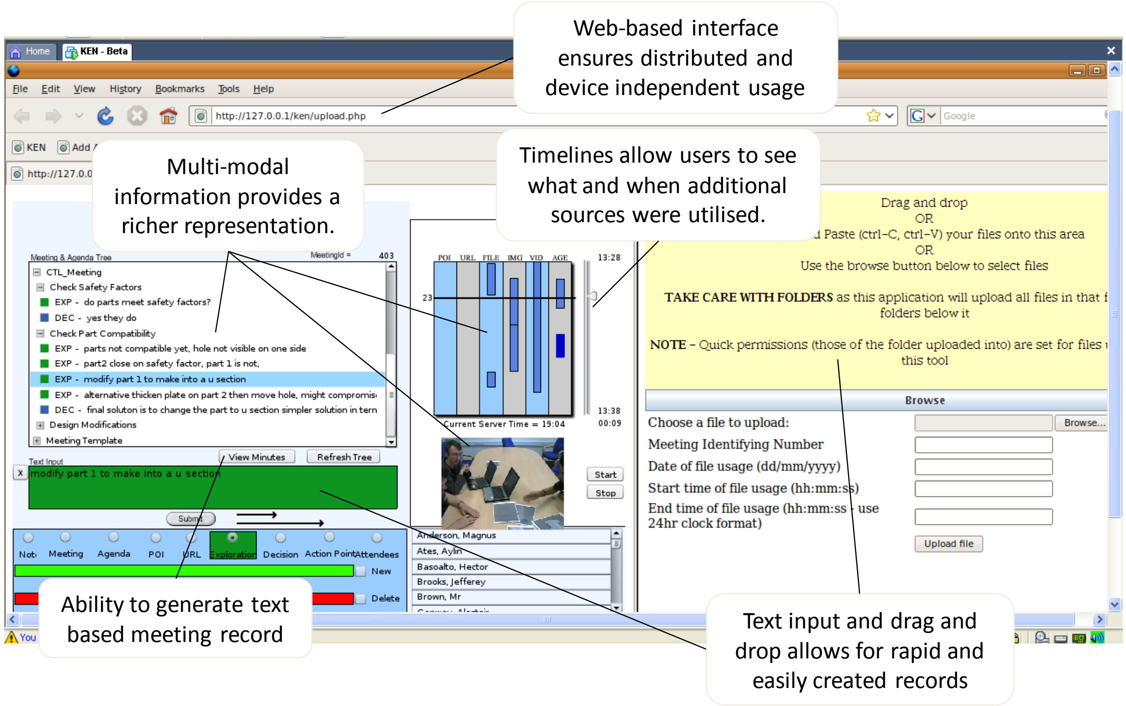


Figure 5.13 KEN software user interface

Data objects such as images, video, audio and documents are uploaded to the database using a Flash-based 'drag and drop' upload form (Figure 5.13) and metadata such as time, date, meeting identifier, agenda item etc. automatically associated with the data, relative to the specific point in the meeting at which upload occurs. The PHP scripts convert the object URLs into xml format, allowing the UI to display the data object links as data 'blocks' on the meeting timeline. This approach allows users to quickly and easily visualise what objects were presented or used at any given point in the meeting and, as the blocks are directly linked to the relational database, users can simply click on the block within the timeline and the relative data file is returned. The KEN interface also possesses the ability to display the data objects in individual data streams with the potential to be fully customisable to specific user's requirements. By way of example, the prototype KEN system shown in Figure 5.13 was configured to display six individual data streams:

1) Agenda Item

2) Video (.flv format),

3) Images (jpeg format),

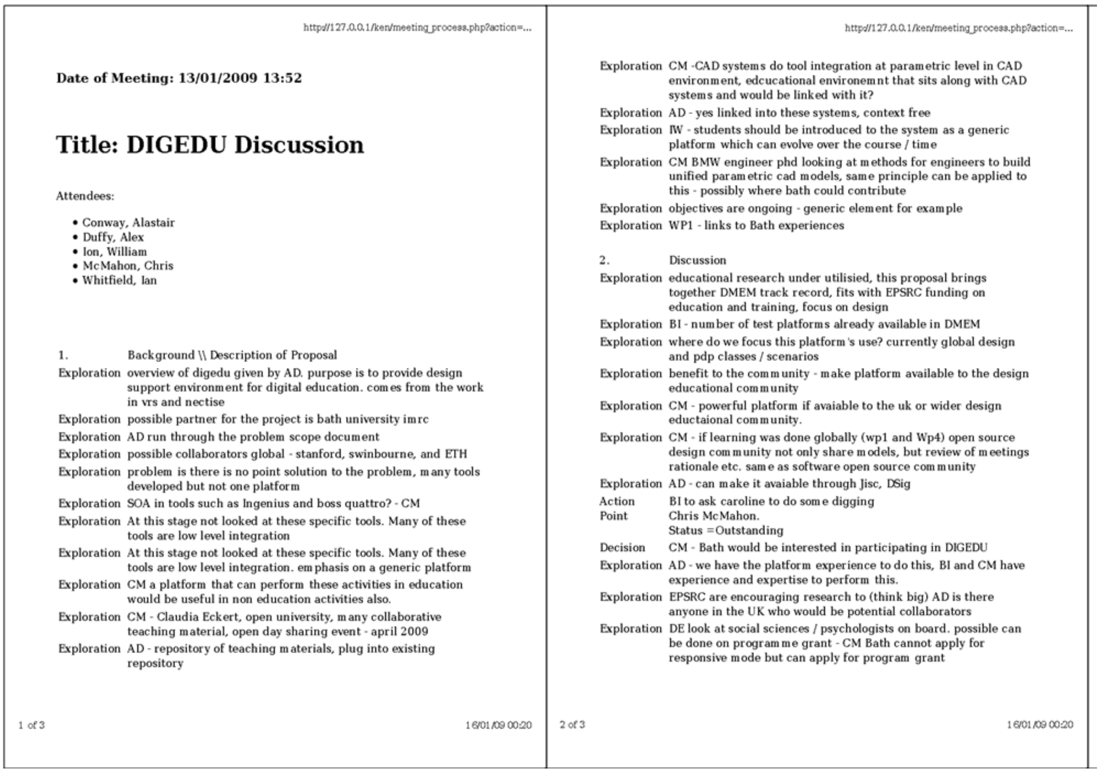
4) File (slides, text documents, CAD drawings etc.)

5) Urls (direct links to webpages)

6) POI (points of interest, e.g. user identified key discussion points)

Throughout the meeting, KEN displays the currently active agenda item and metadata for the meeting (time, date, attendees) and the use of the dynamic database and PHP scripts allows a real-time view of the meeting to be viewed against time. As the KEN software is web-based, users do not need to install software on dedicated machines thus access to all meeting data stored in the repository can be gained through connecting through a web-enabled device.

In addition, functionality was developed which allows the user to create an entirely shareable textual record of the meeting based upon a generic meeting minute template (Figure 5.14). At any point during the meeting or post meeting, the user has the ability to create and view the current meeting record in a ‘standard minute’ based format. Upon the user selecting the ‘View Minutes’ function in the KEN UI (Figure 5.13), the system automatically populates a predefined template document with all recorded data within the database relative to the current meeting. This record displays all the exploration, decision and action points recorded throughout the meeting incorporating metadata such as meeting title, time, date, attendees and agenda points, in effect, replicating a traditional text based meeting record with no additional effort or post processing required by the user.



http://127.0.0.1/ken/meeting_process.php?action=...

Date of Meeting: 13/01/2009 13:52

Title: DIGEDU Discussion

Attendees:

- Conway, Alastair
- Duffy, Alex
- Ion, William
- McMahon, Chris
- Whitfield, Ian

1.	Background \\ Description of Proposal
Exploration	overview of digedu given by AD. purpose is to provide design support environment for digital education. comes from the work in vrs and nectise
Exploration	possible partner for the project is bath university imrc
Exploration	AD run through the problem scope document
Exploration	possible collaborators global - stanford, swinbourne, and ETH
Exploration	problem is there is no point solution to the problem, many tools developed but not one platform
Exploration	SOA in tools such as Ingenius and boss quattro? - CM
Exploration	At this stage not looked at these specific tools. Many of these tools are low level integration
Exploration	At this stage not looked at these specific tools. Many of these tools are low level integration. emphasis on a generic platform
Exploration	CM a platform that can perform these activities in education would be useful in non education activities also.
Exploration	CM - Claudia Eckert, open university, many collaborative teaching material, open day sharing event - april 2009
Exploration	AD - repository of teaching materials, plug into existing repository

1 of 3 16/01/09 00:20

http://127.0.0.1/ken/meeting_process.php?action=...

Exploration	CM -CAD systems do tool integration at parametric level in CAD environment, edcucational environemnt that sits along with CAD systems and would be linked with it?
Exploration	AD - yes linked into these systems, context free
Exploration	IW - students should be introduced to the system as a generic platform which can evolve over the course / time
Exploration	CM BMW engineer phd looking at methods for engineers to build unified parametric cad models, same principle can be applied to this - possibly where bath could contribute
Exploration	objectives are ongoing - generic element for example
Exploration	WP1 - links to Bath experiences
2.	Discussion
Exploration	educational research under utilisied, this proposal brings together DMEM track record, fits with EPSRC funding on education and training, focus on design
Exploration	BI - number of test platforms already available in DMEM
Exploration	where do we focus this platform's use? currently global design and pdp classes / scenarios
Exploration	benefit to the community - make platform available to the design educational community
Exploration	CM - powerful platform if avaiable to the uk or wider design eductaional community.
Exploration	CM - if learning was done globally (wp1 and Wp4) open source design community not only share models, but review of meetings rationale etc. same as software open source community
Exploration	AD - can make it avaiable through Jisc, DSig
Action Point	BI to ask caroline to do some digging Chris McMahon. Status =Outstanding
Decision	CM - Bath would be interested in participating in DIGEDU
Exploration	AD - we have the platform experience to do this, BI and CM have experience and expertise to perform this.
Exploration	EPSRC are encouraging research to (think big) AD is there anyone in the UK who would be potential collaborators
Exploration	DE look at social sciences / psychologists on board. possible can be done on programme grant - CM Bath cannot apply for responsive mode but can apply for program grant

2 of 3 16/01/09 00:20

Figure 5.14 'Traditional' minutes from KEN

5.3.4.3 Development summary

The KEN demonstrator possesses the ability to quickly and unobtrusively create richer representations of meetings by displaying and organising multi-media generated during the meeting. Using pre-defined meeting structure templates, based upon the meeting process model proposed in Section 5.2 and drag and drop file upload facilities, the user has the ability to record not only the decisions and actions specified during meetings but also to document the exploration activities which led to the decisions and actions being taken.

Building upon the concept of creating object views (Section 5.3.1.4) the KEN demonstrator software utilises timelines to create a recognisable structure for users to follow the information flow. The metadata which can be extracted automatically from various elements of multimodal information such as audio, video, word processor documents and images provide the system with a defined and easily traceable structure which can be displayed to participants via the user interface.

In addition, the ability to upload and view media such as video and audio associated with the meeting at a later date enhances the overall record of the meeting and draws on the principle employed by systems focused on post-processing where the key factor is that a complete and accurate record of the meeting can be captured using video and audio.

The KEN system differs from previous work as it tries to bridge the gap between current live capture and post processing systems by utilising a combination of both principles. The users have the ability to see what is being utilised in the meeting and review the minutes and actions at any given point during the activity. The use of timelines allows an easily recognisable structure to be developed for the meeting, drawing from the principle of IBIS and the work done by Buckingham-Shum (2006),) Conklin (2003, 2006) and Bracewell et al. (2004, 2007) to name but a few. The ability to view all media associated with the meeting at a later date enhances the overall record of the meeting and draws on the principle employed by systems such as Informedia and the Ferret browser whose key selling point is that a richer representation of meeting activities can be achieved by incorporating video and audio.

The key goal of the KEN development is to enhance the record of activities and decisions made collaboratively and in synchronous situations to allow them to be revisited at latter stages in the design process, whilst also supporting the need to document real-time synchronous activities. The aim of this demonstrator system was to showcase the potential of the underlying architecture by providing an enhanced record of activities and decisions made collaboratively and in social situations, and allow them to be revisited at later stages in the design process without creating additional work for the participants.

5.4 *Synchronous Knowledge and Information Capture (SKIC) Framework*

Sections 5.1, 5.2 and 5.3, coupled with the literature and exploratory studies undertaken within this thesis have identified three key areas of synchronous working where improvements can be made; the organisational structure of such activities, the process undertaken throughout and the mechanisms put in place to accurately document and capture the information and knowledge as it is generated. The derived premise from this work is that an organisation adopting all or any of the three models within their synchronous design activities would be best placed to provide enhanced information and knowledge capture, generating more accurate and therefore usable records of the design process throughout the engineering product lifecycle. However, although each of the three models has presented an individual case for adoption, for an organisation to achieve the most benefit it must integrate the three models within its core working practices, thus a framework is required. The requirement for the development of a synchronous knowledge and information capture framework replicates the fourth and final research question:

4. *Can a framework model be developed to enhance the practice of documenting design knowledge and information at the point of generation?*

The answer to this question is fundamental to establishing the contribution to knowledge of this research, and also in meeting the final objective O-4 '*Utilise appropriate methods or modelling techniques to satisfy the information and knowledge needs of engineering design practitioners.'* Only if the solution can be proven to enhance the practice of knowledge and information capture will the overall aim of the research be achieved.

A framework, in the context of this research is defined as a set of rules, models or ideas used to deal with problems or to provide a course of action. Building upon this definition, the three models proposed so far must integrate to create a framework which organisations can adopt to achieve best practice in knowledge and information capture within synchronous engineering design activities. With the individual elements modelled (organisation and process perspectives) and an information capture architecture proposed, these elements combine to form the Synchronous Knowledge and Information Capture (SKIC) framework as presented in Figure 5.15.

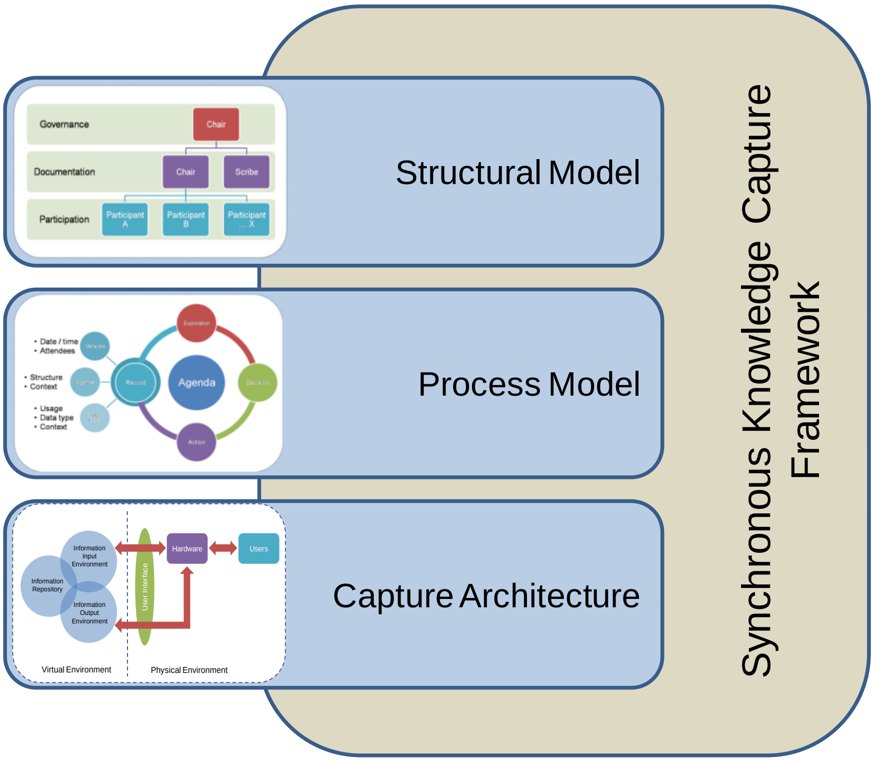


Figure 5.15 Synchronous Knowledge and Information Capture Framework

As established from the literature (Section 4.4.1) synchronous activities such as meetings are significant activities undertaken *throughout* the various stages of the engineering design process. Essentially meetings are critical elements of the design process and specific instances where much of the information and knowledge (both product and process) is generated. Therefore it becomes clear that to extract maximum benefit, the SKIC framework should be applied at each stage of the design process where synchronous activities such as meetings occur (Figure 5.16).

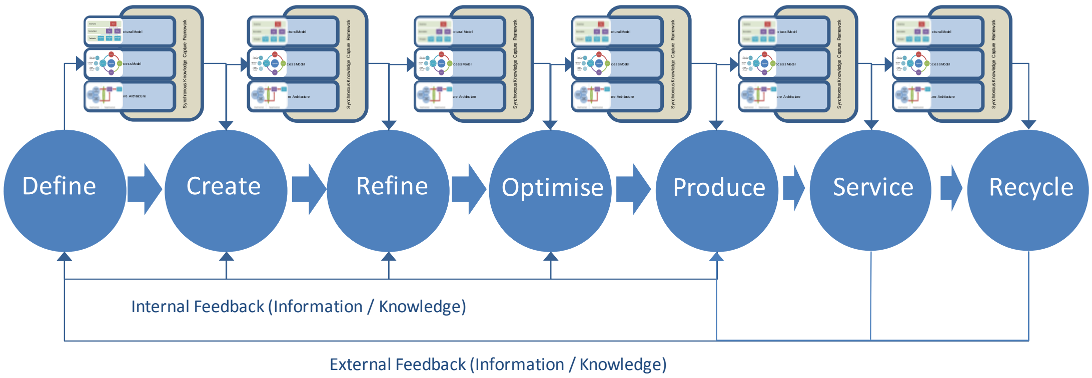


Figure 5.16 SKIC Framework as part of the engineering design process

From this model (Figure 5.16) it is possible to reason that the framework will have a positive impact upon the information knowledge feedback loops, both at the internal and external level. The structuring of the information through the application of the process model will help provide consistent and recognisable structure to the documented record. Adoption of the organisational models of formality will help a business to organise and develop its knowledge and information best practice regardless of the formality level of the situation and level of occurrence. Finally, the implementation of a capture tool based upon a proven system architecture will ensure that organisations are in the best possible position to leverage key benefits from the knowledge and information generated throughout the engineering design process.

5.5 *Chapter summary*

This chapter summarises the key learnings from the research and translate these into a specification and architecture which allows for the potential development of an effective synchronous knowledge and information capture framework. For this thesis, this has manifested in the development of a novel Synchronous Knowledge and Information Capture framework. With the focus of the synchronous activities placed on engineering design meetings, building upon the established literature and earlier exploratory work, three novel individual models were proposed: an *organisational model* used to define the level of formality of the meeting; a *process model* proposing a method of structuring and conducting a meeting; and an *information capture system architecture* designed to enhance the documentation of the episode. The proposition at this juncture in the research is that if deployed individually, the *organisational model* and the *process model* will provide added structure to the way an organisation undertakes their knowledge and information capture activities within engineering design meetings, thus making it easier for them to capture these activities. However, when combined with the proposed *information capture system architecture* the resulting Synchronous Knowledge and Information Capture (SKIC) Framework provides the mechanisms to create an overall *enhanced* record of design activities through facilitating the capture of the information and knowledge as it is generated, and through the ability to document much of the context laden information not presently found within traditional documentary practices.

Ultimately the application of the proposed SKIC framework to synchronous design activities has the potential to provide a better understanding of the product and process decisions made throughout the lifecycle of the product. However, in order to prove this theory and ultimately answer the fourth and final research question *“Can a framework model be developed to enhance the practice of documenting design knowledge and information at the point of generation?”* evaluation and validation of the framework and individual models within experimental studies must be undertaken.

Chapter 6: Evaluation and Validation

The fourth chapter of this thesis looked at identifying design activities where information and knowledge loss was prevalent and in doing so proposed the fourth research question:

4. *Can a framework model be developed to enhance the practice of documenting design knowledge and information at the point of generation?*

The development work of the Synchronous Knowledge and Information Capture (SKIC) framework presented throughout chapter 5 has begun to answer this question; however, to provide a definitive answer, validation and evaluation of the framework must take place.

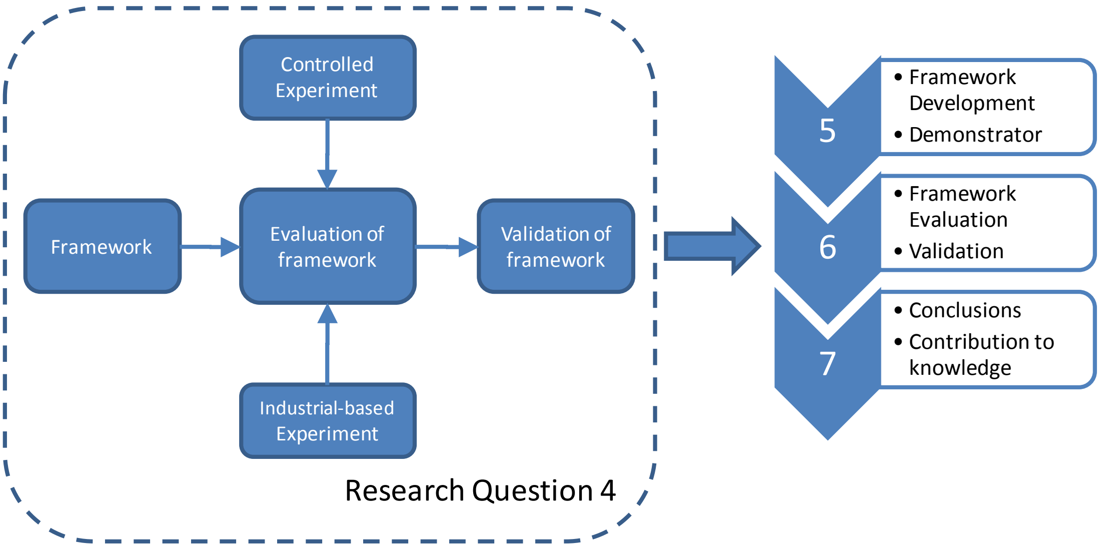


Figure 6.1 Structure of Chapter 6

As illustrated in figure 6.1 above, this chapter charts the undertaking of a series of experiments designed to demonstrate and validate the potential of the SKIC framework. The experiments were designed to assess the framework with respect to its application within multiple formalities of engineering design meetings (evaluating the effect of different *organisational models*) and the effectiveness of the *system architecture* in providing an accurate representation of the activities. In addition, the *process model* proposed in Section 5.2 was utilised to help structure the documentation of the meeting activities.

6.1.1 *Methodology*

The techniques and methods adopted to conduct the evaluation and validation activities were based upon a combination of experimental based research as discussed in Section 2.3 and a meeting evaluation framework proposed by Post, Mirjam et al (2008). Experiments provide researchers with a unique opportunity to perform analysis of models, frameworks or tools within a defined context whilst experiencing relevant *'real-life'* events or conditions and their relationships in the context under study (Yin 2009) and the adoption of methods such as Post et al's framework help identify the necessary variables and metrics required.

6.1.1.1 Evaluation variables

Within their "Evaluating meeting support tools" publication, Post, Mirjam et al (2008) propose a framework for studying meeting behaviour (Figure 6.2). Within this framework, Post et al. identify three key variables when analysing meetings: *input* variables, *process* variables and *outcome* variables.

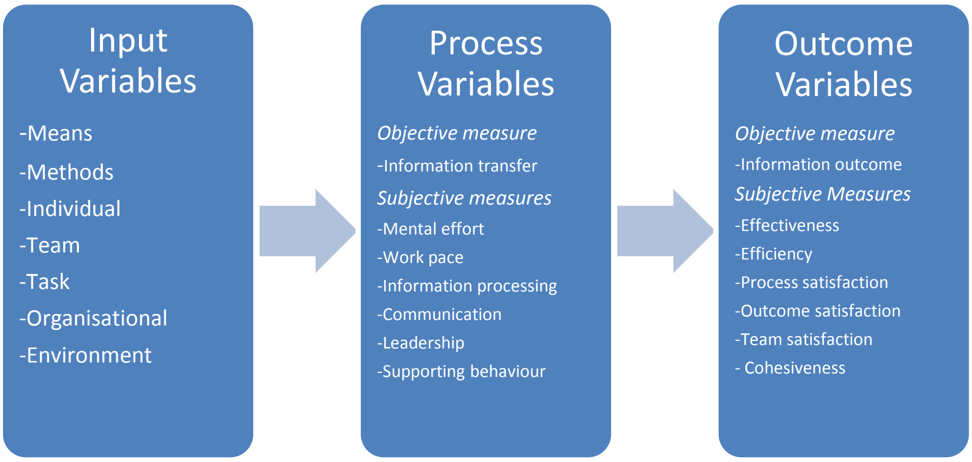


Figure 6.2 Meeting behaviour framework (Post, Mirjam et al. 2008)

6.1.1.1.1 ***Input variables***

The *input* variables refer to systems and tools that support the undertaking of the meeting, methods for undertaking particular tasks (e.g. meeting protocols) and organisational factors such as team structure and meeting environment (Post, Mirjam et al. 2008). For this series of evaluation and validation studies, a number of input variables were defined.

As discussed throughout Sections 4.4.1.1 and 5.1, different organisational structures and formality levels can have an affect on meeting activities, both in the effectiveness of the activity measured against the agenda and also in producing a record of activities. Thus to measure the effectiveness of the proposed SKIC framework, multiple formality levels (1-5) were adopted throughout the sessions. This would in effect allow the researcher to evaluate the effectiveness of the information capture approaches when utilised within the different levels of formality and structure.

In addition to the formality levels, a second input variable introduced for the studies was the use of multiple documentation approaches. For the purposes of validation and evaluation, the information capture and storage architecture was evaluated through the use of the KEN demonstrator system as the prime meeting documentation mechanism within the experiments, with traditional paper-based records and video ethnography techniques employed (where possible) to provide a basis for comparison. The design episodes were documented using a digital video camera to monitor the face-to-face interactions between the group and also the utilisation of information objects during the course of the meeting. The use of video ethnography techniques allowed accurate monitoring of the episode whilst remaining unobtrusive and removed from the ongoing work process. The audio from the meetings was transcribed and a modified version of the Transcript Coding Scheme (TCS) applied as in the exploratory study described in Section 4.6. The basic structure of the TCS was left unmodified. However, the transcript codification categories were modified to enable the identification of three of the four generic meeting activities identified in Section 5.2; that of *exploration*, *decision* and *action*, with the fourth activity being the documentation itself. The modified Transcript coding scheme can be found within Appendix C. The codification of these meeting activities allowed for direct comparisons to be made on the quantity of decisions and actions recorded using the KEN system as compared to the traditional documentary techniques.

6.1.1.1.2 *Process variables*

Process variables are seen as measures of performance and Post et al (2008) propose the measurement of these using an *objective* measure - information transfer and *subjective* measures – mental effort, information processing, etc. as shown in Figure 6.2. For this series of validation studies, Post et al's *objective* measure (information transfer) was adopted. To calculate the information transfer (It), Post et al. record the number of information objects that the individual participants utilise during their decision making process, then, the total number of information objects utilised during the episode (Iu) divided by the total number of *transferable* information objects provided to the participants (Ip), multiplied by 100 represents the percentage of correctly transferred information per documented activity (Post, Mirjam et al. 2008). This can be expressed using the formula below:

$$It = \left(\frac{Iu}{Ip}\right) \times 100$$

As described above, Post et al define a number of subjective measures as part of their process variables. However as this series of studies focused on evaluating and validating the effectiveness of the SKIC framework in terms of the information captured, subjective measures such as 'ease of use' or 'speed of capture' were not deemed necessary and therefore not incorporated into the analysis.

6.1.1.1.3 *Outcome variables*

The third and final set of variables is *outcome* variables. These are referred to as measures of effectiveness used to assess the overall quantity and quality of the end result (Post, Mirjam et al. 2008). For this series of studies, the overall evaluation of the framework was undertaken to evaluate how effective the proposed SKIC is at creating richer representations of synchronous design episodes. This was measured by first calculating the accuracy (%) of the *decisions* captured (Dc) in comparison to the transcript (Datum) expressed as a percentage (Da):

$$Da = \left(\frac{Dc}{Datum}\right) \times 100$$

A similar formula was then used to calculate the accuracy (%) of the *actions* captured (Ac) in comparison to the transcript (Datum) expressed as a percentage (Aa) as is presented below:

$$Aa = \left(\frac{Ac}{Datum}\right) \times 100$$

This allowed the overall accuracy of the information capture to be calculated using the following formulae:

$$Ia = \left(\frac{(\mathrm{Da} + \mathrm{Aa} + \mathrm{It})}{300}\right) \times 100$$

That is, the overall accuracy (Ia) of the system in terms of capturing information can be determined by calculating the sum of the accuracy of decisions (Da) captured (%), the accuracy of actions (Aa) captured (%) and the percentage of information transfer (It); divided by the sum of maximum percentages (300), multiplied by 100 (to express as a percentage). By way of example, the information accuracy for Session 2 of the controlled experiments (84%) was calculated as follows:

$$Da = \left(\frac{24}{28}\right) \times 100 = 86$$

$$Aa = \left(\frac{2}{3}\right) \times 100 = 67$$

$$Ia = \left(\frac{(86 + 67 + 100)}{300}\right) \times 100 = 84$$

The use of the formulae above allows the effectiveness of the overall framework to be determined through quantitative analysis of the accuracy of the information capture in comparison to the transcripts of the meeting and also traditional documentary practices

6.1.2 *Controlled Experiments – Design of a Wine Cooler*

The first series of experiments were undertaken by a group of five engineering design students studying product design engineering at masters' level. The experiments were designed to replicate the process of undertaking the design of a consumer product (a wine cooler) during defined design episodes. The same group of participants were used in each episode to ensure consistency in the design outputs and documentation activities. The task given to the design team was to develop the design from concept through to final design. The team was instructed to assume that market research and analysis had been conducted prior to the meeting and a design brief and design specification was provided as part of the initial task clarification (Appendix C). In total six episodes were undertaken over a period of two weeks by the group as described in Table 6.1.

Table 6.1 Experimental activities undertaken

Design Episode	Activity Description	Duration (mins)	Formality Level
Task clarification	This session will encompass the introduction to the design task and the initial idea generation. The team will meet with the "client" where they will be presented with the design brief and also an outline design specification. This is the opportunity for the team to clarify the task and begin the process of assigning tasks and discussing initial ideas.	60	3
Brainstorming and concept development	The aim of this session is for the team to generate ideas and conceptual solutions to the problem.	120 (approx)	2
Conceptual design evaluation and selection	This session will allow the team to present their conceptual ideas to each other and the client. The aim of the session will be to evaluate the designs and select which of the concepts the team will concentrate on.	60	4
Embodiment design development	This development session will focus on developing the conceptual design into more detailed solutions.	120 (approx)	1
Embodiment design review and selection	During this session the teams will present a range of detailed and embodiment designs for the chosen concept. The aim of the session will be for the team and the client to evaluate the designs and select which of the designs the team will take to the final design stage.	60	4
Final design review	This session will focus on the design team presenting their final design to the client.	60	5

For all episodes within this series, video and audio recordings were made and the Transcript Coding Scheme utilised. The use of transcription ensured that a completely accurate record of the meeting was available; forming the data against which the KEN and paper-based documentation's accuracy could be measured. This methodology allowed analysis and evaluation to be performed at two levels:

1. The KEN tool was analysed and evaluated in terms of accuracy of information capture and retention (through measurement of the number of decision, actions and information transfer in comparison with both the paper based minutes and the transcript)

2. The KEN tool was evaluated in terms of applicability to multiple formality levels, (through the accuracy of information capture at each formality level) thus also evaluating the theoretical applicability of the SKIC architecture.

6.1.2.1Analysis and Evaluation: Decisions, Actions and Information Transfer

The results from this series of experiments (presented in Tables 6.2, 6.3 and 6.4) highlight the effectiveness of the KEN demonstrator system when directly compared to traditional paper based meeting minutes. As summarised in Tables 6.2 and 6.3 respectively, over the six episodes undertaken, the KEN system accurately documented a total of **58%** of the decisions and **63%** of the actions recorded through complete transcription, compared to the minutes which accurately documented **23%** of the decisions and **38%** of the actions. This manifests itself as a **35% increase** in the number of decisions recorded and a **25% increase** in the number of actions recorded, indicating a significant gain in the accuracy of the record through the adoption of the KEN tool. In terms of documenting the information objects used, the KEN system recorded an information transfer rate of **100%** whilst the paper based minutes did not document the information objects utilised (**0%**) (Table 6.4).

A meeting data set consisting of; the project brief, product design specification, brainstorming, conceptual sketches, full codified transcript, text based KEN record and meeting minutes from one of the sessions has been included as Appendix C. For reasons of brevity, the remaining data sets are available for analysis upon request.

Table 6.2 Wine Cooler Experiment: Summary of Decisions Recorded

	Formality	Transcript (DATUM)	Minutes (Paper based)		Knowledge Enhanced Notes	
Episode	(1 - 5)	Documented	Documented	Accuracy (%)	Documented	Accuracy (%)
Session 1	3	16	7	44	15	94
Session 2	2	28	3	11	24	86
Session 3	4	19	7	37	8	42
Session 4	1	12	0	0	2	17
Session 5	4	32	5	16	12	38
Session 6	5	3	3	100	3	100
	Total	**110**	**25**	**23**	**64**	**58**

Table 6.3 Wine cooler Experiment: Summary of Actions Recorded

	Formality	Transcript (DATUM)	Minutes (Paper based)		Knowledge Enhanced Notes	
Episode	(1 - 5)	Documented	Documented	Accuracy (%)	Documented	Accuracy (%)
Session 1	3	5	1	20	5	100
Session 2	2	3	0	0	2	67
Session 3	4	3	3	100	2	67
Session 4	1	3	0	0	3	100
Session 5	4	10	5	50	3	30
Session 6	5	0	0	0	0	0
	Total	**24**	**9**	**38**	**15**	**63**

Table 6.4 Wine Cooler Experiment results

			Information Objects										
			MS Office Documents			Media			Files		Quantity		
Episode	Decisions	Actions	Word	Excel	PowerPoint	Audio	Video	Image	PDF	Other	Total	Possible	Transfer (%)
Session 1 - Task Clarification													
Meeting minutes (paper)	7	1	0	0	0	0	0	0	0	0	0	3	0
KEN Record	15	5	2	0	1	0	0	0	0	0	3	3	100
Transcript	16	5	2	0	1	0	0	0	0	0	3	3	100
Session 2 - Brainstorming and Concept Generation													
Meeting minutes (paper)	3	0	0	0	0	0	0	0	0	0	0	2	0
KEN Record	24	2	0	0	0	0	0	2	0	0	2	2	100
Transcript	28	3	0	0	0	0	0	2	0	0	2	2	100
Session 3 - Concept Evaluation and Selection													
Meeting minutes (paper)	7	3	0	0	0	0	0	0	0	0	0	2	0
KEN Record	8	2	0	0	0	0	0	2	0	0	2	2	100
Transcript	19	3	0	0	0	0	0	2	0	0	2	2	100
Session 4 - Embodiment Design Development													
Meeting minutes (paper)	-	-	0	0	0	0	0	0	0	0	0	5	0
KEN Record	2	3	0	0	0	0	0	5	0	0	5	5	100
Transcript	12	3	0	0	0	0	0	5	0	0	5	5	100
Session 5 - Embodiment Evaluation and Selection													
Meeting minutes (paper)	5	5	0	0	0	0	0	0	0	0	0	5	0
KEN Record	12	3	0	0	0	0	0	5	0	0	5	5	100
Transcript	32	10	0	0	0	0	0	5	0	0	5	5	100
Session 6 - Final Design Review													
Meeting minutes (paper)	3	0	0	0	0	0	0	0	0	0	0	1	0
KEN Record	3	0	0	0	0	0	0	1	0	0	1	1	100
Transcript	3	0	0	0	0	0	0	1	0	0	1	1	100

6.1.2.2Analysis and Evaluation: Formality Levels

Through establishing the effectiveness of the KEN tool, it was also possible to analyse the applicability of the SKIC framework within multiple formality levels. This analysis was geared towards understanding if the framework and associated models (meeting process, organisational and capture) were applicable at all formality levels of synchronous episodes, as defined in Section 5.1. To measure this, the accuracy of information capture at each formality level was examined to identify any significant discrepancies between the five different levels.

Table 6.5 Information accuracy within multiple formalities

	Minutes (paper based)				Knowledge Enhanced Notes			
Episode	Decisions (%)	Actions (%)	Information Transfer (%)	Accuracy (%)	Decisions (%)	Actions (%)	Information Transfer (%)	Accuracy (%)
Session 1	44	20	0	**21**	94	100	100	**98**
Session 2	11	0	0	**4**	86	67	100	**84**
Session 3	37	100	0	**46**	42	67	100	**70**
Session 4	0	0	0	**0**	17	100	100	**72**
Session 5	16	50	0	**22**	38	30	100	**56**
Session 6	100	0	0	**33**	100	0	100	**67**
Aggregate	*35*	*28*	*0*	***21***	*63*	*61*	*100*	***75***

Table 6.6 Effectiveness of the KEN tool within multiple formalities

		Accuracy (%)		
Episode	Formality	Minutes	KEN	Difference
Session 1	3	21	98	77
Session 2	2	4	84	80
Session 3	4	46	70	24
Session 4	1	0	72	72
Session 5	4	22	56	34
Session 6	5	33	67	34
			Aggregate	54

The results from this series of experiments were interesting. They do not provide conclusive evidence that the application of the SKIC framework is more effective at one specific level of formality than at others. However, what this data does indicate is that the application of the SKIC framework consistently provides a significant increase in accuracy (averaging 54%) and therefore a more efficient record of the design activities when compared with paper based techniques, regardless of the level of formality within which the synchronous activities occur. Overall it is possible to conclude from these results that the application of the SKIC framework has a positive effect on a design team's ability to generate more accurate, and therefore reusable, records of the synchronous design episodes.

6.1.2.3Analysis and Evaluation: Enhanced Knowledge & Information

With evaluation performed on the accuracy of the KEN demonstrator tool, it was also possible to identify specific examples of how the utilisation of multimodal information can provide users with greater knowledge and rationale of how decisions were reached.

By way of example, the meeting record for experimental episode 1 is shown in figure 6.3. As can be seen from the figure during the episode a decision was taken to design the product for use within a modern household kitchen environment (shown as A). The KEN tool allows the user to identify the time at which the decision was made (6 minutes into the meeting) and through viewing the meeting timeline (shown as B) provides the users with knowledge of the specific resources utilised in the decision making process (shown as C). In this example the file in question was the product design specification (included within appendix C, page 270) and the team were in the process of establishing the target demographic.

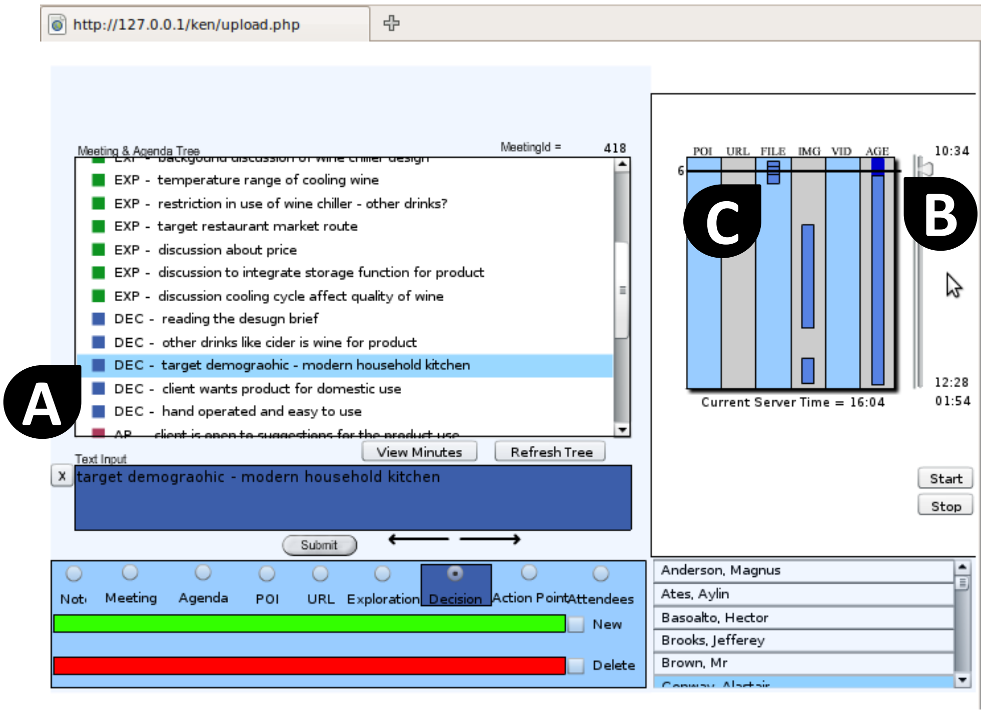


Figure 6.3 Experimental Episode 1 KEN record

To illustrate the benefits further, a second example is shown in figure 6.4. As before, during the meeting (experimental episode 2) exploration activities were undertaken around the functionality of the product being developed (shown as A). As in example 1, through the KEN user interface it is possible to identify the time the activities occurred (9 minutes into the meeting) through viewing the specific point at which the meeting timeline cuts across the multiple media channels (shown as B). This therefore provides the users with knowledge of the specific resources utilised in the decision making process (shown as C). In this example the image was of concept A (included within appendix C, page 281).

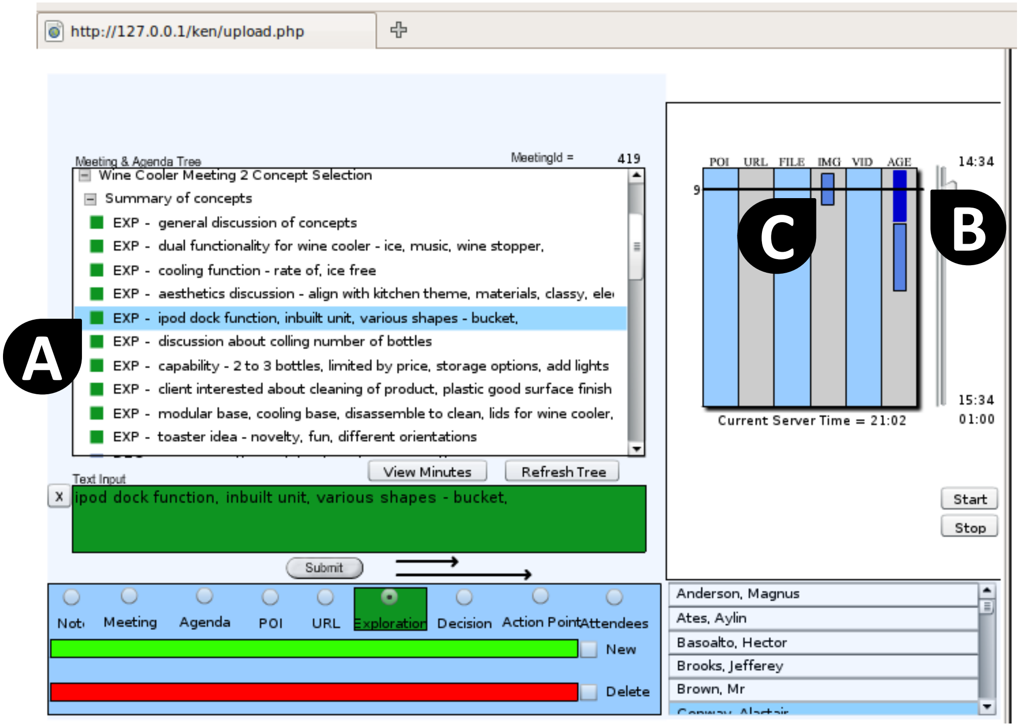


Figure 6.4 Experimental Episode 2 KEN record

These examples are symptomatic of all episodes undertaken within the series of experiments and serve to validate one of the key aims of the tool and indeed, the overall approach to information capture: through presenting an enhanced representation of the activity under study, more information, knowledge and rationale on the decisions and actions being taken can be recorded and subsequently interrogated.

6.1.2.4Participant Feedback

Although subjective measures such as those proposed by Post et al were not used for evaluation purposes, as part of the experimental activities, the participants were asked to provide general feedback on the experiments and in particular the use of the KEN tool. Table 6.7 below summarises the questions posed to the participants upon completion of the experimental project and the feedback received.

Table 6.7 Feedback received on experimental activities.

GROUP FEEDBACK	
Question	*Did using the KEN tool affect the way you worked as a group or affect the design process you adopted?*
Answer	When you write the minutes you take a step back from the design process, so it didn't affect the process and It didn't affect the way of working for the group. Having a note-taker who is someone familiar to the team helps reduce intimidation for saying things.
Question	*How easy was it to document less formal activities like brainstorming and concept development?*
Answer	Certain things like brainstorming its hard not to become involved. Less formal the activity the harder it is to keep track of topic, summarising is difficult
SCRIBE FEEDBACK	
Question	*Did the classification of exploration, decision or action prove problematic for recording?*
Answer	Most activities and discussion comes under exploration, so it's not problematic, deciding on the actual decision was a key element though and having to think of what category it falls under, and quickly.
Question	*Was the tool easy to use?*
Answer	Learning to use it or having experience is required to use the tool but after a couple of uses it became easier to use, overall it's fine to use. The ability to identify the source of decisions is very useful for reviewing the actions and decisions.
Question	*Was it physically tiring or draining using the tool?*
Answer	You have to keep focused and concentrate on the task and discussion, it's not draining using the tool specifically and keeping focused is needed for any minuting activity.
Question	*Did it force you to record items in structure which is not natural in comparison to other minutes?*
Answer	There was some difficulty in choosing between the types of information, it does force a structure compared to paper based but then saves you from having to go back over the notes and distil the meanings later, and I would usually spend time adding in or editing the minutes after the meeting.
GENERAL COMMENTS	
Comment	It would be useful to be able to score out or cancel a decision, not delete, just indicate it had been changed.

Comment	A spellchecker is needed in the tool.
Comment	In comparison to other projects, there is not usually a separate minute taker so the person taking notes is involved but this generally leads to less decisions being recorded. That is probably meeting dependent though and the more formal the meeting the more likely to have a separate note taker.

Overall, the feedback from the group involved in the experiments can be deemed to be positive with some interesting insights and comments provided. There were no apparent negative effects reported from using the KEN tool to document the activities. Structuring the meeting around the process model and incorporating the exploration, decision and action activities appeared to give a recognisable and positive structure to both the undertaking of the activities and the documented records. However, it was highlighted that the scribe was presented with the issue of deciphering between interjection categories and as such the time required to make the decision could potentially have an effect on the scribe's ability to document accurately.

The feedback on the use of the KEN tool was positive and immediate benefits realised such as the negated need for post processing activities, the predefined structure and the ability to identify the sources used to make decisions. Interestingly it was commented that the ability to view modified or cancelled decisions would be a welcome addition, a feature present in much of the IBIS software developments such as DRed and Compendium (Conklin 2003; Bracewell, Ahmed et al. 2004).

6.1.2.5Conclusions from the Controlled Experiments

The results from the series of controlled experimental studies highlight three interesting observations;

1. Utilisation of the KEN tool provides on average a documented record of decisions and actions which is 54% more accurate than paper based techniques. However, there is still a significant difference (on average 25%) between the accuracy of the KEN tool and transcription techniques.

2. A richer and more context laden record can be achieved through the use of the KEN tool to document the utilisation of information objects and the

application of the process model to provide structure and consistency to the documented records.

3. Adopting and implementing the combination of the capture architecture (demonstrated through the KEN tool) and the meeting process model has shown a consistently positive effect on the user's ability to actively generate and structure more accurate records of design activities, regardless of the meeting formality level.

Overall, the application of the SKIC framework and underlying models to the undertaking and structuring of engineering design meetings, and in particular the use of the Knowledge Enhanced Notes prototype within the experimental episodes presented above, has served to demonstrate the effectiveness in providing a more complete and accurate depiction of synchronous design activities. However, this series of studies was conducted as a controlled study with the episodes created specifically for the purpose of testing and with limited external influences on the episodes. To achieve a true representation of the system's validity, it was deemed necessary to apply the system within an industrial context.

6.1.3 *Industrial Experiments – Project progress meetings*

For the second series of experiments, it was necessary to apply the system within a 'real-life' industrial context. For this permission was sought and granted to utilise the KEN documentation system to document a series of project progress meetings undertaken between Company B, a major multinational aero engine manufacturer, and the Advanced Forming Research Centre (AFRC), a research centre operating within the field of forming and forging.

In total, five episodes were documented and analysed, with the KEN meeting record being directly compared with the official progress meeting minutes to measure the effectiveness of the system. These industrial-based episodes were undertaken as formal review meetings with a predefined structure in accordance with the organisation's internal working processes. The structure and formality of each episode was equivalent to that of formality level 5 as defined in Section 5.1.5, whereby a designated chairperson and meeting scribe were utilised.

Owing to the commercially sensitive nature of the issues discussed during these meetings, video and audio recording was not permitted. Thus, it was not possible to use these episodes to measure the accuracy and efficiency of the KEN tool compared with transcripts of the undertakings. However, as the previous study measured the ability of KEN system to aid in the documentation of information against transcripts, this exercise was adapted to form a direct comparison between the developed capture system and paper-based methods, hence providing more data for comparison.

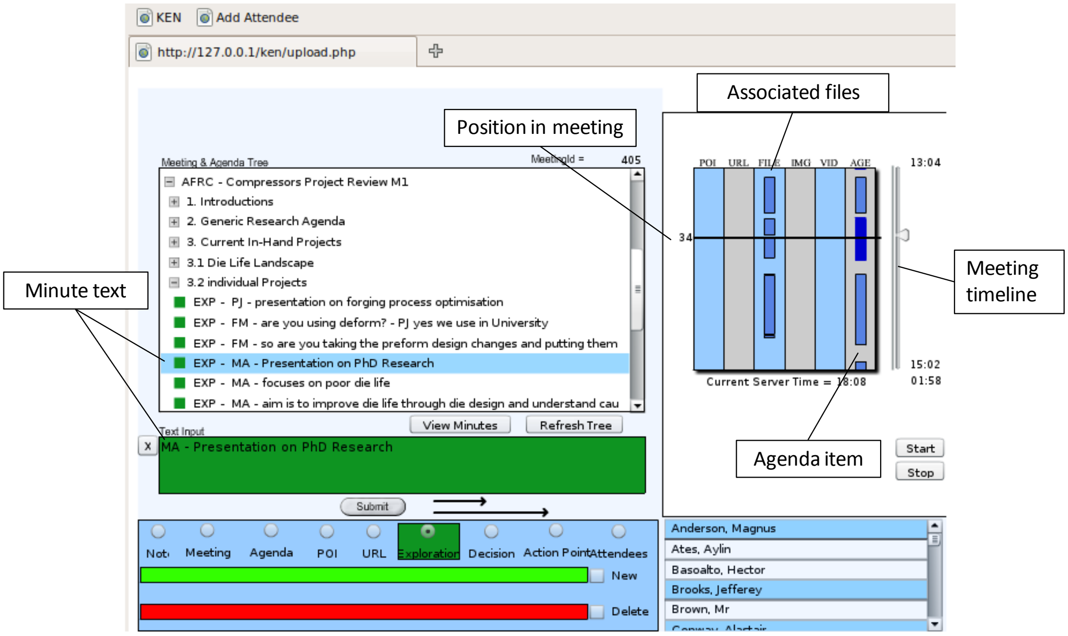


Figure 6.5 KEN Compressors Review

Within this series of episodes, previously generated documentation such as spreadsheets, slides, images and reports were used as support in the discussions leading to the decision. The use of KEN to document this activity allowed these data sources to be uploaded in real-time using the Flash-based drag and drop upload form at the point in the discussion at which they were utilised. As shown in Figure 6.5 this allowed the individual data sources such as the PowerPoint presentation files to be recorded and synchronised with the meeting timeline and text records created during the activity, returning an accurate and richer representation of the discussions and the point in time at which each element was presented.

6.1.3.1Analysis and Evaluation: Decisions, Actions and Information Transfer

The analysis of the records (shown in Table 6.8), highlight that there is very little difference between the number of decisions and actions recorded using KEN and those present in the official meeting minutes. In most of the episodes the number of actions and decisions differed by only one or two and therefore these discrepancies are assumed to be due to the human element within the study. This however illustrates that throughout these episodes the use of the KEN system was as efficient as traditional methods and thus does not present any significant disadvantage to the user. In fact, where the KEN system presents an advantage is in the analysis of the information transfer. On average, the percentage of information transfer for the KEN system was 87%, whilst the traditional paper based records failed to document the information objects. A meeting data set consisting of a text based KEN record and meeting minutes from one of the industrial experiment sessions is included as Appendix D. The remaining data sets are available for analysis upon request.

In addition, analysis was performed on the time taken to create the finalised meeting records. Over the five episodes, the average time taken to record and prepare the KEN record was 87 minutes, equal to the average duration of the meetings. However, the average time taken to prepare the traditional meeting record was172 mins, thus over the course of the five episodes an average 51% saving on time was identified through the use of the KEN system. This time saving can be attributed to one significant factor in the design and use of the KEN system as a documentation tool; there is very little or negligible post processing time required for creating a shareable and readable meeting record. This is in direct contrast with that of the use of paper based records whereby the scribe must interpret and construct the meeting record from the notes written throughout.

Table 6.8 Industrial experiment results

			Information Objects											
			MS Office Documents			Media			Files		Quantity			
Episode	**Decisions**	**Actions**	**Word**	**Excel**	**PowerPoint**	**Audio**	**Video**	**Image**	**PDF**	**Other**	**Total**	**Possible**	**Transfer (%)**	**Preparation (Mins)**
Session 1 (M1)														
Meeting minutes (paper)	3	5	0	0	0	0	0	0	0	0	0	7	0	240
KEN Record	3	5	2	0	2	0	0	0	2	0	6	7	86	118
Session 2 (M2)														
Meeting minutes (paper)	2	11	0	0	0	0	0	0	0	0	0	3	0	120
KEN Record	3	10	0	3	0	0	0	0	0	0	3	3	100	85
Session 3 (M5)														
Meeting minutes (paper)	1	14	0	0	0	0	0	0	0	0	0	5	0	240
KEN Record	2	14	0	0	3	0	0	0	1	0	4	5	80	112
Session 4 (M6)														
Meeting minutes (paper)	0	10	0	0	0	0	0	0	0	0	0	7	0	140
KEN Record	1	12	2	0	3	0	0	1	0	0	6	7	86	73
Session 5 (M7)														
Meeting minutes (paper)	0	8	0	0	0	0	0	0	0	0	0	6	0	120
KEN Record	5	9	1	0	2	0	0	1	1	0	5	6	83	48

6.1.3.2Analysis and Evaluation: Knowledge objects

As with the evaluation performed in section 6.1.2.3 it was also possible to identify specific examples of how the utilisation of multimodal information can provide users with greater knowledge and rationale of how decisions were reached.

Figure 6.6 highlights one example of where greater knowledge of the design activity can be gleaned through the use of the KEN system. Within industrial meeting 6 a review of a project progress was presented (shown as A). At the time at which the update was being given was made (highlighted through B) it is clear that a specific *file* was being utilised (shown as C). In this example the file in question was a PowerPoint presentation on the project progress which users of the system are able to download by simply clicking on the 'data block' on the timeline. This provides the user with an enhanced understanding of the context in which the exploration activity was recorded, as the file provides additional context not present in the text record.

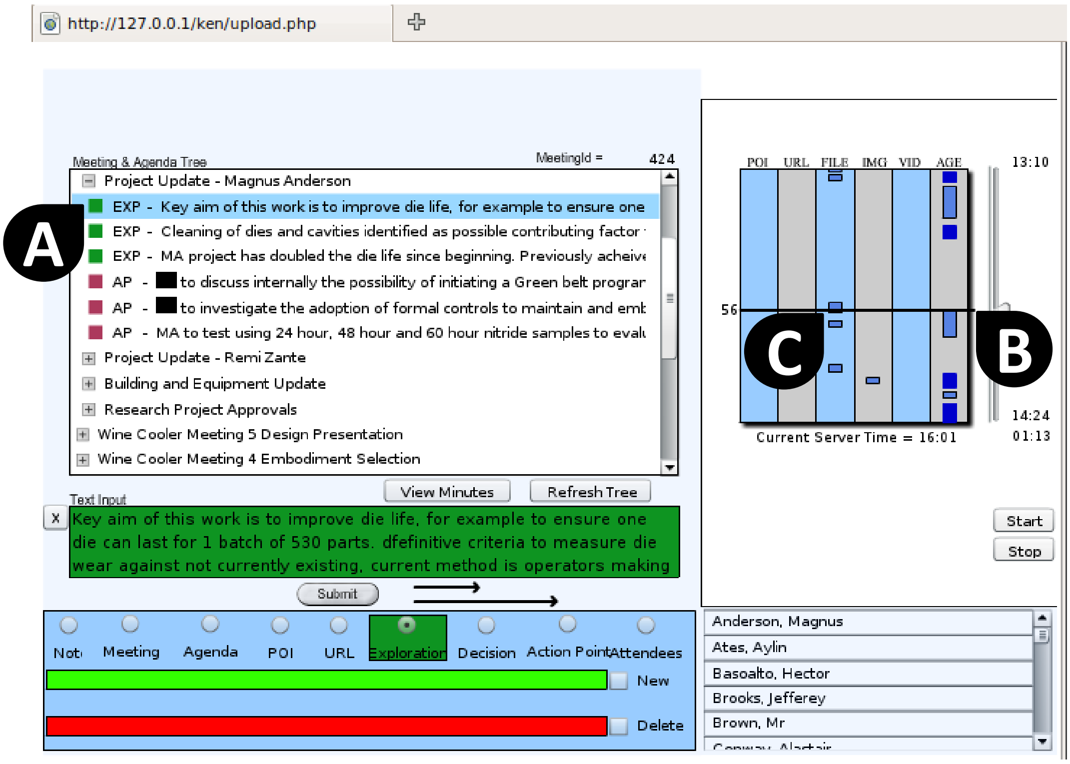


Figure 6.6 Industrial Episode 6 KEN record

A second example is presented in Figure 6.7. Within this episode (industrial meeting 7) a 4-box chart was presented which shows the key progress and obstacles of a specific project against time and the interjection at which the chart was discussed shown as A. For a user to gain a full understanding of the chart which was presented, they are able to identify the time at which the update was being given was made (shown as B) and are then presented with the specific *file* which was being utilised (shown as C). As with the previous example this functionality provides the user with an enhanced understanding of the context in which the exploration activity was recorded, in the context of project progress for this example.

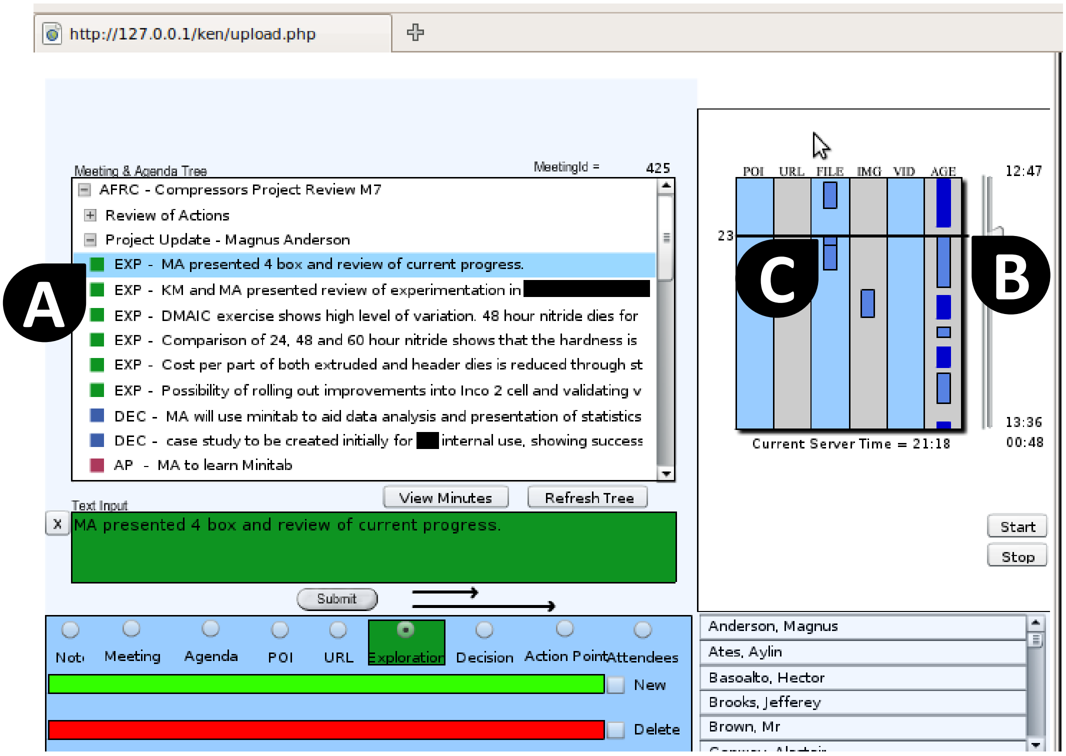


Figure 6.7 Industrial Episode 7 KEN record

The examples again illustrate the potential of the system architecture as alluded to in section 6.1.2.3 and helps to present to the user an enhanced representation of the activity under study encompassing more information, knowledge and rationale on the exploration activities, the decisions and actions undertaken throughout the episode.

6.1.4 *Conclusions from the evaluation and validation studies*

Overall, both controlled and industrial based studies presented some interesting and positive results. The analysis shows not only that the KEN system itself is a useful tool but that the theoretical architecture upon which the system is based is also valid.

The differences in the results between the controlled experimental studies and the industrial based studies highlight that although in both sets of studies the KEN system has recorded more there is still a significant difference between information documented by the prototypal tool and the information recorded by full transcription. Although the analysis shows that the use of the KEN system does not provide an entirely accurate representation of synchronous episodes it has shown significant increase in the recording of information when in direct comparison to other widely adopted paper based techniques. In addition it enables the users to record much more contextual information such as the information objects presented in the meeting and has also shown a significant time saving due to the reduction of post processing activities. The use of the KEN software to document the activity allowed for the data sources such as images, documents and files to be uploaded and incorporated into the meeting record using the Flash-based drag and drop upload form at the point in the discussion at which they were utilised. As was shown in Figure 6.3, this allowed these data sources such as PowerPoint slides and documents to be synchronised and displayed against the meeting timeline. The addition of information sources such as audio, video and text records created during the activity ensured that a more accurate, browseable and significantly richer representation of the discussions leading to each decision made was created allowing users to revisit these decisions and gain greater insights into the decision rationale.

In addition, a shareable meeting minute document was generated by the KEN system, comparable with the paper-based traditional minute record in terms of structure, information content and also level of detail. However, the key difference between the two methods lies in the fact that users were able to generate the KEN minute document automatically and in digital form, thus the document is inherently more shareable than the paper-based minute which would need post processing to produce the same digital record.

6.2 *Chapter Summary*

The fourth chapter of this thesis looked at identifying design activities where information and knowledge loss was prevalent, and in doing so proposed the fourth research question:

4. *Can a framework model be developed to enhance the practice of documenting design knowledge and information at the point of generation?*

The work presented thus far has provided a clear answer to this question. It is entirely possible to define and develop a framework which is proven to enhance the documentary practices within specific situations. For this thesis, this has manifested in the development of the Synchronous Knowledge and Information Capture framework, incorporating the specification outcomes developed in previous chapters and the proposed architecture. These factors combine to develop three models of synchronous design episodes; an organisational model representing the level of formality of the meeting, a process model showing the most effective method of conducting a synchronous design episode, and an information capture solution designed to enhance the documentation of the synchronous episode. As well as proposing a viable solution to the problem, this framework presents a system architecture.

The Synchronous Knowledge Capture Framework was evaluated through application to eleven sample case studies conducted both in controlled environments and industrial ‘real-life’ scenarios. These experiments were designed specifically to evaluate the efficiency of the proposed knowledge capture framework and associated models when used in synchronous design episodes. The analysis of these experiments has shown that the theoretical SKIC framework, when applied to synchronous design activities such as meetings can enhance an organisation’s documentary record of design activities through providing a more accurate representation of the decisions, actions and exploration activities undertaken throughout the overall product lifecycle.

PART E: DOCUMENTATION

Chapter 7: Conclusions and Contribution to Knowledge

Throughout each chapter of this thesis a summary has been presented, highlighting the key elements of work and significant findings which have arisen. The aim of this chapter is to conclude and summarise the key findings of the work and, in doing so, answer the research questions and provide an overview of the contribution to knowledge that this thesis has made. The structure of this chapter is presented in Figure 7.1 below.

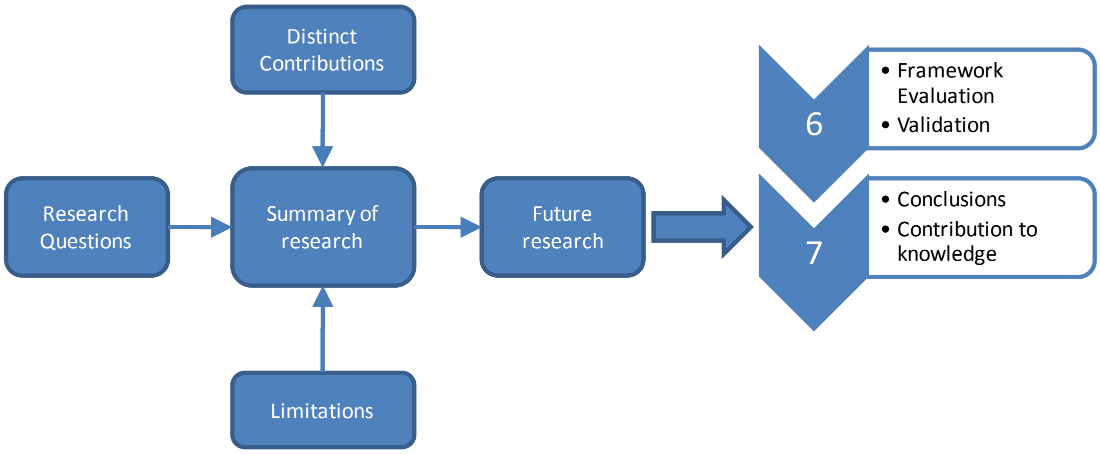


Figure 7.1 Structure of Chapter 7

First, the findings of the study are summarised based on how they answered the research questions. Second, the distinct contributions of this research are presented and summarised. Thirdly, the limitations of this research are discussed and outlined and the recommendations for future research provided. Finally, the key points of this research are concluded.

7.1 *Answering the research questions*

This section will aim to provide succinct answers to the research questions set out in Chapter 1 of the thesis. To meet the research aim and objectives, four primary research questions were derived.

7.1.1 *Research question 1*

This question aims to meet objective O-1 through establishing the context of the research problem, gaining a better understanding of how and where product and process information and knowledge are used within the engineering lifecycle.

1. *Does the identification and retention of product and process information impact upon the engineering lifecycle?*

The identification, capture, and retention of product and process information and knowledge do impact upon the engineering lifecycle. Information and knowledge play a key role in ensuring that the development of the product meets the necessary criteria. As is explicitly shown in Figure 3.6, Pahl & Beitz demonstrate that the flow of information throughout the design process is a complex and critical element directly leading to the successful conclusion of the design activity (Pahl and Beitz 1996). What is also evident from the literature is that with the shift in focus from product delivery to product service comes a need to retain product and process information for extended product lifetimes, which can be some 10, 20 or 30 years. The aim therefore is to assist design engineers to record more information than traditionally documented, providing a much richer product history and allowing the design process to be revisited and subsequently reused if and when necessary. If design engineers are to capture information and knowledge with a view to re-use at later stages in the product lifecycle then the focus must be on developing rapid, effective methods of capturing both formal and informal information at the point at which it is generated rather than through retrospective analysis.

7.1.2 *Research question 2*

The second research question looks to build upon objective O-1 by identifying particular stages or phases of the generic engineering lifecycle where the process of capturing of knowledge and information has been recognised as being inefficient or problematic, and thus working toward O-2.

2. *Are there specific stages of the engineering design process where knowledge and information capture is inefficient?*

The literature study performed within Chapter 3 gave an indication that knowledge and information capture is inefficient throughout the entire engineering design process and is not a problem specific to individual stages. This observation was compounded by a review of surveys conducted to establish the information and knowledge needs and wants of the engineers currently working within design. However, to explore this research question further, and establish if the literature is representative of industrial practice an exploratory study was devised. The exploratory study was conducted within a large multinational engineering organisation providing an overview of the elements of information which organisations record, are available and are required throughout the engineering lifecycle of large made-to-order engineering products, in this case naval ships. Through the undertaking of semi-structured interviews, this study highlighted the types and instances of information used and required at each stage of the engineering design process. The study highlighted a key consideration for furthering the research within this PhD study; the inefficient capture of information and knowledge is not bound to one particular stage of the engineering design process but rather can be deemed to be a by-product of the processes employed. These findings are in line with the exploratory literature study performed within this chapter. That is, the key to creating an organisation whose management of engineering design knowledge and information is truly efficient is to implement effective processes and methods into the overall engineering design process in addition to the necessary tools and mechanisms.

7.1.3 *Research question 3*

Research question three was proposed to identify particular activities undertaken within the generic engineering lifecycle where the process of capturing of knowledge and information has been recognised as being inefficient or problematic. This question further defined the focus of the research and contributed to meeting objective O-3 of the work.

3. *Are there specific activities employed within the engineering design process where knowledge and information capture is inefficient?*

Social and collaborative situations such as engineering design meetings were identified as specific activities which can be deemed as critical to the engineering design process and yet regarded as inefficient in capturing knowledge and information using traditional methods, techniques and tools. In addition, engineering design meetings are regarded as synchronous episodes which are conducted throughout all stages of the design process and indeed the product lifecycle, allowing a broader view of knowledge and information usage to be established. The reason for this ineffectiveness is clear. From the literature reviewed and also exploratory studies undertaken, the structure and protocols adopted as part of engineering design meetings can be seen as key to providing a representative record of the activities. In many cases these protocols and structures are not adequately developed and implemented within organisations, leading to discrepancies in how records of design activities are constructed. The studies undertaken throughout Chapter 4 have highlighted the need to develop a framework which organisations can adopt to provide the necessary structure.

7.1.4 *Research question 4*

The fourth and final research question is fundamental to evaluating this body of work's contribution to knowledge and meeting the final objective O-4. Only if the solution model can be proven to enhance the practice of knowledge and information capture will the overall aim of the research be achieved.

4. *Can a framework model be developed to enhance the practice of documenting design knowledge and information at the point of generation?*

The development work presented within Chapter 5 and the evaluation and validation experiments detailed throughout Chapter 6 has provided a clear answer to this question. It is entirely possible to define and develop a framework which is proven to enhance the documentary practices within specific situations. The approach taken was to develop a number of individual models, each with the potential to enhance the design activity records and combine them into a framework which any organisation, regardless of size or industry focus, can apply. The result of this work is the Synchronous Knowledge and Information Capture framework. As described extensively in Chapter 5, this framework consists of three individual models; the *organisational* model representing the level of formality of the meeting, *process* model showing the most effective method of conducting a synchronous design episode, and information *capture system architecture* designed to enhance the documentation of the synchronous episode. The Synchronous Knowledge Capture Framework was evaluated through application to eleven experiments conducted both in controlled environments and industrial 'real-life' scenarios. These experiments were designed specifically to evaluate the effectiveness of the proposed knowledge capture framework and associated models when used in synchronous design episodes. The analysis has shown not only that the theoretical SKIC framework can potentially enhance an organisation's knowledge and information capture abilities but also that the individual models and system architecture are valid within the defined context of engineering design meetings.

7.2 *Distinct contributions made by this work*

As defined in Section 1.2.1 the overall aim of this research was to aid the process of capturing information and knowledge for engineering design episodes. The research activities and work presented within the previous four chapters clearly demonstrate this aim has been successfully achieved. In doing so, this doctorate study has also presented a number of distinct contributions;

a) It provides an exploratory study of information and knowledge usage and documentation practices within social and collaborative design episodes,

b) It presents a summative model of the design process based on a number of well established and referenced works,

c) It proposes five distinct levels of formality against which synchronous situations such as meeting can be classified.

d) It proposes a framework which is shown to enhance the structuring and documentation of engineering information and knowledge.

Table 7.1 below cross references these key contributions against the research objectives and questions within this thesis, also identifying the relevant chapters. The following sections briefly summarise these key contributions.

Table 7.1 Summary of key contributions

Contribution	Objective(s)	Research Question(s)	Chapter(s)
Exploratory study of information and knowledge usage and documentation practices within social and collaborative design episodes.	O-1, O-2, O-3	1, 2, 3	3,4,5
A summative model of the design process based on a number of well established and referenced works.	O-1, O-2, O-3	2, 3	3
Modelling of distinct levels of formality against which synchronous situations such as meeting can be classified.	O-4	3, 4	5
Synchronous Knowledge and Information Capture (SIKC) framework which is proven to aid organisations in the structuring and documentation of engineering information and knowledge.	O-4	3, 4	5,6

7.2.1 *Exploratory study of information and knowledge usage*

As is evident from the literature and exploratory studies undertaken as part of this study (Chapters 3, 4 and 5), and as demonstrated in Figure 7.2, there is significant difference between the current knowledge and information documentary practices employed and the desired documentary practices within engineering design organisations. Current organisational practices provide adequate support in the exchange of formal design information such as geometric data and specifications embedded within formal reports and computational models. However, over extended lifecycles it is increasingly desirable to communicate much more informal information and knowledge about the design and design process, including design decisions, constraints, rationale, modification or changes, not all of which are currently captured.

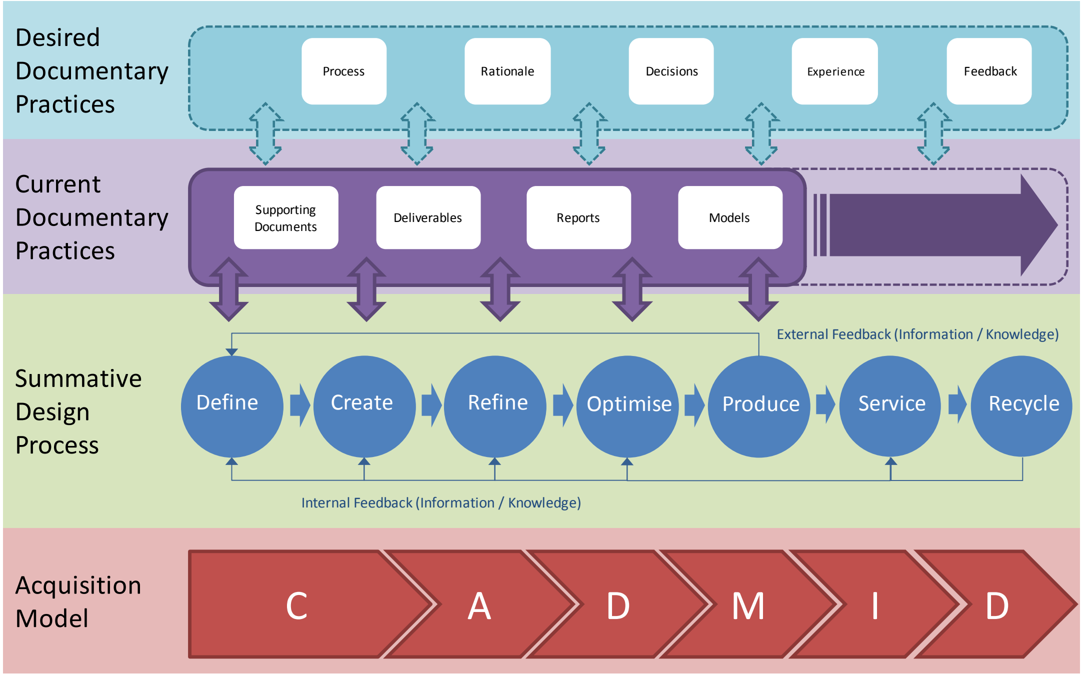


Figure 7.2 Through-life knowledge and information engineering model

Previous work and the plethora of tools and techniques found in the literature tell us that the identification, capture and subsequent reuse of design knowledge and information are recognised as critical by much of the engineering design community. However, what is most apparent from the review is that for these techniques, tools and methods to be truly efficient in capturing knowledge and information, there is a need to address more than just the capture mechanisms.

It is recognised that working synchronously in engineering teams and engaging in episodes such as engineering design meetings is critical to engineering design and such episodes generate significant informal knowledge and information elements. Current documentary approaches and systems are not sufficient at providing the necessary flexibility for varying degrees of meeting formality and structure and thus the capture activities remain inefficient. From the literature reviewed and also exploratory studies undertaken, the structure and protocols adopted as part of engineering design meetings are highlighted as key to providing a representative record of the activities. In many cases these protocols and structures are not adequately developed and implemented within organisations, leading to discrepancies in how records of design activities are constructed.

The study of engineering knowledge and information usage in design activities has highlighted the need for organisations to understand the criticality of information and knowledge capture for any organisation undertaking the development of products or projects. It has demonstrated that the overall structure of the activities must be defined, the process must be modelled and the capture mechanism architecture designed to fit with these models. Only then will organisations truly be in a position to optimise their ongoing design activities through greater understanding of the decisions made and the contextual data surrounding these.

7.2.2 *Summative design process model*

Throughout this research, the key existing models of the design process were identified and the need to define the stages of design recognised. However, what was also apparent was the lack of a summative model of the design process which adequately represents the key elements, methods and stages which can be gleaned from the analysis of these key pieces of work. For this thesis, the selection of a specific existing model would not suffice; instead, a summative model was developed incorporating the key aspects from the existing work. From reviewing the commonly cited and adopted models of design, and the extensive literature studies undertaken by Cross (2000), Wynn and Clarkson (2005), O'Donovan et al. (2005) and Huet (2006) it was possible to extract the core generic stages of the design process and create a model for use within this thesis. This simplified model as shown in Figure 3.6 consists of five stages, *Define*- encompassing the definition of the user need and problem specification, *Create*- the initial conceptual design work undertaken, *Refine* – the embodiment and detailing elements of the design activity, *Optimise* - the evaluation and optimisation of the design and finally *Produce* – encompassing the manufacturing and distribution of the final solution to meet the demand. Such a model of design process provides a platform upon which further studies of engineering design activities can be based. The model itself is not intended as a new process model but rather a mechanism to graphically surmise some of the key research work into the engineering design process, providing a useful starting point for further research within the field of engineering design processes.

7.2.3 *Modelling of meeting formalities*

As discussed in Chapter 4, there are many different formalities and categories of meetings and as such, the governance and subsequently the organisation of meetings is directly proportional to the level of formality at which the meeting will occur. Further, the formality and structure applied will define the level of governance required to effectively undertake the meeting. Building upon the description of meeting formalities proposed in Section 4.4.1.1, a platform upon which to model the organisational aspects of meetings in relation to their formality was proposed. Using a five point scale of formality (where 1 was least and 5 most formal), this work presented five different models of meeting formalities as detailed in sections 5.1.1 through 5.1.5. These models provide useful mechanisms for researchers to structure and analyse synchronous activities such as meetings, allowing tools, techniques and processes to be measured within multiple formalities.

Although these five models were designed for use within the engineering design context, and in particular to help assess the level of formality applied to design episodes; they are directly transferable across multiple contexts. In fact, it is anticipated that the models could be applied not just to meeting situations as presented within this thesis but also to other conceivable synchronous activities such as seminars, training and review sessions. In addition to the applications within research activities, there may also be scope for organisations and companies to use the models to achieve direct practical improvements in structuring their core business activities. For example, the models could potentially be used to assess and ultimately restructure synchronous activities within the business processes, giving the organisation insights and understanding of how many of their design and non design related synchronous activities are undertaken. In all, the models are another transferable element of research presented within this thesis and as such provide a direct contribution to the domain of synchronous situations.

7.2.4 *Framework to enhance design knowledge and information capture*

A key contribution made by this thesis is the development and validation of the Synchronous Knowledge and Information Capture framework as presented in

Section 5.4 and Chapter 6. The development of this framework was based upon both theoretical and practical data and as result the SKIC framework has been shown to have a positive impact upon the accuracy of information and knowledge which organisations can record. The SKIC framework coupled with the literature and exploratory studies undertaken within this thesis have identified three key areas of synchronous working where improvements can be made; the organisational structure of such activities, the process undertaken throughout and the mechanisms put in place to accurately document and capture the information and knowledge as it is generated. The derived theory from this work is that an organisation adopting all or any of the three models within their synchronous design activities would be best placed to provide enhanced information and knowledge capture, generating more accurate and therefore usable records of the design process throughout the engineering product lifecycle. However, although each of the three models has presented an individual case for adoption, for an organisation to achieve the most benefit it must integrate the three models within its core structure and thus an overall framework such as the SKIC is required.

7.2.4.1Application of the framework

With the SKIC framework described and validated within Chapters 5 and 6, consideration must be given to how an organisation can practically apply the framework within their organisation. Although the framework and the models therein are sufficiently generic to allow application within any industry, there may be a need for organisations to adapt and integrate the framework within their current working practices. This section details a proposed process of application.

7.2.4.1.1 *Stage 1: Analysis of current meeting activities*

For the integration of this work to be a success, organisations must first have a deep understanding of their meeting practices and the processes currently employed. This is expected to involve a modelling exercise to identify the various types of meetings run within the business and where these meetings sit with respect to the formality levels defined. By way of example, Table 7.2 presents a hypothetical analysis undertaken by a research based organisation on their meeting activities.

Table 7.2 Example meeting activities analysis

Research Centre A		
Meeting title	**Description**	**Formality Level**
Board	These sessions are where the principal executive decision-making body meets. The Board, amongst other things, approves the annual operating budget and annual research programme for the centre.	5
Technical Board	The Technical Board sessions are forums whereby all tier 1 representatives are invited to meet, discuss and ultimately recommend the research strategy and direction to the Board.	5
Capability Group Meeting	Sessions designed to allow researchers and staff working within specific capability groupings to meet and discuss ongoing research and issues.	2
Operations Meeting	Monthly sessions whereby operational aspects of the research centre are presented and discussed with all staff. These include equipment procurement, staff loading and events.	4
Research Meeting	Monthly sessions whereby current, future and potential research activities are presented and discussed with all members of staff.	4

The five levels defined within this work each propose a structure for the governance of meetings to suit different situations. However, the adopting organisation may find that the meetings which they currently undertake fall within a multitude, or perhaps all of the formality levels presented in this thesis. The task the organisation should then look to undertake would be to adopt and integrate the relevant governance model presented at each formality within their current activities.

7.2.4.1.2 *Stage 2: Adoption of meeting process model*

As presented in section 5.2, the meeting process model was developed using published literature and experimental activities and as such is generic enough to represent almost all meeting activities undertaken within any given organisation. It has been shown through this work that providing and replicating structure to activities such as meeting can aid the collation and documentation of the decisions and actions undertaken throughout the design process. Therefore to achieve an enhanced record of design activities, a defined process for undertaking meetings such as the model presented in this thesis should be adopted.

7.2.4.1.3 *Stage 3: Integration of meeting support tools*

An organisation wishing to enhance their engineering design process documentation activities will be presented with an almost limitless choice of tools, both physical and virtual, which can be used to capture more information than possible without these tools. However the tools alone are not the answer. This thesis has shown that only through the adoption of tools, process models and also an understanding of the structure, can a truly enhanced record of activities be achieved. Therefore before choosing to adopt any specific tool or toolset, an organisation must first look at how these tools can be integrated into the way in which the organisation currently or will potentially operate. This is the issue that the SKIC framework is designed to address. The integration of the information capture architecture, along with the process and organisational model into a single framework presents any organisation with a flexible, adaptable and fully integrated method of improving their current meeting documentary practices.

7.2.4.1.4 *Stage 4: Staff awareness& training*

A fundamental element of any knowledge management endeavour is to ensure transparency and awareness of the activities amongst the organisation's staff (Akhavan, Jafari et al. 2006). If an organisation's staff is not aware of what they are undertaking, or why they are adopting new practices, then the effectiveness of their knowledge management activities may suffer. In the adoption of the SKIC framework, staff awareness is fundamental to the successful integration. Sessions to present the method of undertaking meetings and the use of any tools adopted should be organised and run, ensuring clarity and reasoning for adopting such techniques is understood not only by the staff responsible for organising and running the meetings but also the staff who participate in such activities. If an organisation provides an 'operational handbook' or such documents issued to staff as part of their training, then these process models and directions on the use of support tools must be integrated within these documents.

7.3 *Limitations of the study and future work*

As is the case with almost all research undertakings, limitations are present in the studies undertaken as part of this doctorate research. This section will summarise some of the key limitations recognised by the author throughout the undertaking of this research.

A significant limitation of this work, and indeed any research conducted into through-life engineering, is the associated extended lifecycles. For this thesis this manifested itself as limitations on the ability to review the information usage within the entire lifecycles. Ideally to identify the issues of information and knowledge use throughout the engineering lifecycle, a researcher would identify specific elements of information and chart their usage and development throughout the life of one or more projects or products. However, with some product lifecycles averaging at 20 years this was not a feasible approach for a doctorate study. Therefore to combat this issue, a view had to be gleaned from individuals working at each stage in the lifecycle. To gather this view, interviews were performed with individuals involved in long term design projects. From this, other limitations were identified; the data being gathered from the interviews were based upon individual's recollections and not on documented evidence. For this element of the study, the accuracy of the interviewees' data was not deemed critical as this was being used in conjunction with the literature to understand where in the design process information and knowledge was utilised most. In the end the conclusion was that there were no specific stages of the design process in which information and knowledge usage is more prevalent, in fact information and knowledge are critical throughout all stages of the design process.

As with all case-based research undertakings, the number of case studies and experiments undertaken are critical to the validity and analysis of the research results. This research was limited in both the number of organisations involved in the experimental activities and also the level of confidentiality associated with them. Ideally this work would have undertaken experiments within a number of companies (in the region of six to eight); however owing to the time required to gain approval to conduct the experiments and indeed the nature of many of the organisations approached (both commercially and military sensitive) this was not possible. Instead a number of controlled experiments were undertaken, designed to replicate industrial scenarios, and combined with the industrial based experiments which were possible.

The use of controlled experiments presented some further limitations and issues. Firstly, there is the potential for the researcher or participants to bring bias to the experiments. To limit the potential for bias, the participants chosen had no prior exposure to this PhD work and were briefed only on the task which they were to complete, not on the expected outcomes from the experiment. Also, the researcher was not an active participant in the experimental activities and remained detached through each session, removing the potential for influence or bias on the results. In any case, concerns over bias can be levelled against any research method and cannot be guaranteed to have been eradicated completely.

Secondly, there is potential that artificial and incomparable results may stem from the activities. Some may argue that the experimental variables are manipulated to ensure that the experiment measures what researchers want to examine; therefore, the results are contrived and have no bearing on reality. However, the counter argument would be that experimental research derives the research question from a 'real world' scenario, studies it under controlled conditions, and then provide an answer which is directly applicable within the original 'real world' context. This provides the researcher with control over the variables, increasing the possibility of more precisely determining individual effects of each variable and monitoring the interaction between variables.

Finally, there were recognised limitations in the approach taken to validate and evaluate the SKIC framework. The measures put in place for validation and evaluations are robust in terms of analysing the accuracy of the record of activities generated by the KEN system, however it is recognised that the system does not explicitly identify elements of knowledge or information within the record per se. Thus, interpretation of the records by the user still has to be carried out. In addition, validation of the system outputs by the users was not explicitly documented during the experimental activities and therefore feedback on the effectiveness of the system form the user's viewpoint is not present.

7.3.1 *Future Work*

It is anticipated that development of the SKIC framework will continue with application of the models within a number of other organisations. In particular, building upon the use cases presented within this thesis, the KEN prototype system and the meeting process model will continue to be utilised throughout synchronous design and non design related meetings within the Advanced Forming Research Centre. However it should be stressed that although the context within which the framework and toolset were developed was one of engineering design, the underlying models and the toolset are entirely generic in their applicability within any industry and any organisation.

A significant area of interest to the author is the coordination of synchronous and asynchronous design records, where engineers may work as part of a group or as individuals and where different forms of record are necessary to adequately capture the processes and rationale employed in each mode. Further work will explore complimentary approaches to information and knowledge capture within each mode of working with the intention to integrate the synchronous records of activities generated within the KEN system with other asynchronous records created through other, similarly prototypal systems.

7.3.1.1Future vision

The envisaged future for the framework and models proposed within this thesis lie within combined approaches to knowledge and information documentation where synchronous and asynchronous records of activities are combined within a 'holistic' capture framework. The underlying theory is that this holistic approach has the potential to provide more complete depiction of the activities undertaken throughout the life of a product or project than currently possible.

As it stands, the documentary records produced by asynchronous working based developments such as the COSTAR design system (Ritchie, Sung et al. 2008) can be seen as limited without capturing the exploration and decisions leading to *why* the particular activity or series of activities were undertaken initially. Conversely, the utility of synchronous based systems such as KEN and DRed (Bracewell, Ahmed et al. 2004) could be vastly enhanced by capturing the detailed processes that led to the formulation of issues *to be discussed* within synchronous modes of working. This is a recognised issue and one which Post, Mirjam et al. (2008) allude to within their meeting cycle (Figure 4.5).

Essentially, the author recognises that the tools and methods, both reviewed and proposed, within this thesis are not mutually exclusive and there may be a resulting overlap of documentation. Therefore, the combination of information and knowledge capture performed during both asynchronous and synchronous activities has the potential to create a significantly enhanced overall design process model and record, enhancing not only the through-life support of the product but also subsequent projects.

7.3.2 *Reflection on experience*

As with any research activity spanning a number of years, the author has accrued a good understanding of where and how the activities conducted within the thesis could be improved and also where the key strengths were. This short section will reflect on some of these elements as seen by the author at the end of the PhD journey.

Firstly, the value of adopting and defining a research methodology for the study to follow cannot be underestimated. Although there are countless methodologies available for students to review and adapt to suit, many identify one single methodology and use this as the basis of their work. However, the chosen methodology should be one which fits within the aims, objectives and context of the work. For this study it was recognised that a combined approach would only serve to provide greater structure and validity to the activities and therefore two methodologies were adapted and utilised.

The key driver of this work stems from an industrial need (to enhance knowledge and understanding capture for a move to through life product support) and therefore it was critical for industry to be involved in the investigation, description and also the analysis phases of the research. As highlighted in section 7.3 this thesis is limited by the number of industrial organisations involved in the research activity. If the work was to be repeated or indeed for future work which may arise from this study, then greater industrial involvement and at an earlier stage would be sought. This is true not only of this study but of any PhD wishing to be directly relevant to industrial problems, engagement with the end users or beneficiaries will not only strengthen the development and validation work undertaken but could also lead to further implementation and uptake of the solutions.

Overall, the *positivist* or descriptive approach which this doctorate study adopted has ensured that the selection of the research methods, techniques, tools and also the analysis methods are consistent with the overall ethos of the work: to observe and understand the issues and then provide a solution which is of direct and measurable benefit to the users.

7.4 *Concluding remarks*

The work reported within this thesis stems from the current paradigm shift from product delivery to through-life service support within the engineering industry. Many companies are now faced with the challenge of creating accurate and reusable documents of design activities in order to support their products through life. This work has served to address one key aspect of this challenge, the need to create richer and more accurate records of synchronous design activities.

The development of enhanced documentary systems complimented with multi-modal data objects such as audio and video has the potential to improve the recording of knowledge and information for re-use at latter instances in the product lifecycle. The aim is to assist design engineers to record more information than traditionally documented, providing a much richer product history and allowing the design process to be revisited and subsequently reused. If design engineers are to capture information and knowledge with a view to re-use at later stages in the product lifecycle then the focus must be on developing rapid, effective methods of capturing information at the point at which it is generated rather than through retrospective analysis. However, architectures and tools alone are not sufficient, to ensure that these developments are utilised to their most effectiveness process and governance models are also required.

The SKIC architecture defined and evaluated within this thesis was developed specifically to enhance the capture of discursive and collaborative aspects of synchronous design activities and, in doing so, document not only the discussions and decisions made therein but also the information resources utilised within such design situations. The mechanism to achieve this was demonstrated through the development of the prototypal Knowledge Enhanced Notes (KEN) system introduced within this thesis. Through the undertaking of design-based case studies, the records generated by the KEN system serve to highlight the possibility of providing a more complete depiction of activities undertaken, and in doing so, provide positive direction for future development of such documentary activities.

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Appendix A: Interview Transcript 1

Date: 18th February 2008

Time: 14.00

Location: Company A

Scotstoun, Glasgow.

Participant: Pat Kettle (PK) – Company A

Interviewers: Alastair Conway (AC) – University of Strathclyde

Robert Saxby (RS) – Company A

Ross MacDougall (RM) – Company A

Speaker	Transcript	Time
PK	Ok currently I'm the design manager for a project to reactivate 3 ships for the Chilean government, these 3 ships have been in service for the royal navy for about 10 and 15 years the ships were originally built, well 2 of them were built here on the Clyde at Yarrows and 1 was built at (ineligible) on the Tyne and in 1989 I was the design manager for the design of the propulsion system for these ships so I know them from way back prior to that I was actually in the Navy for 15 years and I was actually the customer for the type 23's when they were sort of at the paper stage in design so I have been with the ships almost since they were clean piece of paper but not quite. So currently my role essentially for ships second hand ships is associated with the design manager. What we do is we are taking a ship sometimes these ships have been left for scrap, you know they are decommissioned and just left over there to rot and we have to try and bring them back to life or the previous owner will get straight out of the driver's seat and we will get in when the thing is hot, we have got every single stop in between. So as a role of the engineering that, one is that we need to bring the ship within back up to specification again by doing maintenance, normally planned and unplanned maintenance which would be the same as any capability or re-fit upgrade. But I	00:08

	tend to look at engineering systems as being inside a boundary and inside that boundary is safe and outside that boundary is not safe, inside that boundary we have got to makes sure that equipment is effectively safe, we are doing maintenance on it we are operating it to the right instructions, and there's something else, but we do the full gamut when you leave a ship to rot you, the last one out switches off the light, you stop all the maintenance procedures so its starts corroding and rusting, immediately you take that out of the safe operating envelope so one of our tasks is to bring it within the anti surveying operating envelope.	
AC	Is that, I mean you mention bringing it back up to specification is it specification as new as when it was first put into commission or is it something like I don't know after if its changed, obviously if ships are in service 10 15 years they probably change and get upgraded	02.31
PK	Well we essentially bring it to the same state it was when it went through sea trials at the last set of sea trials, now sea trials, when the ship sails down here from the Clyde it will do a set of contracted sea trials ok, and the ship is in pristine condition and its ace, but as years go by it gets heavier they put more paint on it and they add a few more wiz bangs and a few potatoes this kind of thing a few more bodies so the ship displacement changes and the performance changes slightly and so we tend to do it from the ships do if you like an annual set of trials so we relate ourselves back to the last couple of sets of sea trials, not the, initially the contracted sea trials	02.43
RS	Do you use the test forms like the previous test forms? was that something that was pulled out at all?	03.30
PK	We have to, we have to be, the whole thing about the second hand ship market is that it is second hand ok, ehm and if we are in the second hand market, excuse the wee joke but you have to decide whether you are at the Arthur daily end or the network Q end. Ok? Now if I was at the Arthur Daily end I would just fix it up and say you know "it looks alright to me off you go" if you are at the network Q end you do lots of trials and you test everything. Now what we have to do is make a judgement on how extensive the trials are, and I mean essentially for a second hand ship you really want to show that we have reactivated it to what it was, we are not trying to prove that the fire system will put out fires I mean the guys doing type 45 will let off the fire extinguishers, the will measure the gas levels and things, we just need to make sure the thing is functioning and essentially that's what the navy does itself	03.36

	year on year on year after it goes into a refit, is just to make sure that it's a refit. So the set of sea trials that the guys do here in Scotstoun get condensed into a much briefer from eh for annual service and it's not normally seen by the people here in Scotstoun, ok, and I've seen them cause I was in the navy but it is a very much simplified version and the sea trials they are really design to throw up any faults not really testing the performance, if you are in a ship and it goes full power, you know it's difficult to know whether its 27 or 27.6 knots cause of the wind and the things affecting you, and you can really only tell by how much fuel you are using and the torque in the gearbox so the engineering performance gives you. So really the set of sea trials, we don't call them trials as demonstrations ok, and that is if you like a slight slackening on the system to just really demonstrate the performance which in many ways is a moveable feast.	
AC	And the ones that you, mentioned were done in service were condensed ones… are they based on the original ones that were done?	05.47
PK	Yes they are yeah, yeah, yeah	05.53
AC	So it's a case of they would probably take what the original sea trial was and say right ok certain elements are there…	05.55
PK	They take what the original sea trials was and they also act on, if you like, what they did with other ships previously and so there is a group of people, the ministry of defence has its own if you like machinery trials unit or weapons specialists or whatever and they if you like condense the trials, weapons are a slightly different subject by the way it's always important with ships to separate the combat systems, the munitions systems from the platform systems, by and large the reason for that is that the ministry hangs on to the responsibility for how the combat system as a whole works, now that is breaking down now with the later ships and certainly in the earlier ships the ministry's involvement in the weapons system was much more all embracing. Eh the platform systems really has been handed over to industry since eh 1982, around that era. So there is a slight difference in the areas there	05.59
AC	So what I mean the test reports that get done for these sea trials the annual ones do they get given if for example you get given a ship that you are, say another government wants to take onboard and it's been in the service for 15 years, would you get a set of these reports for the last 15 years say 15 reports, is that the kind of documents you get given with it?	06.52
PK	Well we would certainly ask for them yes, whether we would get them or not is another	07.13

	matter. This is one of the areas where the ministry is not very good is actually keeping its records ehm and ehm yes we would use, certainly we would expect to see the last 2 or 3 years sets, they normally keep them to for bad trials.	
AC	Is that just kinda word documents or paper copies or something like that or?	07.32
PK	At the moment… its… of the generation of ships I am working with they are on hard copy only…ehm…but they are generated on a computer based system, so a laptop, they now have a laptop so they can plug into the system, we don't get access to that we just get access to the hard records. So in our experience, the ships we have done all the records we get are hard copy in that includes the drawing as well and it is one of the serious disadvantages that we have, so if you like, im working for Chilean at the moment but previously I was working as the engineering manager for Romania so one of the additional tasks for reactivation of ships is not just to bring it back into life but actually to make modifications to them to put bigger and better whiz-bangs on them so for the type 22 destroyer eh frigates we sold to Romania we put a gun, a Mitchell gun on the front, the magazine and a hoist between the two and we put some different sensors on it different computer battle management system on it and so in order to be able to make the modifications to the drawing we had to reconstitute it the as fitted drawings by 2 things, 1 is getting the old drawings and then going on board to make sure that the drawings actually represent what's there cause ship builders don't always build the ships to the drawings.	07.35
AC	Yeah some things get made, sometimes modifications might get made as and when…	09.03
PK	Yeah, so at the moment one of our issues is if you like is in this technology trying to move from hard copy to soft copy tools	09.06
RS	What were the drawings for the 22s then was that in particular software in terms of trying to get access to them, did we have those or was it something we got from the MOD?	09.17
PK	It's what we got from the MOD, we have to, we were a slightly different company at the time and ehm although there actually still records here the CAD system has changed twice since those days	09.28
RS	Sounds vaguely familiar really doesn't it…	09.44
PK	And that will be one of our problems with eh you know the reactivation market is if we are 10 years down the line well each technology will have moved twice in that time	09.45

AC	I think that's, as Robert said that's something that's quite common to the other folk we have been talking to as well, things like CAD systems or even document systems have been changed	09.57
PK	And I have to say also that those days when we did the Romanian I didn't have access to the Yarrows design team so I had a design team which had AutoCAD so we used AutoCAD, ehm we reconstituted that. So I mean one of these tools where you can stick the laser in the middle of a machinery compartment which flashes around and measures everything would be ideal for the kind of work we do	10.06
AC	So do you get any I mean obviously if there is work been done, modifications been done do you get a report of what was done and maybe why it was done? For example if, some bulkhead or something has been modified or some cabin has been changed within the ship during the lifecycle of what 10 15 years and that modification, is it a case of just getting the drawing with the modifications on it or do you get a reason why it was done and I don't know if there is any…	10.29
PK	No the situation is not quite so easy as that and I'll explain as to why. I can probably find the people who did it if I spend a long enough searching for them the ministry when it adds modifications as a cost saving measure would decide not to update the drawings in many cases and so there is a case where the drawings you do get are a long way out of date because they don't have these modifications added in, ehm the ship's companies themselves don't find it too much of a problem because all they are doing is operating it and the ship repair authorities are used to that kind of environment, but it is an inconvenience ehm and so there needs to be an effective way of doing these modifications quickly sand simply but also to keeping the records.	10.53
AC	So what did you, did you like you said have to actually go speak to the folk that did them or try and track down the folk that did the modifications to see why it was done and why exactly it was done then?	11.55
[PK]	Yeah we would do that yes it depends on how important the modification is. If we are ripping something out well then we just take notice of it or we may just re-constitute it in our own minds as to how it's meant to work but the reason it works is the ministry is a mansion of many rooms ok and the way the ministry works is that it has a sort of a ship project group which has experts in gearboxes, experts on guns experts on [inaudible] equipment, experts on propellers, experts in anchors so you have to decide which area of expertise you want to	12.03

	go to and then by working with the ship project group and the specialists you then can perhaps find out why things happened but we only need to find out things that we need to know, ok because… well I'll come back to that one in a minute. Because A second-hand ships people are expecting a real bargain for second hand ships you know no money at all and they expect to…so you can't expect or anticipate the same services you might get from a new build ship so we essentially patch it up and we do what we need to do, so if there is a modification over there that we don't recognise ok it's not on the drawings but it's not part of our work and all we have to do is get it to work, or a few changes or something then we will do it, we won't get overly excited about it. So its really only in the areas where we have to do work that we would really seriously contemplate changing the drawings, and there are occasions, this time for example for the 3rd ship we took out one of the great big gear wheels inside the gearbox, well in fact the biggest gear it was about 2 and a bit metres across a great lump of metal, we had to cut a hole in the ships side and everything, move all the gear out the way and then fleet it out and up on a crane. Now when you just get in the removal route for that getting access to it as through the ship, you do need to look at the drawings and there may be differences there but you really only need enough to be able to put it back, so there is always this sort of narrow path here to do that, but there is one aspect of second hand ships that you do need, I need to tell you about because it really does kind of flavour the picture a bit. There are two things I need to tell you; one is that it's a changing environment… that warships have always been built by the ministry of defence, Ok, way back to admiral nelson and king Arthur and all that lot. And they have always been a law unto themselves they are not subject to the merchant shipping act, nor much of the civilian legislation ok, now that's changing very rapidly now, but for many years, the ships warships have not needed to comply with national legislation, however and they still don't, however there is a state policy that they will equal or better than merchant ships standards ok so let me give you an example, the titanic went down you had to have lifeboats along every ship. But a warship you can fill up with lifeboats along the side so it'll say we won't have lifeboats we'll have inflatable rafts instead, ok it's a different standard it's a different way of solving the problem but it is much more reliant on the crew's training and things. Never the less the world is changing and it is changing for warships and eh… and we have to as I say equal or better, the point here is that when a ship here is built, the type 45 destroyer, its actually owned by the ministry of defence ok, they have the insurance on it, and we work on it and we look after it as their agent but actually its owned by them. The difference in the second hand market is that eh is that the ship the ownership of the ship is transferred from the ministry of defence to COMPANY A ok so we actually have a navy COMPANY A albeit of 2 or 3 ships	

	which and they have guns and things on they don't have any ammunition but they have guns and things on it	
RS	Is it still a warship?	16.54
PK	Sorry?	16.55
RS	Is it still a warship not a merchant ship?	16.56
PK	A warship, however if we take it to sea it becomes a merchant ship ok and we have to, indeed when the people here in Glasgow take this out the type 45 destroyer to sea it's a merchant ship, at least it used to be, it used to go out under the red ensign but ive noted of late it goes out under the blue ensign the reason for that is that its still recognised as not being quite a merchant ship and so there are one or two corners but when we take a ship to sea as COMPANY A I have to show the government agencies that the ship is safe to take to sea and so we do call in maritime coast guard agency as they do here in Scotstoun to make sure we have got enough life rafts on board we have enough fire extinguishers eh you know all the lifebelts, you have got fire fighting gear, what else do they do… oh, ive also got to make sure to tell them that we have got a qualified crew we need to make sure that the master is capable of operating you know ships naval ships, the chief engineer is so you have got all the staff there, but the other thing I have to do is I have to make sure that the ship will float upright and wont sink in a storm so we have to demonstrate that the ship is stable in stability terms and the way it floats and we have to make sure that it is strong enough and for that we do use an outside classification society, Lloyds register of shipping ok, who are essentially an independent auditor of what we do. When the ship goes down the Clyde or when we take it to see, the maritime coastguard agency is satisfied, the Lloyds register is satisfied, COMPANY A is satisfied and the MOD is satisfied so there quite a lot of people in there but if you were to look at the legislation you will find its very grey in a number of areas, you know its not quite, but the important thing is that Lloyds register MCAA, COMPANY A and the MOD are satisfied the ship takes to see, more people are happy, so it is a slightly a red areas, grey area and that also reflects across other aspects because once the ship is owned by you become responsible for its safety is all respects ok	16.57
AC	So you mean when it transfers over from MOD to COMPANY A for example its no longer MOD that's responsible for the safety its COMPANY A is that?	19.29
PK	Yeah well its kind of like that and the difference is, that if they have design feature that	19.38

	accidentally kills someone say, ok, if we COMPANY A had designed that system into the ship we would be responsible for it but if the ship we receive from the MOD was unsafe and had a feature in it, and we've had feature that we have argued a toss about, do we need to take your one out put a new one in that kind of issue on safety ehm…so for example we had to, I found out that they needed to change the shafts on eh the propeller shafts and so as a safety issue I raised it and indeed that's what happened so there are safety issues like that where you need to do it. Ehm… then, so the ministry is, we become responsible for what we do, they are responsible for what they did and then the future owner is going to be responsible for what they do, so we have to, we COMPANY A have a policy a very clear policy for two things, one is product safety, and the other is engineering governance, which is making sure that our engineering processes and practices are above board and that requires us to provide design certification, so we have this transition from a previous owner to our ownership to the future owner and we need to make sure that the paperwork in terms of its safety and its design certification and that its fit to go to sea you know passes through those two transitions, those two interfaces there. So a lot of documentation we need just to be able to satisfy ourselves that the ship is actually safe to take on in the end we have to do a little fancy footwork and one of the fancy footwork we did was to makes sure that when we take the ship from the MOD we give it back to them. So that takes us out of the loop as it were	
RS	What did the MOD give us, was there sort of certification coming from the MOD, was that level of documentation arrived	21.43
PK	No… in the, at the moment there are no ships, well there are one or two ships that are now having partial certification in that when we first set off they had to have fire certification for magazines, explosives, personal rescue, propulsion and manoeuvring, fire fighting, stability and structural strength and they are all fairly standard things for ships, and so the type 23 frigates might have one or two of them bearing in mind that the ministry itself in transitioning from having nothing, I mean they won the battle of Trafalgar without a safety case, they one the battle of Trafalgar without any design certification you know, I wouldn't say the ships were safe but they still won it, and so we won a lot of naval battles without any of this fancy stuff and so, and the reason the ministry hasn't doen a fast transition is because its exempt from the law which is another thing why it travels at a different speed. So, we COMPANY A are a commercial company, we are liable to the law under all circumstances, we don't have the same protection as the MOD, not in the second hand market and not in brand new so, we don't have a set of certification. I had to make one up. And to get that agreed, you know within the system, did we get certification? We got, no we didn't, we	21.51

	didn't get any certification, we got indications, we got a partial certification fire fighting in certain areas but we had to make sure that certification in our area was good enough but COMPANY A because it's a large company and has sort of large tentacles everywhere we could take advice from the people in the air world who have to certify their aeroplanes before they go into the air we've got access to lawyers we have got lots of senior engineers who we can consult so we put together a package of design certification which said we will assume the ship we are getting is fine , although we know its not, we know that we have to certify everything that we do ok and we need to hand on the baton for the next part of the relay and in terms of safety and this gradual building up of the safety case we have to say to the people well the ministry you know have started this off and we are going to take it a bit further and when you get it you are going to have to get further still so by way of example all ships now when we put together they have a thing what they call a green passport for disposal (inaudible), they need to know everything about that ship was made of so that when they come to dispose it they know that's asbestos or whatever, not that we have that anymore. But they didn't have them when they built the type 23s, just didn't do it and it was just the way it was and I don't think they did it in most things, so these things had to be reconstituted and we did get one eventually, whether its perfect I wouldn't like to say but it is much better than it was	
AC	So you actually had to go and pretty much do what should've been, or what now would've been done…	25.00
PK	No, no…there are things that the ministry did but they only did it after we got the ships ok so we are doing, I shouldn't give them too hard a time but we are living in a period where the MOD itself is transitioning from the old way of doing things to the new way of doing things for at the moment the ministry of defence, when the ship sails down the Clyde here in previous years that's the last we saw of it, didn't know what happened or they did with it after that. But now COMPANY A are going to this sort of through-life support business down in Portsmouth you are now going to get very much more involved, where you have been involved in the support in the past is that the navy have owned the ship or the MOD have owned the ship and they have said to themselves oh bugger me I've broken this can you come and fix this, I want you to do this and do that to it, ok and we did it without thinking, ok and that was that, but nowadays we have to get involved in taking charge for contracting for availability we want this ship running for 135 days a years so that means we need to transition ourselves to be able to provide all the support and there's a business opportunity for us as well to get into this area to actually take on some of the work which the ministry's	25.04

	been not so good at in the past and they have become a lot worse at because of the stringent defence cuts there have been of late to take it on and make it much more efficient because we want to get into a situation where the guys here build the ships procreate them, the paperwork which is then if you like is updated on an annual basis and we want to take a ship that we just need to update it for the one two years that we have it and we just take it and move on so we are currently coming out of the stone age of paper, drawings and certifications etc etc. as that happens our responsibilities increase, does that make any sense?	
AC	Absolutely, absolutely…so when you get for example if you get a ship from the MOD which you were gonna pass on to somebody or you were going to put onto someone else or put on isn't the right word., sell on to someone else, reactivate for them, would there be a difference between what you get from the MOD and what you pass on? A significant difference in terms of not just volume of information but also types of information for example drawings reports, maintenance ehm…testing	27.06
PK	The answer in the types of the information no, the types of information you know once the ship has been built it may have a green gun instead of a blue one but the information you need for that is still the same. Ok we put a magazine on so we change the drawings and we took out where we keep the wine and the beer and the spirits and they put it somewhere else so we put racks in there to put bullets but we still have the same kind of information so the same information pack that is produced by a shipyard in terms of the physical configuration of the ship is the same there is some documentation that's required for the way that the MOD process ehm things… im going to step into slightly unknown territory cause i don't know how we do it here but the ship, the navy uses an s232 it's a form for when they want to go and dock a ship and its a form they use they get the information out to make sure you put all the thing underneath the ships in the right place, the supports and you flood it out, you do all the right check to make sure you've not left any valves open and so there are certain named processes like that which they do have sort of through-life activities for the do it the MODs way, they will have some equally equivalent here, I don't happen to know what it is, it may even be based it may have the same information on it ive never seen it so there are some process issues which are slightly different and the other issue is that they do simplify the trials that's a very good one that you mentioned and they have processes at the moment for… as an engineer one of the things we are obviously very interested in and at this end here is to make sure that the ship configuration is described so every part on that ship is not only catalogued but all the documentation that refers to that part is referred to but that's not just the technical description of it that's the training document you need for it, that the book	27.31

	of references the guide, the handbook and the spare parts, the stuff you carry on board, and so its important for us as the owner of the ship is to make sure we don't lose this thing called configuration if you lose configuration then its very difficult to re-establish it and you know, you make a modification, you step onto one of these ship you change the drawing s for this and you've got the drawings for this but you also need to change all the handbooks ok and has that been incorporated, is it safe, have you looked at all the hazards around , have you done that, has that been a, have you doen another training needs analysis to make sure the guys on board have known, so there is this sort of maintenance of configuration that s very important to the passing on and if you like this is , it is an extensive area and covers just about everything you could think of, so you've seen the databases that they have in service, well we kind of need to keep those going through-life.	
RS	Was that something that we could do then was provide that level of information down to each part on the ship and relate it to operating documentation and things like that was that all…	30.52
PK	What we want to do essentially the database comes out of the build area s it goes with the ship and then eventually you just want to be able to tap into it again, make your modifications and then hand it on, but it takes time for data input and time is money, so this is one of the area that we have, the ministry has been a little bit lax on the sort of updating of the drawings	31.05
RS	It makes you wonder how they have really exercised any kind of design authority over it when a fairly big element of that is the configuration control of the design.	31.35
PK	Well I think that's another lesson that the ministry is learning at the moment, because we don't, we COMPANY A have become the owner of the ship and we have this policy for product safety, I actually had to go and find, the project goes and find a director who signs to the effect that this ship is safe, ok if you go and speak to a director and you want him to say its safe that concentrates his mind wonderfully, ok you have got him by the short and curlys and he is going to make sure that he gets the evidence he needs to satisfy him that you know the thing is done. The ministry have never had quite that, they have much more of a matrix management system and they will pool little empires and experts in areas in a very much more old fashioned style, but they are now getting people to sign on the dotted line and it is beginning to expand, and they are coming out from behind their exemptions from legislation and have to be even better, so you know its good, its good news, they just haven't got there	31.44

	yet. As an aspiration though for the support business, when they were re-activating vessels I have to say we are talking about, you know we have talked so far about the building here in Scotstoun and im here at the other end where we throw the ships away. But actually there's 15 years of service in there, but if I say well that's the end of when the ministry have got it its probably another 10 years 15 years with the next customer so we want a system which actually just goes through that, one of the reason that the ministry gives us the ships into Company A ownership is actually financial and I don't pretend to understand it but because the money inside the ministry belongs to different people if they sell us the ship the MOD keep the money, if they don't it goes to the treasury and its that kind of issue	
RM	You pre-empted a couple of questions I was gonna ask about the value to the Ministry and the value to COMPANY A, its obviously a very worthwhile thing the re-activation and selling it on but its difficult to see you know how much the ministry are making out of it and how you know, how interested….	33.49
PK	I don't think the Ministry are making anything out of it to be honest	34.11
RM	Are they not… its COMPANY A …?	34.13
PK	COMPANY A are making money out of it because they are employing people to do work and basically they get their profit on the work that's done	34.15
RM	Im trying to see the incentive for the MOD to keep up records you know if there's sort of…you know is it…	34.25
PK	Oh I see… right well I think I think that ehm that comes back to this question or the fact that ok im working in re-activation so that's 1 year out of a 35 year life these guys build it for 7 years , what do we do for the other 30 years and the answer is the ships in service and actually the money to be made by COMPANY A is as much as if not more during that 30 year period than it is during that initial stage of build, ok so where it comes to helps the ministry out is that they say how many people do you need in the back office as support team to keep these ships at sea, we have a design problem you need to go to the company what's the problem here…dadedadeda, new changes, capability, the other thing that happens at the MOD the threat the MOD is facing is always changing, the Afghans' this times it's the Iraqis' next time it'll be the whoever and you know the threat will change so they are always modifying, tweaking ships, always doing capability upgrades, technology is improving all the time so technology is being inserted into the ships as well and so, the ministry has got to	34.33

	respond, the in service problems they have to do capability upgrades, they have got to do all design certification and safety to keep the ship legally, and then they have to do the maintenance, like your car you take it to the garage once a year, well you have to do the same with ships and so the whole costs for that is done via a bunch of people in Abbey wood in Bristol, the dockyards and the sailors, sailors are very expensive so what they would like to do is make sure they can get people in to do the sailors jobs, they are now finding the civil servants are too expensive so they would like to cut down on the number of civil servants, so if they have 100 civil servants doing it and COMPANY A can offer to do it for 60 people then its good for us its good for the MOD and that how we make money and that's the revolution that's going through the system at the moment	
RM	Aye, aye, rather than it being an end total it's an iterative thing, the other… Lloyds are they involved all the way through, do they do an annual, my naivety slightly, ehm their records when you say they are part of the safety case how do their records stack up?	36.40
PK	Well their records stack up very well I mean what Lloyds come and do essentially is what they do for the merchant ships now merchant ship masters are probably even worse than the MOD in that they will do the least possible that they need to do so the Lloyds surveyors will always go onto the ships regularly, under the UK flag will go on and inspect them and they will find defects and they will say, this ship cant go out to sea until you fix this that or the other, the owner knows that, there's no question about it, he may not want to pay them much and he goes and does it and Lloyds register has asset of design rules ok which says how to design a ship, and the reason Lloyds was brought in in the first place was that ships kept sinking so they needed it to get insurance, if you could get an independent viewer to go in then your insurance premium was a lot less and that's how it started but now Lloyds and other classification societies have also become government agencies for making sure that merchant vessels comply with the merchant shipping act ok so merchant ships also have to have all these rules about stability ok and structural strength and safety and fire safety and lifeboats and ship configuration and so as the ministry comes out from behind hiding behind this exemption under law its beginning to use the classification societies because the ministry used to own its own set of rules ok for designing a ship, completely separate from Lloyd register, completely separate from, but they had hundreds of civil servants there just keeping these rules up to date so what they decided to do was they would actually get, they would transfer their rules to Lloyds register for Naval ships so Lloyds register now have a set of rules for naval ships so do the other classification societies, ok, and so the Lloyds register now look after the stability and structural strength on the aircraft carrier im looking	37.01

	at they are also looking at unmanned machinery spaces and a much wider range of activities, that helps us COMPANY A particularly, well not only does it satisfy the legal requirements but in terms of our design process and particularly important one is we get independent verification, I do a design calculation about putting a seat here or something then I get my friend next to me to check it, if im designing a the dimensions of a submarine pressure hull I cant get the guy next to me I have to go to a completely new company over there and they will double check that, so all these various grades of double checking, so yes Lloyds register are involved with ships they are intimately involved in this day it wont get any less and they certainly do hull structure and the stability, previously I got to, and that's all im doing on the second hand market because im playing on the fact that ive got other certification for the work that we do I did try and use them previously on the first ship, it wasn't very successful because you need a firm foundation that you get here in Scotstoun when they first built the ship because if you get Lloyds register to look at the fire fighting appliance which they are doing for type 45 or they will do for the aircraft carrier and then you maintain that, the surveyor comes once a year and he has a, he has his complete record and history of the ship and we have it too and this is the way we are transitioning to it so Lloyds register is a very important part to play and they will be an on cost, you know, a regular annual cost, their structure has to be looked at once a year if you put a weight on over and above a certain amount then you have to re-do the stability calculations and then you may have to do what they call an incline test where they put weights on the ship to understand how its going to move… so in actual fact although I am doing reactivation its only really a specialised part of a 30 year rolling program, of taking the ship and all the things we needed in reactivation is the same as they need for the normal annual year or thing, the only difference is that sometimes it goes outside this boundary I call the design envelope where they leave it to rust so for example gear boxes are meant to have dehumidifiers running all the time when they are operating and if you switch them off and they get rusty so, you cant use the gear boxes when they are rusty you have to do some cleaning that you wouldn't normally do and when they are clean they are back inside the envelope and you can operate again so its best to think that the work I do as an ongoing thing and we, certainly COMPANY A have aspirations to get into this market now being able to look after ships much more cost effectively than the MOD do at the moment so there's this conglomeration joint venture going on in Portsmouth and they will be looking at us to take far greater responsibility you know we, fortunately being in a company because we can make decisions you know we have our own hierarchy and things but by and large you are allowed to make a decision without too much you know checking out, and that speeds things along as well so, there's is money to be made, much	

	money to be made and basically we will do it more cost effectively and the secret to doing it cost effectively is looking after the documentation and having the documentation in the right way so actually it doesn't need to be reconstituted and it can be processed by fewer people.	
AC	At your end when you actually pass the ships over to the new owners or whatever you want to use the terms for, what, do they say this is what we want as our kind of minimum set of information from you? Is there any kind of instances or is it just a case of you going right this we've got here you go, take it all?	43.13
PK	Ill answer, ill answer that question in two ways, the first way is that as Navy's they tend to be less, we tend to sell them to 3rd world nations ok so their navy's and their civil servants if you like aren't quite so far down the track as ours so their maintenance systems are probably worse than ours and they are certainly different, don't get me wrong, the Indians an the Chileans modify their ships quite happily and they get what they do but they do it in a slightly different way, they don't have the same perspective on safety as we do here in the full west and so they have reduced standards, they kind of take the view we will get what we get I mean it's a good deal and eh and they also go by what the royal navy has had we want this ship and we want what the royal navy had, so if it had records for this, this and this all they want is the same as that, they don't tend to come, haven't really known them to ask for anything over and above what the royal navy had ok, they will have what is in the ship files all the hard copies all the filing cabinets, the only areas we do take things out there are certain areas of combat systems that are obviously classified and we actually turn down the gain in certain areas, and of course we do sanitise it, so the ship is not quite so capable as it was with the royal navy you know, its less range or this that and the other or less targets all sorts of things so we do sanitise it and downgrade all of the equipment, and we don't tell them what we have done although they know what equipments we have fiddled with, no they tend to want everything that the navy had and actually in truth is if the navy was operating the ship ok there is nothing more that they would need	43.31
AC	But would that stop you from providing sort of the maintenance test documents extensive test documents during the upgrade and refitting or is that…	45.33
PK	They end up… well, for platform systems they tend to be, they don't tend to be classified very highly so they get even confidential documents for that, combat system records no they wont get those, not in performance terms but they will in terms of maintenance eh and they will get the test results from the demonstrations that they get so there is a slightly grey area	45.42

	there ehm… the other area that is a little bit challenging at the moment for getting the…when the ship is in service it does have engineering service or safety issues and the navy has a fleet of 13 ships it actually sends out documentation to about particular problems, you know, the such and such thing doesn't do this when you want it to do, so they send something out they call a 2022 but what it is, is its just like a sort of notification from the design authority and so there is document, and additionally this is kind of just process stuff that the MOD do themselves, one of the disadvantages we have got in our system at the moment and its worth picking it up actually if you look at the documentation is, most engineering systems work with feedback, they need feedback to work, we say goodbye to the ships as they sail down the Clyde, we don't get the feedback to make our products better and so what would happen is if we can get this feedback in service is that we can learn from it and design and build our ships better but also it apply to much earlier stages and that's something, well I don't think its really readily appreciated that its something we would benefit from to get this feedback in service back into the new build	
AC	I mean is that something that you do maybe not a structured process for it but is that something that you try and encourage or you would try and encourage yourselves if there was a major or if there is something that you know we designed this ship it went to the MOD it came back to us now its getting reactivated, if we had done this better initially you know…	47.36
PK	Well I have done it, I mean I have told you I change propeller shafts or had to repair propeller shafts because ive discovered we are still building them the same way on typ45s here albeit there some minor changes on them, but I have discussed the problem with them and people are satisfied that what we have done is ok and I think they have made enough changes to make the difference I think but I wouldn't put my hand on my heart and I think there are issues of major steering failures when the ship suddenly went into another one so there are major failures like that that ive become aware of that ive spoken to type 45 and you know what happens is that the people building ships here they are not necessarily doing it on their own they do get feedback from the ministry of defence and the operators but its not always that comprehensive its only by who you know and who you talk to, there isn't a proper organisation or process that allows you to do that and this is for our own advantage for our own engineers if we can get a young engineer out here say and we cans end him down to Portsmouth to work for 2 or 3 years and then bring them back here to design a ship and then the management are going down there again and come back, then that's how you get the, one of the reasons I got this job was I was a naval officer, you know propulsion plant so although ive never done a design calculation in my life or not an official one you know I	47.54

	bring to the party that, ive never met someone who's done an engineering who knows it all, it has to be teamwork and so if I go speak to a draughtsman he's, the draughtsman in the CAD office he's got skills I'll never have, but I know that, and he knows that but we can kind of work together and to you know… and I think what we are missing at the moment is this feedback from the in-service experience to make our products even better, its happening in the air world I mean in COMPANY A who look after aircraft for the RAF, you know the aeroplanes are actually being maintained on the ground and prepare for flight like a taxi and the pilots says, you say "right you can get into number 6 now and off you go" and "alright number 6 your times" up you know	
RS	It's all availability now isn't it	50.20
PK	It's all on availability, now the problem with ships is that they go away for 6 months of the year and its not quite possible to do that. But there are things that can be done and you know its not beyond the realms of possibility, we have a contractor on board to guarantee person to do that.	50.21
AC	I guess if COMPANY A is moving toward a kind of more through- life support then it would be a case of it would be coming back a lot more often, it would be in the yard a lot more often	50.40
PK	Essentially the new build systems here, that we produce, the information we create needs to be maintained throughout the life of the ship ok so it could be simplified in certain areas, you know the test form we talked about, but providing the information goes to the ship and is maintained on shore well the other thing which is happening in the merchant world which doesn't happy here in the navy yet is that all the readings to the engines and things, are fed over the internet back to the headquarters so the engineers sit in the headquarters and see what needs to be done	50.49
AC	That's kinda like the formula one where the engineers it in the garage and watch it	51.27
PK	So that would be…that would be… yeah exactly, so that would be one way where COMPANY A could actually help support a ship, you know we may not be on it for 6 months but we could do it from a shore based installation, in most engineering you need to put your hand on it and you know smell it and all the other things that make engineering a dirty job, but 90% of it can be or 80% of it can be done from remote so there are ways we can actually make the current cost of ownership much less, but its early days yet and this	51.30

	project, these re-activation projects are where you kind of bring your design, original design skills back into the ship again which is kind of where im involved, my boss the chief engineer has come from was head of combat systems here so many years ago so we are bringing that we have brought that perspective but that same perspective will still have to be applied to an ordinary year in the life of a ship to make sure that its safe, capable of operation and add its capabilities. So if we can have a system that starts form the shipbuilder and then used for the rest of its life, with the feedback coming back to all the other stages that would provide us with the framework I think to.	
AC	Anything else?	53.02
RS	I think that's plenty… you know just about everything	53.03
PK	I just wonder if there's anything else I haven't really said	53.10
RS	Thinking about it as an aside it must be something that happens in the merchant fleet you know the change of ownership, you know you would always envisage them forever passing ships around and transferring ownership and things so I suppose it must be a not unknown event in that	53.13
PK	They sell ships on but they use Lloyds register to check on everything ands then they will know about the systems. merchant ships tend to have everything looked at you know the engineering systems and eh not just the safety features because its hard to divide them the two its like going to the AA to have your car checked if you are going to buy a second-hand one, they have to do it by law so that's why the law is there because they used to bypass it in days gone by. Ehm…so the other thing is, that's a point actually, one of the areas we have been weak at the moment is sort of surveying of ships you know its difficult, if you take a ship on half the, 20 year down the life you are never gonna find any problems until you try and get it to work. Ok so you have to assess the condition of the ship when you take ownership of it and that means its working condition whether there's defects with it and when you go and see it. You know you can go and give it a mark 1 eyeballing or a severe torching but it doesn't tell you whether it works or not so any records we can have can actually not only describe what you have got but how its working and how its functioning	53.28
AC	Uhu…what areas have not functioned in the past…	54.53
PK	The last thing we want to do also is to let go of a ship and let it sit against the wall and rust for 1 or 2 years I mean actually the ministry is losing an opportunity because it does do that	54.55

	with its ships in the past and then its suddenly find its gonna cost an arm and a leg to	
AC	Yeah cause essentially the ships aren't designed to be doing that the ships are designed to be in service constantly	55.14
PK	And, and the other thing to think about in terms of re-activating ships like this you know these guys, the guys downstairs design new ships for new customers so its like a garage so you have a new car over there all bright and shiny and it's the smaller thing but its nice and compact but you can have the bigger Navy had one but its older and you know so there's that equation as well in terms of what a foreign market will want…ehm…from a foreign navy's perspective they have a number of things that they want, what they want is the capability but they also want to get a bit of this technology transfer as well, they don't quite know what the 3rd, the modern navy's are doing so if they were to buy an old ship ok so its 10 years but at least they could see the kind of technology which we use and the way people were thinking and the ways things have changes and that would actually keep them up in the hunt. So there are slightly subtler reasons for going for second-hand ships as well	55.18
RS	I suppose this ones a bit better than the one you had before and then you one you get after that is a step change further on you know it keeps you moving forward	56.24
AC	There is you know, it just about the extension of military power you know if you have got an ex 1st world, 1st nation we have got one of these then you know it has some kind of standing… so, there we are.	56.31
AC	Thank you very much	56.47
RS	That was really good yeah than you very much for your time	56.48
	END OF INTERVIEW	**56.50**

Appendix B: Concept Design Meeting Experiment 1

Date: 23/11/2006

Participants

Chairperson: Marissa Smith (MS)

Designers: Ross MacLachlan (RM)

Jose Hernandez (JH)

Liam Hastie (LH)

Kevin Miller (KM)

Legend

ID Identity of the speaker (initials);

Transcript Text transcribing speech;

Time Time when the intervention ended (minutes: seconds);

Type Intervention type (statement (S), question (Q), answer (A), or feeling/emotion (F));

Role Exchange role (informing (INF), exploring (EXP), resolving problems (RES), managing (MAN), evaluating (EVA), debating (DEB), digressing (DIG), clarifying (CLA), or decision making (DEC));

IT Information type (product (PROD.), process (PROC.) Resources (RES.), or external factors (EXT));

Media Primary Media type (Drawing (D), Image (Ia, Ib, Ic), Model (Ma, Mb, Mc), Gesture (G), Speech (S), Text (T));

Item Agenda Item

Crit. Sit. Critical situations; 1 - Goal analysis and goal decision, 2 – Information and solution search, 3 – Analysis of solutions and decision-making, 4- Disturbance management, 5 - Conflict management

Crit Dec. Critical decisions; _

Transcript Conventions

Text conventions

- Words in *italics* are approximately transcribed
- … In the text marks a pause of 10 seconds or less
- (…) In the text marks a pause of more than 10 seconds
- […] In the text marks a pause of more than 30 seconds
- Underlined words are those which overlap with the transcript following

Specific speaker conventions

- [ID] some or part of the intervention from this speaker was not transcribed and the reason given in the transcript encased in [ ]
- ID = X, the identity of the speaker was not recognised

ID = X, the identity of the speaker was not recognised

ID	Transcript	Time	Type	Role	IT	Media	Item	Crit. Sit.	Crit. Dec.
MS	Right… so you know your design briefs… so…	00:00	S	MAN		S			
KM	Has everyone…oh sorry	00:03	S			S			
MS	Sorry…On you go	00:04	S			S			
KM	Has everyone looked at them?	00:05	Q	CLA		G			
LH	Eh…I had a quick scan…I'll read it now	00:07	A			S			
MS	Right, so the first section of the agenda we want to review the design brief… identify the unique selling point of the cup holder design…so we have ten minutes to discuss that and for you to give some feedback on that to me	00:10	S	MAN	PROC	T			
KM	Right	00:27	S	CLA		S	1		
MS	*Just discuss* it amongst yourselves…im not actually part of the design	00:27	S	MAN		S			
KM	Ok…the unique selling point of it…	00:31	S			T			
RM	Spill… that there should be no spillage	00:36	S	CLA	PROD	T		**1**	
JH	And the fact that it is re-usable as well	00:39	S			T			

KM	Yeah and its biodegradable … so you've got…right its environmentally friendly	00:40	S			T			
LH	yeah	00:46	S			T			
RM	Does it say its reusable?	00:47	Q			T			
KM	Just recyclable	00:49	A			S			
RM	Recyclable…the material being recyclable?	00:51	Q			S			
JH	Hmm yeah …the material of the cup by itself…but I think you can use the cup again	00:54	A	INF	RES	S			
RM	Eh…or the transporter, I don't think we are <u>considering the cup</u>	00:58	S			S			
JH	Ah… I see, see, see,	01:02	S			S			
KM	I mean it could be part of the design but I think it's the nature of the material	01:03	S			S			
LH	yeah	01:07	S	DEB		S			
KM	It wouldn't be able to be reusable…so its just the fact that its recyclable but do you think it's a big deal when it comes to coffee cause like the origin of coffee, countries it comes from, theyll want it to be environmentally friendly	01:08	Q		PROD	S	1	**1**	

LH	uhuh	01:19	A			S			
KM	Erm… so that's one unique selling point	01:20	S	DEC		S			
LH	Is that unique?…cause I thought…I mean you do get other materials which are recyclable and…	01:23	Q	DEB		S			
KM	Perhaps not unique	01:26	A			S			
RM	Hmm… I mean you get starbucks all over the world and they would standardise their cup size anyway for their shops…but then you've got different retailers and stuff like that so..	01:30	S	INF		S			
KM	So its just the selling point then its not unique	01:43	S			S			
RM	yeah	01:46	S	DEC		S			
JH	There's nothing really if you think about it...because well if you can adapt it to different sizes but It means the sizes are going to be different depending on your location	01:47	S	DEB		T		**1**	
KM	Oh hang on *a minute*…you're right it does say re-usable here	01:55	S	CLA	RES	T			
JH	Yeah	01:58	S			S			

KM	It's the very last line here	01:59	S			S				
RM	Oh…ok	02:00	S			S				
KM	So maybe that's what's… eh unique	02:01	Q		PRO D	S				
RM	Yeah	02:03	A	DEC		S				
KM	*Cant believe* we got that out of the road right at the start… that its reusable	02:06	S	DIG	PRO C	S				
RM	Its certainly difficult to make a paper reusable	02:10	S		PRO D	S			**1**	
KM	It is	02:13	S			S				
RM	But if there is no spillage then maybe that's…	02:14	Q	DEB		S				
JH	Yeah that's true	02:17	A			S				
KM	Surely…I mean… surely the spillage depend on how the cups come…you know if they don't have a lid on them then… or if the lid's a bit faulty then its not so much the container	02:21	S		PRO D	S				
RM	The device could provide some kind of covering	02:37	S	EXP		G	1			

JH	Well most of the glasses have you know, a lid that you put on them but still they're not very safe are they? They have little holes and if you move them about they will still spill	02:42	S			G			
KM	Ok well its something to think about in the design I suppose but the unique selling point is that its reusable?	02:51	Q	DEC		S			
JH	Yeah	02:56	A			S			
MS	So everybody's decided that?	02:57	S	CLA	PROC	S			
LH	Yip	02:59	A			S			
KM	Yeah	02:59	A			S			
RM	Yeah	02:59	A			S			
JH	Yeah	02:59	A			S			

RM	I just noticed that…the temperature of the coffee must be maintained…so that a transporter normally wouldn't… maintain temperature…it would just be a card thing holding the coffee so there is nothing insulating it and doing anything more than the cup does itself…is it unique selling points or unique selling point?	03:05	Q	EXP	RES	T			
MS	It just says identify the unique selling point of the cup holder design	03:32	A	CLA		T			
KM	I mean the temperature… I suppose its just as well as possible… you know it doesn't look too stringent *or that* strict	03:36	S	EXP	PROD	S		**2**	
LH	Well…I mean again…is it a unique product anyway…I mean how many… when you walk into these places…which I don't frequent … do you get multiple cup holders or is it just a plastic tray you get for this?	03:45	Q			S			

KM	I've seen people walk around with um you know its like four cups held you know, almost like the egg cartons that you just put it in…but that's all that I know of…	03:47	A			G			
LH	But is that paper?	04:05	Q		PROD	S	1		
KM	it's the egg sorta	04:06	A			G			
LH	The sort of cardboardy stuff?	04:06	Q			S			
KM	Yeah	04:07	A			S			
LH	Id say that's paper yeah	04:07	A			S			
KM	Yeah… you know the paper mashie kinda thing … do you know any other ones?	04:08	Q			S			
JH	I've seen ones that are cool too...there's like …there's two boxes… and they have a handle in the middle…	04:12	A			D			
RM	Yeah	04:20	S			S			
JH	And then you've got a bit like that	04:20	S			D			
LH	Yeah, yeah ive seen ones like that	04:22	S			S			

KM	See that would probably insulate quite well…I mean the cup is submersed in it I suppose so…	04:23	S			S			
MS	We’ve got about a couple of minutes…so if we could try and wrap this up	04:29	S	MAN	PROC	S			
RM	I think we are maybe moving onto solutions before…	04:34	S			S			
KM	Yeah…right ok so… our unique selling point is reusable…that seems to be the only distinguishing thing about it eh?	04:36	Q	DEC	PROD	S			
LH	Yeah… I would say so, yeah… I would say its something that others wouldn’t do	04:46	A			S			
KM	The sizes that differ…	04:48	S			S			
RM	I’m still not sold on the temperature not being a…	04:50	F	DEB		S			
KM	Unique point	04:55	S			S			
RM	I’m not saying the reusable isn’t but I think it might be as well…	04:56	S			S	1		
JH	Yeah, yeah	04:59	S			S			

RM	It says it must be maintained, other solutions don't even seem to attempt…to maintain temperature	05:00	S		RES	T			
LH	There is a bit there says it must be maintained as well as possible…you know its like a kinda	05:12	S			T			
KM	Where as the last one is it must be safe and reusable	05:17	S			T			
RM	Ok	05:24	S			S			
MS	Right…so you've decided the unique selling point is the reusable aspect… why would that be…why is that important…what's the reasoning behind it?	05:25	Q	CLA	PROD	S			
RM	Important to the customer or?	05:36	Q			S			
MS	That you think its important to the customer…why have you picked it as a unique selling point	05:39	Q	INF		S			

KM	It might be an office run that people go on regularly so…keep collecting these or throwing them out or wondering what to do with them back at the office…they've just got one that they can pass to whoever's going out for them so I guess it's a practical…and if it is unique as we think it could be…I think it would save…um its good that it is recyclable but the less that you have to recycle the better	05:42	F	EXP	PROD	G			
LH	To me its more a question of the customers…I'm not seeing the customer as the person taking the coffees out the shop…I'm seeing the customer as the shop…you know it'll be starbucks who orders this and it will be them who will be interested in it being reusable purely to save on the amount of stock they have and the space they need for this.	06:08	F			G			

RM	I mean none of the competitors I can think of… are reusable…so just being reusable differentiates you from…	06:28	F			S			
KM	On its own	06:37	S			S	1		
RM	The competitors… obviously there has to be a good reason for you to do it but that alone…	06:38	S			S			
KM	So from the user…the company…like, the shop and like it distinguishes itself	06:46	S			S			
RM	Yeah	06:55	S			S			
MS	Right, you want to move on to the next point on the agenda?	06:57	Q	MAN	PROC	S	2		
KM	Which is?	07:00	Q	CLA		S			
MS	And that is to…ehm…generate concepts, combine and reduce and select three to take forward…so come up with some concepts for these cups, and then within ten minutes pick three that you want to take forward to go to the next *stage*	07:01	S	INF		T			

KM	*Well,* I mean we've got this one here we could use as the datum or like the…egg	07:20	S	DEB		I			
RM	The tray	07:25	S		RES	S			
KM	The tray, yeah…it holds four	07:26	S			S			
JH	So everyone has to mention, like write out *several* and then we discuss them or do we just go as we speak	07:30	Q		PROC	G			
KM	ehm	07:37	S			S			
RM	I don't know are we to do this individually?	07:38	Q	CLA		S			
MS	No, as a team I think	07:40	A	INF		S			
KM	Just try and bang out some as a group then and then whittle them down	07:42	S	CLA		S			
MS	Whatever, however you feel I think, just go for it	07:45	S	MAN		S			
KM	Right, the quickest way to do it then is just to run with like basic shapes then…so we've got the tray that will take four…we've got this other one	07:48	S	DEC		I	2		
RM	With a handle	07:58	S	RES	PROD	G			
KM	With the handle…which is	07:59	S	DEB		G			

RM	Either hold it like a tray or carry it by <u>handles</u> or…	08:01	Q			G			
KM	Yeah	08:03	A			G			
RM	Hang it off your body	08:05	S			G		**2**	
KM	Interesting…or stack them…in some way…if possible	08:07	S	EXP		G			
JH	What about something that is…this can be foldable…it says two or more so what about adding more foldable spaces you can unfold to put more cups in…so *whether* you have two you can put three or four… but if you want two you don't have to unfold the other bits	08:11	S			D,G			

RM	It's kinda like…uh no…I think the…ive never seen the option of folding bits you know or not…but the…the wine carriers you get from off licenses or supermarkets have like space for maybe six made out of corrugated card and they're just folded up…with a handle…which is kinda like that but you wouldn't have the option of	08:28	S			G,I					

LH	I think the problem you've got is because …the foldy out bits, they create a sort of wall if you like…so when you fold it out you know…it goes from being flat, to coming out to the wall…but the actual floor part has to be something else that comes from below or wherever…so it tends to be that once you've made these things up, like those, its pretty rigid…and it's a case of you don't use the other ones that your not using, they're just there…so if you actually try and fold that out, you cant…I don't think its very simple to just fold it out, you know what I mean?…uhm	08:53	S			D,G			
KM	Would we be over complicating the design by having that…a folding	09:21	Q	CLA	PRO D	S	2		
LH	I think so, it would be easy to get, like I said like the walls to come out, but then get the sort of part underneath to come out and lock in	09:28	A	EXP		G			
KM	Yeah…unless the…yeah	09:34	S			S			

LH	So I think…I mean the important things from that point of view at supermarkets and off-licences is that it can go from being something very flat and easy to store to something made really quickly…you know if you think of the McDonalds kinda model where you get the staff flicking these things out you know onto the counter sorta thing…uhm so something that you can, I don't know, expand easily…store easily…uhm…would probably be a bonus as well	09:36	S			G		**3**	
KM	So we would want them to say, be flat packed but then in the shop be just…	10:03	Q			G			
LH	Flat packed or stackable	10:09	A	DEC		S			
RM	Its just the payoff between whether its worth getting this expandability over just having a range of you know one for two cups and one for four	10:13	S	DEB		G			

LH	Unless you've got the two cup model which can be slotted into another two cup model to make a four cup model	10:23	S			D			
JH	That's a very good idea	10:27	F	RES		S			
LH	Like some sort of jigsawy thing…but then the obvious problem you've got there is that you've got two handles so if you take that one from the sort of side view…you know you've got one here…here, with a handle up here, if you link that straight into another one you've just got two handles so maybe if you had one…with a handle like kind of you know curved towards that direction…so if you link it up you've kinda got the other handle beside it…but I don't know if that would be nice to carry about as just one… if the handle doesn't have to be paper it could be string or something like that	10:29	S	EXP	PROD	D	2	**2**	

RM	Could you maybe even get three units together…so you could carry six	11:03	Q			S			
LH	I mean, what sort of numbers are we, I guess six in each hand would be pretty much the maximum we would be wanting to carry anyway isn't it…so that would be like 12 cups of coffee sort of thing…so yeah if there's a way to get maybe three of those to slot together ehm that would be nice	11:11	S			G			
KM	OK	11:30	S			S			
RM	Its…its maybe a bit odd to first identify that reusable is the…the kinda unique point of it and then we haven't discussed that …in the design	11:31	S	DEB	PROC	S			
KM	Well,	11:46	S			S			
JH	Is that not more about materials?	11:48	Q			S			
RM	Well, yeah I guess is probably relevant	11:51	A	EVA		S			

KM	I think this, the very design of this, is reusable because its something you take apart when you got back somehow, and then next time your going out for two you know just take the two along, like you know we need four this time slot another, another two on, so I think that concept is inherently reusable…and but what im worried about is that we are just going down the road of one concept…like we would want to explore a few…I mean its easy enough to bang out silly concept ideas isn't it	11:53	S			I,G	2		
MS	Right… so…you've got about another 5, 7 minutes to go	12:25	S	MAN	PROC	S			
KM	How many ideas do we have to take <u>forward?</u>	12:28	Q	CLA		S			
MS	Three to take forward…	12:29	A	INF		S			
KM	Three?	12:30	Q	CLA		S			
MS	Yeah	12:30	A	INF		S			

KM	It doesn't matter how many we generate, right so we thought of the tray…which is pretty basic…and we thought of the two cup holder…and then, are there any other ideas?	12:31	Q	EXP		D			
[JH]	I think its just a matter of seeing how they're actually being transported cause… these ones are being held in the bottom, these ones can either be held by the bottom or if it depends on the shape of the box, because cups are not straight… so you can hold them by the middle like that drawing you have there…or maybe using the lids as well as carries, you know like you just [sound not transcribable] and you just carry them so *I think it might* be good to see how else can you transport them other than the usual ways [speech not audible]	12:45	A		PRO D	I, D,G		**2**	

RM	It would be brilliant for just a big…lid with a handle on it that you just click on to the top and just picks them	13:15	F			G			
JH	You can put just [speech not audible]	13:21	S	DEB		G			
KM	Yeah	13:23	S			S			
LH	Yeah	13:25	S			S			
KM	OK… so would that be circular then would you say or rectangular or anything	13:25	Q	EXP		D	2		
RM	Maybe rectangular with kinda rounded…rounded edges like that so they fit the contour of the cup	13:30	A			D			
KM	So if your looking at it from underneath it then you're seeing again the kinda rectangle bit…there's these kinda indents that would hold the cup	13:37	S			D			
RM	Yeah…so maybe some kind click it in a, that would form a lid and maybe be able to control the temperature better	13:46	S			G			
KM	Yeah	13:55	S	RES	PROD	S			
JH	Yeah	13:55	S			S			

KM	And would they just em… hang then…so they'd look like…and its snapped into the top now…ok	13:57	S	CLA		D			
JH	Just carry it from there or something like that then	14:10	S			I			
KM	What's do yous think about that?	14:13	Q			S			
RM	It might be difficult to set them down again, you know, how do you get them off there	14:15	A	DEB		G			
JH	That'd just be like the other one	14:20	S			G			
[LH]	Yeah… you'd have to have some of them sorta lined up before you…I like it yeah…but something goin on the same sort of principle…youd just have a really long tube…maybe with two handles… one either side and all youd do is [sound not transcribe able] put one in, then put another one in, then put another one in..	14:21	S	EXP	PRO C	G, D		**3**	
KM	See I think that would work	14:36	F	RES		S			

JH	I think that’s a good idea too	14:37	F			S	2		
LH	It might be tricky to get them out, youd really need to sorta put your arm all the way down sorta	14:38	S	EXP		G			
JH	You can just do it little by little, just lift it up, removing the bottom then you can just move the ones	14:43	S		PROD	G			
LH	Yeah yeah	14:48	S			S			
RM	Its like a Pez dispenser	14:49	S	INF		S			
LH	Aye and you can carry it by sort of…you could carry it by a wee handle on the top… kinda thing…and that would keep all your coffee kind of altogether so all the heat would be contained and you know the heat from the lower ones would heat the top ones and all that sort of thing…spillage wouldn’t be too likely as well…well actually thats not true	14:51	S	EXP		D, G		**2**	

KM	If they're tight… but if they're tight in then they're not gonna be moving around so…where as if your carrying them in a tray they're all gonna jiggle about a little bit…em, right we've gotta get three to go with, so I think the first idea, the one that slots into each other, we could go with that so its pretty much that except extendable yeah?	15:08	Q	CLA		G, I		**3**	
RM	Uh huh	15:28	A			S			
MS	So it's a slotted in	15:29	Q			S			
KM	Yeah…three like slotted together rectangles…two linking to	15:30	A	DEC		G			
RM	Modular	15:36	S	INF		S			
KM	That's the word your looking for	15:37	S			S			
MS	Modular design	15:40	S			S			
KM	Em…the next one's cylindrical…and em…should we go for the basic tray or just hanging?…id say we could just work with the hanging one and just see	15:41	Q	DEB	PROC	I			

RM	Well…there's maybe similar issues in detaching the cups from that one as there are from getting them out the tube again…so we're gonna have to think of a release mechanism at some point	15:55	A			I			
KM	Ok if we go with this one then at least we can compare it against the boxes that are basically out there already…what do you think?	16:09	Q			I			
RM	Yeah	16:14	S	DEC		S	2		
MS	What are we callin that? Like a grip lid or something?	16:15	Q	CLA		S			
KM	Eh yeah	16:17	A			S			
RM	A hanging	16:18	S			S			
MS	Hanging	16:19	S		PRO D	S			
KM	Or lid grip	16:20	S	INF		S			
MS	Lid grip	16:21	S			S			
RM	Big Lid	16:24	S			S			
KM	Yeah	16:26	S			S			
RM	Multi lid	16:27	S			S			
MS	Right…so the third and final phase is to identify the final concept	16:32	S	MA N	PRO C	T	3		

KM	So…and this could just be the training from my undergraduate course but if the take a datum…like the standard one which is available and then rate the other ones against it…like minuses pluses, how many can it hold, how stable is it, what's the spillage like, whats the temperature like	16:38	S	INF		T, I, G			
LH	Evaluation matrix	16:56	S			S			
KM	Yeah that's the one	16:57	S			S			
RM	So what are we evaluating	16:59	Q	CLA		S			
KM	Well, lets see we have got the three…and the datum is going to be…the, the normal tray	17:02	S	INF		T	3		
RM	Or do we maybe have to take one of our selected ones as a datum	17:09	Q	DEB		S			
KM	As a datum…I think we could take one that's not	17:12	A			S			
JH	Nah I say we take that one there	17:15	S	DEC		I			
KM	So we've got the…we've got the tray	17:17	S	CLA	PROD	T			

LH	Yeah I think we should use it against the products out there just now so	17:22	S	DEC		S			
[KM]	Yeah… we got the one that you carry…then we've got the [speech not audible] and the variables that we are gonna go for are…	17:25	S	INF		S			
RM	Reusable has gotta be one of them	17:35	S	DEC		S			
MS	What do you call that matrix again?	17:37	Q	CLA		S			
LH	Eh…Evaluation matrix	17:39	A	INF		S			
KM	Morphological chart	17:40	A		PRO C	S			
RM	Or is it?…morphological is ideas	17:43	Q			S			
KM	The idea generation	17:46	A	DEB		S			
LH	Yeah yeah	17:47	S			S			
RM	So its an evaluation matrix then	17:48	S			S			
KM	That's it yeah…so its back to what it was	17:49	S	INF		S			
MS	that's alright…I couldnae spell it anyway	17:54	S	DIG		S			
[LH]	Or is it a convergence matrix then?… no, no, evaluation matrix	17:55	Q			S			
MS	We're callin it that	17:57	A	DEC		S			

KM	So we're going for reusable…temperature	18:00	S		PROD	T			
JH	Temperature of coffee…spillages as well…number of cups	18:02	S			T			
RM	Adaptability to different cup sizes	18:14	S			T	3		
KM	Cup sizes and cup numbers…what about cup sizes, yeah, sorry I just wrote that	18:17	S			T			
LH	Yeah	18:18	S			S			
KM	Right so should we just go with these five then?	18:32	Q	CLA	PROC	T			
RM	Spillage	18:34	S	INF		S			
KM	We've got down	18:35	S			S			
RM	Have you?	18:36	Q	CLA		S			
KM	Yeah, reusable, temperature, spillage, the number of cups and cup sizes	18:37	A	INF		T			
[JH]	But like how will we [audio not understood]	18:41	S		RES	S			
RM	Sorry?	18:46	Q	CLA		S			
JH	Recyclability is just, we are not meant to consider, cause it depends on the material	18:47	S	DEB		S			
RM	Yeah	18:50	S			S			

LH	Yes	18:50	S			S			
RM	Unless theres maybe other features that would make it… like how easily you could take it apart…or	18:53	S			S			
LH	Well one of the things it says is its gotta be mostly made out of paper…so…each of these designs…you know we'd have to consider how much paper, you know if we would need to use any other materials in that, you know if youre talking about a grip one you might have some sorta spring, plastic mechanism, *that's unnatural*	19:03	S	EXP		T			
KM	So should we put material for requirements, that's another one	19:21	Q	CLA		T			
LH	Or just mostly paper	19:24	S			S			
KM	Yeah	19:26	S	DEC		S	3		

RM	Well I think maybe the datum one, you know how it says you have to be fifty percent or less mass of binder, that paper mashie stuff maybe doesn't…eh have less than fifty percent binder	19:27	S	DEB	PRO C	I, T			
KM	That's a good idea	19:42	F			S			
RM	But and to be honest all the concepts needs to be kinda foldable apart from that one	19:44	S			I			
KM	Ok so if we are rating this eh standard one, reusable?…its pretty reusable	19:52	Q	EVA		I		**3**	
LH	I think it is yeah	20:01	A	DEC		S			
JH	Do you think if its wet…it just eh…it doesn't work anymore? Cause the carton it gets very soft so…but if I… I mean they don't need to pay for it	20:02	Q	EXP	PRO D	G			

LH	I mean I find it a bit tricky cause…if I was making something that I wanted to be reusable I wouldn't make it out of paper cause I think that as soon as you pick up something made out of paper you just want to throw it away	20:14	A			S			
KM	Cause If you use it in like the rain…then its you know its inherently un reusable	20:22	S			S			
RM	Or just even if you know the fact that every time you go to the shop you're gonna get a… you can get a new one… you're not gonna carry it about with you	20:26	S			S			
KM	Well I forgot we don't have to rate the datum…	20:35	S	INF	PROC	S			
RM	Its just more or less	20:37	S			S			
KM	Yeah…the cylinder then, is it more or less reusable than the… the tray?	20:39	Q	EVA	PROD	I			
MS	You've got ten minutes to come up with your concept	20:45	S	MAN		S			

JH	I think its more reusable now…cause its more of a novel idea, so people might like to stick with it	20:49	F			S			
KM	Id say that's probably fair…just the novelty of it would make people reuse it	20:56	F			S			
LH	I dunno id be tempted just to say the same…cause you know its the same material…uhm…cause you can say that novelty factor but on the opposite hand you can say…you know its bigger to store…harder to carry maybe, you know so its bigger are you gonna shove that in your boot and drive it back to the coffee shop	21:02	S	EVA		G	3	**3**	
KM	It fits in the corner somewhere though, whereas well I guess you can just lean it against the walls	21:16	S			G			
JH	Yeah…*it doesn't have to be massive*, if its just this size you can carry four cups	21:20	S			G			

RM	Depending on how the cups are attached… it may be…maybe its less likely to cause spillage	21:28	S	DEB		S			
KM	Oh definitely	21:37	F			S			
RM	And for that reason	21:39	S			S			
KM	So that gets a plus for spillage	21:40	S	DEC	PROC	T			
RM	So for that reason it is more reusable so realise	21:42	S	DEB		S			
LH	Oh yeah	21:45	F			S			
[KM]	Reusable, temperature I guess is a plus cause of what you just pointed out, [audio not understood] spillage, number of cups, well there is one, two, three, four, you know and it doesn't really matter if it holds	21:46	S	EXP		T, G			
LH	Yeah and it wouldn't be difficult to get us to just cut it at different heights…to accommodate different glasses or cups	21:58	F			G			

KM	But there's still going to be a determined number in it so to differentiate it from the one that is modular I think we should just make it the same as this one…eh cup sizes…well you'd have to watch what your placing it in, if you've got a tiny espresso cup	22:02	S			G, I			
LH	See this is tricky yeah, you'd have to a different size I guess for each cup	22:16	S			S			
KM	But I guess its still better than this other one…yeah…its better than that one cause a tiny cup would just slip through the bits…we'll give it a plus…and mostly paper? Same?	22:19	F		PRO D	I, T	3		
LH	I… eh don't see any reason why it wouldn't be…the only thing that bothers me is	22:30	F			S		**3**	
JH	But if you have a surface and all the pressure is gonna be falling on that little surface…so I think that's the only problem really…cause its made out of paper I think its gonna be weaker	22.34	S	DEB		G			

LH	yeah	22:43	S			S			
KM	Maybe a minus then	22:45	S		PROC	S			
RM	It will have a more complex internal structure to hold the…the cups which could generate more paper…or less to be honest	22:46	S			G			
KM	We’ll give it a minus	22:57	S	DEC		T			
LH	I think yeah it’ll be a minus cause it’ll definitely be more paper if its not needing other materials as well	22:58	F	RES	PROD	S			
KM	So the next ones this, the modular idea but based on the one that already exists…reusable? Cause we were thinking make it foam board so its very good…temperature…compared to this	23:03	S	EVA		I			
RM	Slightly more if its got sides	23:19	S			I			
KM	Yeah its positive, marginally…spillage…they're held in place aren’t they so…	23:21	S			I			
RM	If you’ve got a handle, definitely	23:27	S			G			
JH	Yeah…You will never get touched by the coffee	23:28	S			S	3		

KM	So its positive…number of cups…its modular so, that’s gotta be a plus…particularly relative to this one	23:30	S	EVA	PRO C	G, T			
LH	Reuse again as well…does that kinda fall into spillage…I guess would be a main	23:40	S	DEB	PRO D	S		3	
KM	Yeah just keep that in under spillage…cup sizes…its not…id say its probably the same as the datum… because it still holds them, reasonably	23:42	S			T			
JH	Well… the thing is it depend on what you have here… cause if you have...like a flower kinda thing with cups…you can use to different sizes and they will just fold to the sides and then if you take them out they will just spring back	23:55	S			I			
KM	That’s the same as…the tray though isn’t it?…	24:08	Q	CLA		I			
JH	Hmm…yeah	24:12	A	INF		S			

KM	It looks like the thing that you just push in…so will we make it the same?…as the datum…and mostly paper…I think it might have to be plastic eh	24:14	F	DEB		I, T			
RM	Nah, those wine ones are kinda	24:24	S			S			
JH	Can be carton is says somewhere here	24:29	S	INF		T			
RM	It says corrugated cardboard qualifies so it could be that… corrugated card stuff	24:30	S			T			
JH	Which is quite straight isnt it	24:34	Q	CLA		S			
RM	Yeah its quite strong as well	24:37	A	INF		S			
KM	Ok so we can run with that then…so we give it a…better than the…like normal datum	24:39	S	DEC	PRO C	T			
RM	In terms of… how much paper is used?	24:46	Q	CLA	PRO D	S			
KM	yeah	24:48	A			S			
RM	I say more is used	24:50	S	DEB		S	3		
KM	More paper?	24:52	Q			S			
RM	Do you not think?	24:53	A			S		**3**	

LH	You've got the walls and stuff and…	24:54	S			S			
KM	Yeah…so that's gonna be a negative then isn't it	24:56	Q		PROC	T			
RM	yeah	24:59	A	DEC		S			
KM	And the last ones this eh…the old lid grip…ehm…reusable…it s flat…its sits against the wall…if it is gonna be a plastic kinda snap grip thing, people will be more likely to keep plastic than something that's all paper…so maybe plus again	25:02	S	EXP	PROD	I, G, T			
RM	It cant be plastic though	25:24	S			S			

LH	Well it says…you know…as much... should be mostly made out of paper so im taking it that we should avoid all other materials if we can but if it becomes a part of the design…I mean there are potential ways you could do that with paper I guess…but…you know I reckon itd be much easier to do with a bit of plastic and springs, you know the actual lid part kinda thing…uhm…im trying to think of something that ive saw one on…	25:28	S			G			
KM	Not that recyclable if its plastic though	25:49	S			S			
[LH]	You're right cause i mean it does kinda mean…[audio not understood] I dunno is there a way we could do that with paper?	25:53	Q			S			
JH	You make up cardboard and you have holes like you have a seat kinda thing and you like grip them…from the circle but the thing is that will only work in one dimension…you know you have only one lane to gather up	25:58	S			G			

KM	I think we should look at is as a plastic thing…fair enough it could be...but if we look at it all as paper cause we don't have like a	26:12	F			I, G			
LH	Yeah, yeah I think that's true	26:20	S			S	3	**3**	
KM	So we will just put that as a same	26:23	S	DEC	PRO C	T			
MS	You've got about five minutes left just to come up with your	26:25	S	MA N		S			
KM	Ok…temperature…its just hanging again like that so its gonna be the same…spillage…I mean	26:28	S	EVA	PRO D	I			
JH	Its probably be worse	26:34	S			S			
KM	I mean what about the cup…its held by its lid the whole time and I think that idea	26:25	F			S			
RM	There might be improved temperature because you are covering	26:39	F			I			
KM	All the lids…that's right, that's right	26:43	S			S			
RM	But I mean the body of the cup would still be exposed so…depends how much heat is lost through the body	26:45	S			G			

MS	Right ok, in the next five minutes we really need to come up with a…the concept and eh why we came up with that concept really	26:52	S	MAN	PROC	S			
JH	Is it not gonna be worse at spillages…when you try to remove the lid its gonna	26:57	S	DEB	PROD	G			
KM	Id say that's potential gonna be minus…number of cups, it's limited again so its gonna be the same as the datum…cup sizes, well that's really limited again cause…well unless its going with this	27:03	S			T			
RM	But if the cups suspended by that thing it could be quite…not dangerous but like you could lose a few cups if its only suspended by these tabs	27:16	S			G			
KM	Yeah…so we'll give that minus and mostly paper…well we've already spoken about that so…we'll put same as the datum…so I mean right so if we are going back through these, this comes out worst…this has got the most	27:24	S	DEC	PROC	T			

JH	It's the same but	27:41	S	EXP		S	3		
KM	It's exactly the same…em,so…I like the modular idea cause you can get more for the number of cups…the negatives exactly the same…the cup sizes I think, its not a big selling point, whereas if we want another unique selling point and contributing to what we have identified as the unique selling point, the reusability…if we make it modular then we can go with this size here	27:42	S			I, T			
LH	Ok, how are we gonna make it modular?	28:13	Q	CLA	PRO D	S			
KM	Em I think	28:16	A	EXP		S			
RM	You juts have to have the same unit which can be attached to another of the same unit	28:17	A			G			
LH	Maybe something that you slip down	28:22	S			G		**2**	
JH	Its like a lid thing	28:24	S			G			
MS	So you've decide that your making it as a modular design?	28:25	Q	CLA	PRO C	S			
KM	yeah	28:27	A	DEC		S			

MS	A modular design	28:28	S			S			
KM	And…you know, there’s a number of things, ways we could develop this design further, I mean we could make it longer so that it held four cups so that you could get four, eight, twelve, twenty four, you know not all together…ehm so i think there is the most potential for that one	28:30	S	INF	PROD	G, I			
LH	Yeah I think too	28:49	S			S			
MS	So there’s most potential cause its got room for…to expand it	28:50	S	EVA		S			
KM	Yeah and also the design itself is more	28:53	S			G			
JH	More suitable yeah	28:56	S			S			
KM	And if it is gonna be flat…I mean we were talking about it being flat, you just pop…transportation is easier…its more likely to be reused because its modular…the temperature, its fully enclosed so its going to be better at keeping the temperature	28:58	S			G, T, I	3	**2**	

RM	Has it got a lid on it?…it could have a lid on it	29:13	Q	CLA		I			
KM	Its possible I mean we could make it so the cups go right inside and you fold something over the top of it and the lid comes down it could be part of the modular system…so I think its got the most potential…its got the most potential for design…its got…better…it'll hold the cups better so there should be less spillage…the number of cups its expandable and variable…em…	29:17	A	EXP		G			
RM	And you could just make the compartments… as em… as big as the biggest cup…you could get the market and use something like that inside to deal with smaller cups	29:44	S			G, I			
KM	Or even have dividers so you that you don't even have to have slots you could put like… bits of card that you put in, slam it against the cup and it holds it in place and then…so for different sizes its just	29:56	S			G			

RM	Aye its like just a trough thing that you put card in	30:07	S			G			
KM	Slide it in…so its definitely…I mean if the design is going to go any further its good…I mean the worst that's going to happen is that you're going to end up with lots of lids	30:10	S			T			
RM	So is the design meant to go any further?	30:20	Q	CLA	PRO C	S			
MS	No just to identify the final concept…so you've…just to recap you've agreed on the modular design because you can expand the plastic carrier and you think that will be a good idea because it will be used because its…you can change the capacity of the	30:22	A	MA N		S			
JH	Its foldable also	30:40	S	INF	PRO D	S			
MS	Its foldable	30:42	S			S			

KM	And it should keep its temperature better and it should prevent spillages better…we've got our little em… chart here if you need anything cause its been scientifically chosen…we have followed the proper method…I don't know what that says about brainwashing *the fact that they* probably didn't even use it	30:43	S			T	3		
MS	Right I think that's us	31:19	S	MAN	PROC	S			

Appendix C: Controlled Experiment Data Set

Contents

Project Brief – Wine Chiller

Client: JIBL Domestic products

Background

JIBL Services, has been operating in the servicing and repair of domestic appliances for over fifteen years and despite the recent economic crisis is relatively comfortable financially. The firm is keen to move on to their next entrepreneurial challenge. Through working in the domestic appliance market they have identified an opportunity for a new product. This product, they believe, could form the basis of a new enterprise focused on product development – JIBL Domestic Products.

The firm's initial 'product idea' is for a rapid drinks' chiller, capable of holding three bottles of wine at a time. The requirement being that this device would chill the bottles of wine from ambient to the required drinking temperature in less than six minutes. Although the firm has identified the basic idea they have no preconception of how the product will look or function except the vision of a stylish kitchen appliance that would sit quietly on the kitchen worktop.

Design Task

The task is to design the wine chiller to an embodiment design stage; that is establishing the aesthetics, ergonomics and basic functionality of the product. Market research has determined the following design requirements:

- The target demographic has been defined as 25 – 50 year old, middle to upper class, urban dwellers.
- The proposed selling price for the product is £50 - £60.
- Expected retail outlets to be high end department stores and domestic appliance suppliers.
- The product style should be modern contemporary.
- The chiller should hold a minimum of 2 bottles at a time.

A more detailed product design specification has been created for the wine chiller and all proposed designs must comply with the specification.

Product Design Specification

This is the product design specification for the design of a Wine Cooler. This document is a guide for which the design of the product will follow and be based; it covers all aspects of the design considerations.

Performance

1.1 Must hold a minimum of two 750ml glass bottles.

1.2 Must be able to hold loads of up to 10kg.

1.3 Must maintain a minimum wine temperature of 4^{o}C.

1.4 Must maintain a maximum wine temperature of 20^{o}C.

1.5 Must reduce temperature within a maximum time of 6 minutes (360 seconds).

1.6 Must operate using a standard UK 3 pin plug.

1.7 Operating conditions (see ‘Environment’)

Environment

2.1 Normal use: device will be used in a kitchen area

2.2 Resistant to air moisture: the device will be exposed to the environment which may include air moisture.

2.3 Temperature: the unit should perform and not be damaged by temperatures in the range of -20C to 70C.

2.4 Pressure loading: the unit should perform and not be damaged by air pressures between 0 Nm2 and 10 000 Nm2 (to enable air transport to be possible).

2.5 Corrosion resistance: the device should be resistant to corrosion from all household liquids.

2.6 Dust and dirt: Any part of the device, which could be affected by dust and dirt, should be protected or at least easy to clean.

Life in service

The life of this type of product should be in the range of a minimum of 5 years to a preferred 10 years

Maintenance

The general policy of the competitors is of a maintenance free product. To keep the cost as low as possible while compete with the competitors maintenance free policy the design should comply with the following:

4.1 Be completely maintenance free.

4.2 Where screws, bolts and washers are used, British standards must be complied with (see 'Standards and Specifications').

4.3 The product's mechanism if any should be accessible only by manufacturer or relevant repair shop not by user.

Target Product Cost

The aim is to produce a product, which satisfies the specified requirements and can be sold for the minimum price. The average retail cost of competitors is £50. Allowing for overheads and unforeseen production problems the target manufacturing cost should be between £20 and £40 per completed and packaged device.

Competition

6.1 Oz Clarke OC-WC3 Wine Chiller

6.2 Nscessity Wine Essentials NSBC862T Wine Cooler

6.3 Coolzone CZ51148 drinks chiller

6.4 Antony Worrall Thompson "Signature" Wine Cooler

Packing

The materials for the devices have not yet been specified nor have the size or weight but the following should be considered for the final packaging of the device (see 'Materials' and 'Size').

7.1 Size must be kept to a minimum.

7.2 Cost must be kept to a minimum.

7.3 The package presented to the customer must be physically attractive.

7.4 Weight must be kept to a minimum.

7.5 Should prevent corrosion if applicable.

7.6 Should prevent damage by shock loading, level dependant on material being used.

7.7 Must be easily removed by the customer.

7.8 Assembly and fitting instructions should be provided with the package.

7.9 Company logo should be shown on the packaging.

Shipping/transport

8.1 Packages will be stored for transport with at least 10 per box.

8.2 ISO containers will be used to carry the packages.

8.3 Transport will be by road or rail within the home market.

8.4 Transport will be by air or sea then road or rail within the overseas market.

Quantity

Market analysis indicates that a large percentage of the population do not have such a device of any description. It is then reasonable to assume the market will grow over the next five years considering the current spending trend.

9.1 10 000 units to be produced per annum initially, with production increase to meet demand once the product is established on the market.

9.2 Permanent new tooling should be installed if required but full use of existing tooling and equipment must first be achieved.

Size

10.1 The size of the product should be sufficient to allow it to be used in located on a kitchen worktop.

10.2 The maximum overall dimensions of the product should be 900mm* 600mm.

10.3 Each storage compartment must have minimum dimensions of 300mm*200mm to accommodate a grocery bag.

Weight

11.1 The weight of the device should be kept to a minimum; however strength must be a principal factor if the device is to perform effectively.

11.2 The total weight of the device should be no more than 7kg.

Aesthetics

13.1 Robust image should be projected to the customer.

13.2 Must not be complicated to the eye that is the design must give the consumer confidence in the simplicity of its use.

13.3 Attractive appearance, modern contemporary styling.

13.4 Company name should be visible.

Materials

14.1 The usage of existing materials for manufacture is preferable; it is not foreseen that a new material will have to be developed.

14.2 The material chosen will be easily used in production.

14.3 The chosen material must withstand the necessary environmental conditions (see 'Environment')

14.4 The materials chosen must not oxidise in any way

14.5 Strength must not be compromised for weight reduction.

14.6 The chosen material should be resistant to wear and tear.

14.7 The surface finish should not react with skin, plastic, household cleaning agents, or metal.

14.8 The material should not be poisonous to humans or animals.

Ergonomics

17.1 Hand operated controls must not require a force of more than 4 Nm.

17.2 If possible the design should be based on a one handed operation.

17.3 No sharp edges will be exposed to comply with British safety standards (see 'Safety' and 'Standards')

17.4 Considering senior citizens and the infirm or disabled will be using the product, the mechanism must not be complicated to use or understand.

Customer

The intended customer will be a householder or user, ranging from 25 to 50 year old.

Quality and reliability

To enhance the reputation of the company, a one-year guarantee will be offered.

Testing

23.1 In the instance of parts being bought-in inspection of 1 in 40 will be carried out.

23.2 Batch inspection will be used for production of final product

23.3 The device will be tested in a number of different sized car boots.

Safety

The device will comply with all relevant safety standards

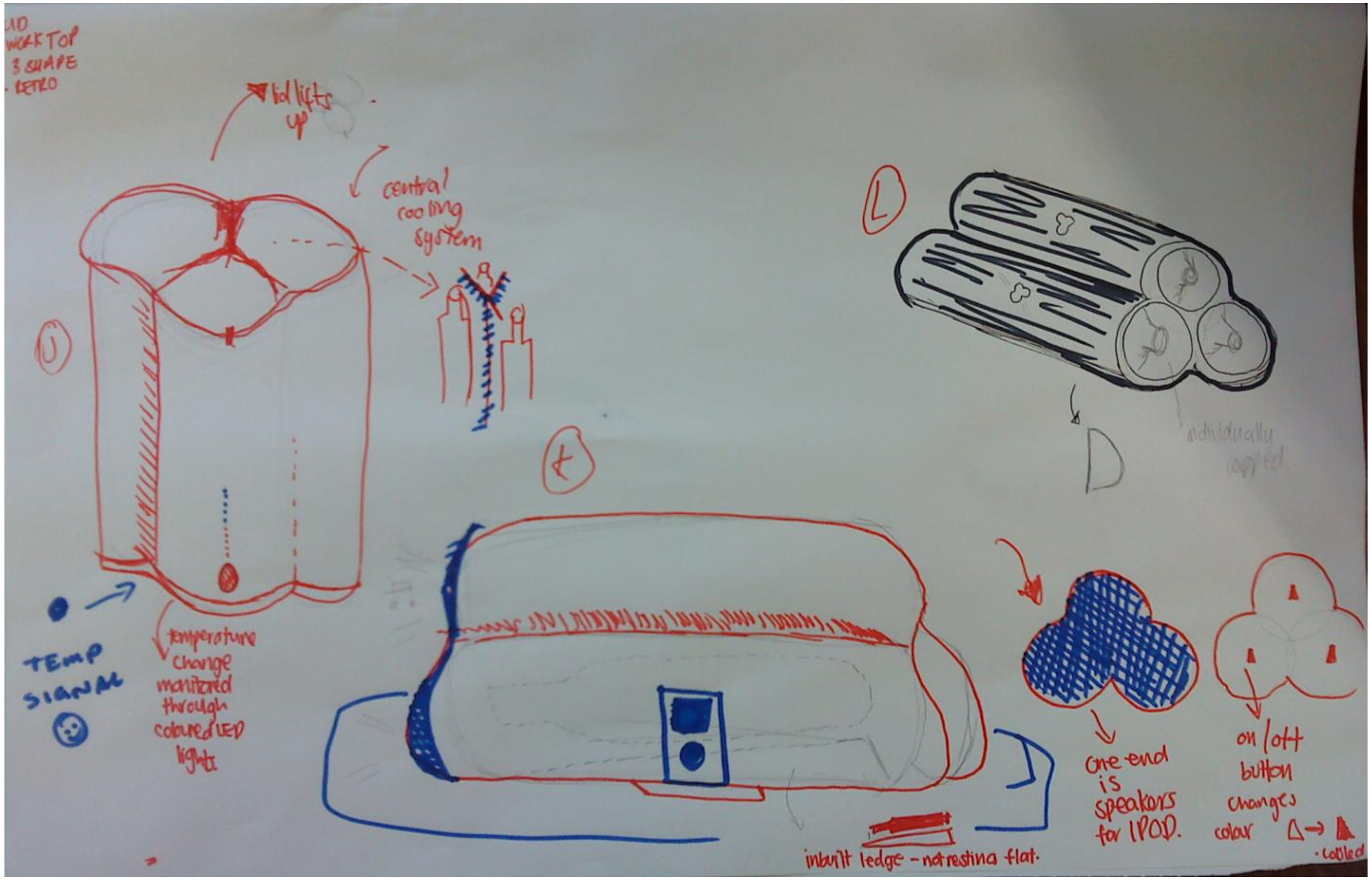
Market constraints

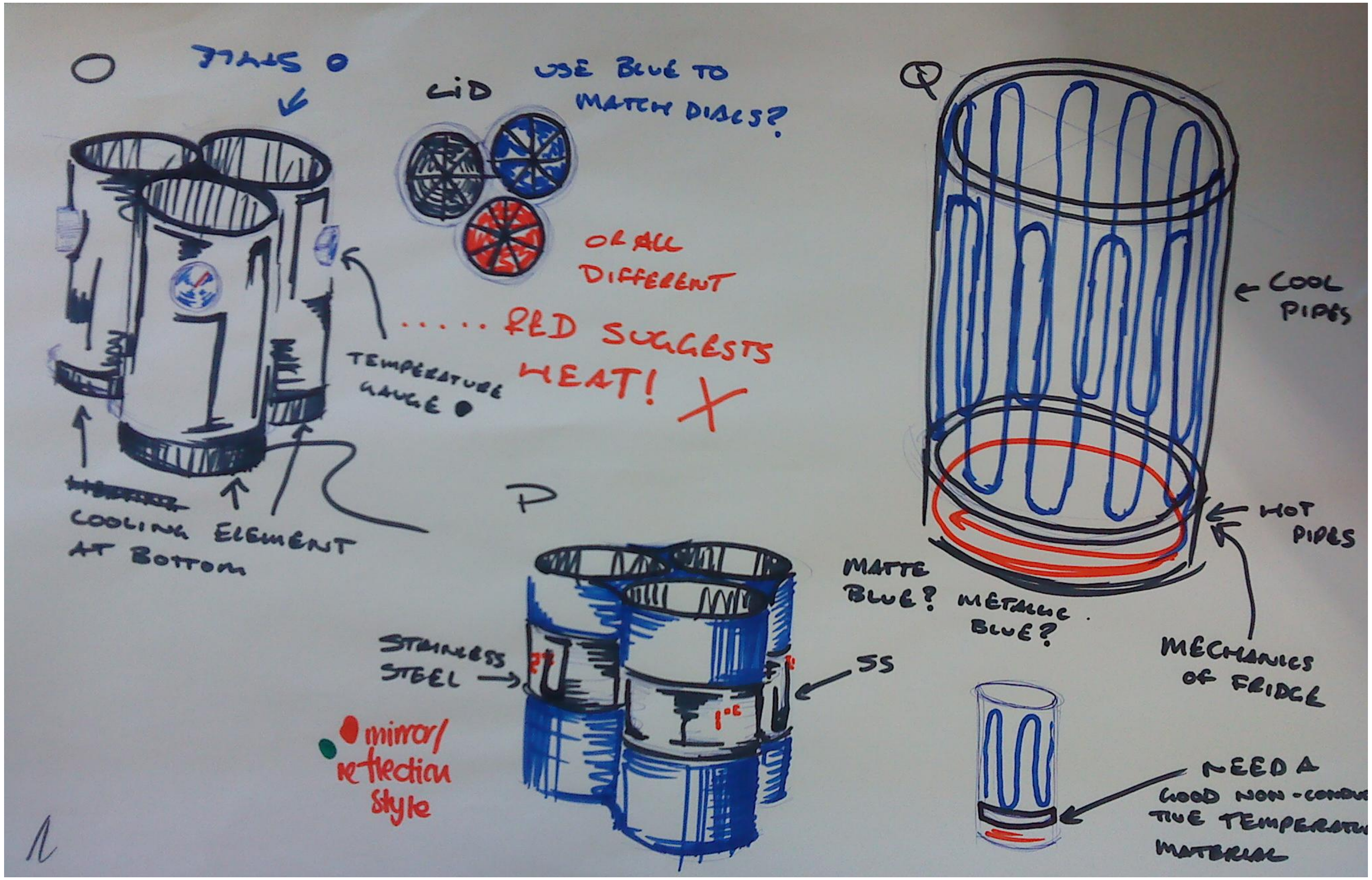
The device will be marketed on a trial basis in the UK and if successful will be marketed worldwide.

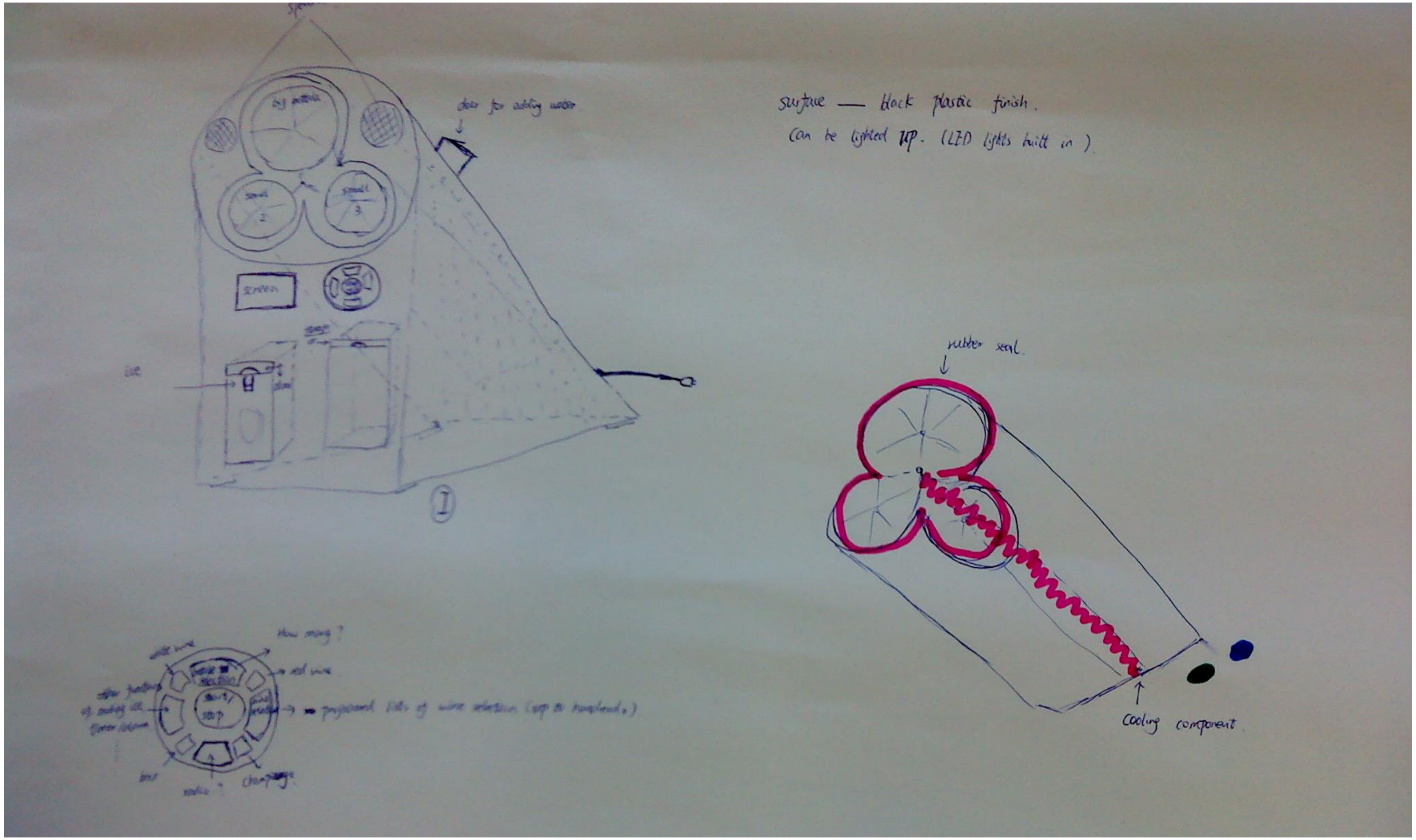
Controlled Experiment - Brainstorming


sealed lid
tall, store on floor
unique shape
horizontal
shape
EXPOSED -
sleek.
Glass
sensor
Can store upright or on side - up to the user
lid
hang
styling
lillie
angle
space - facing different way
natural, stone look and feel
not fit spaces
any dimension can fit
cool all around
sealed
timer
hides cables
expanded tray
cupboard
bottles
ipod docking station
Balance illusion
CUBOARD
WORKTOP

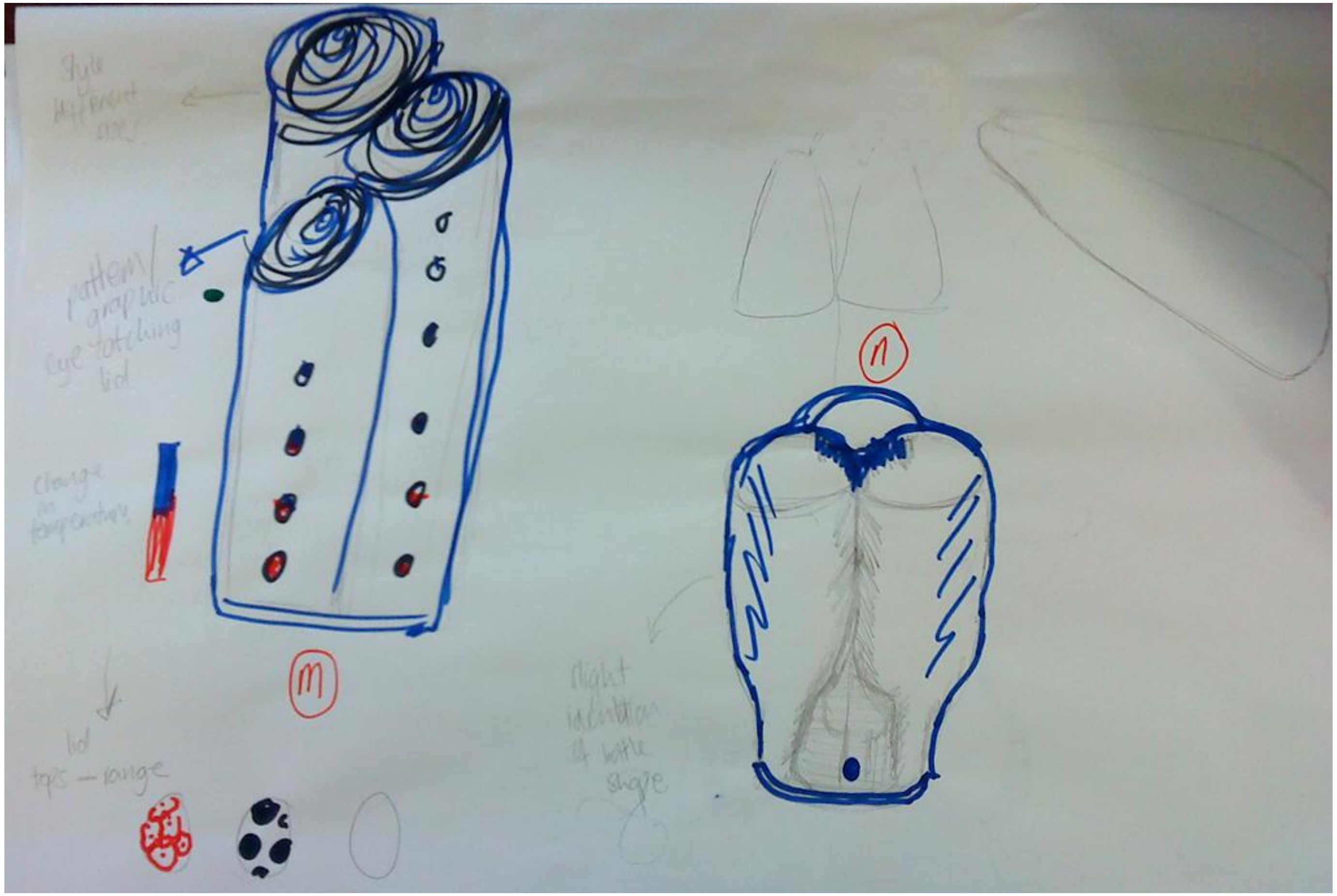
Controlled Experiment – Concept sketches

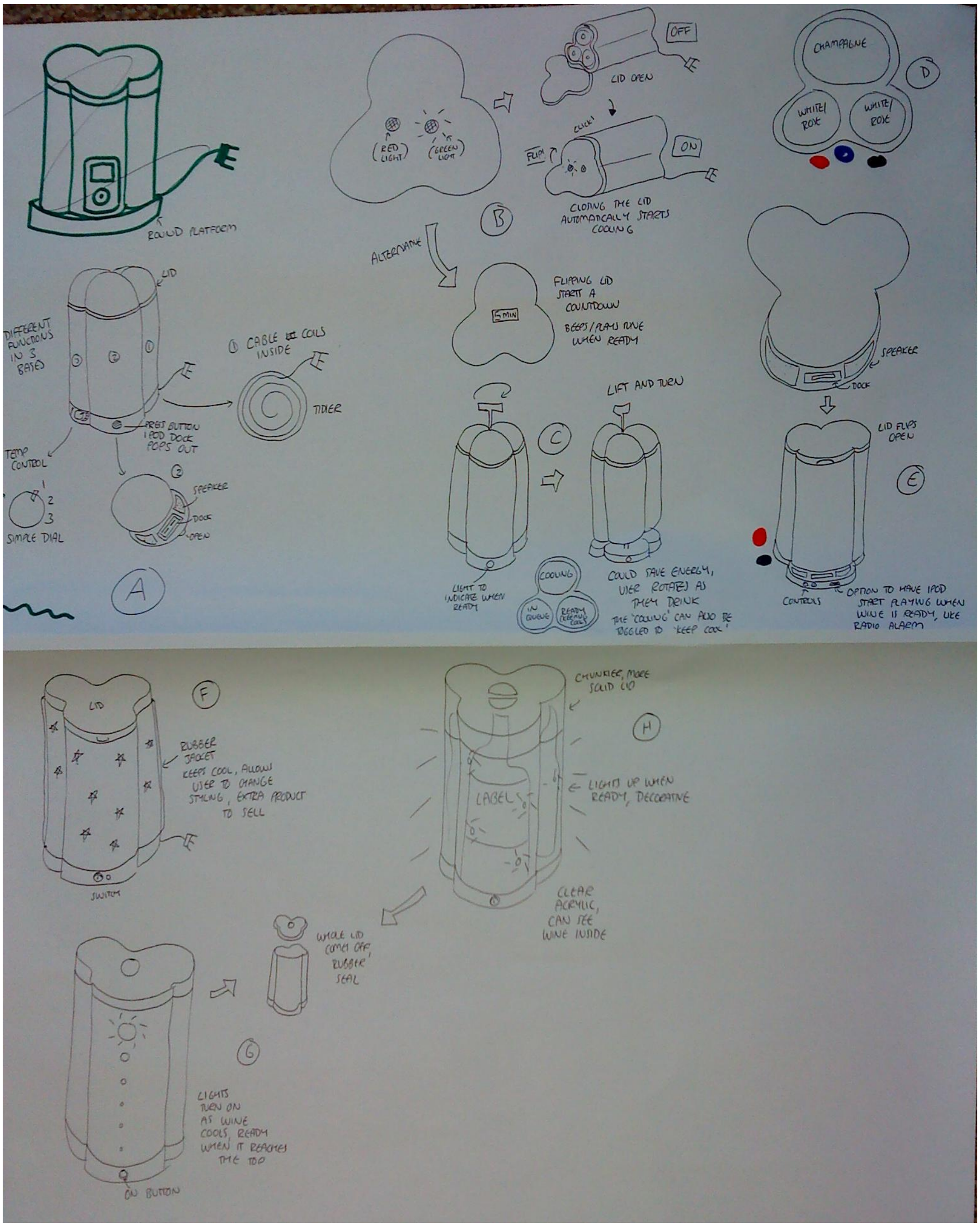



O
DIALS
LID
USE BLUE TO MATCH DIALS?
OR ALL DIFFERENT
..... RED SUGGESTS HEAT!
TEMPERATURE GAUGE
COOLING ELEMENT AT BOTTOM
Q
COOL PIPES
HOT PIPES
P
MATTE BLUE? METALLIC BLUE?
MECHANICS OF FRIDGE
STAINLESS STEEL
SS
mirror/ reflection style
NEED A



door for adding water
big bottle
small 2
small 3
screen
surface — black plastic finish.
(can be lighted up. (LED lights built in).
rubber seal.
cooling component.
How many?
white wine
red wine
programmed lists of wine selection (up to hundreds.)
radio?
champagne




ROUND PLATFORM
LID
DIFFERENT FUNCTIONS IN 3 BASES
① CABLE COILS INSIDE
TIDIER
RESET BUTTON
IPOD DOCK POPS OUT
TEMP CONTROL
SIMPLE DIAL
SPEAKER
DOCK
OPEN
A
RED LIGHT
GREEN LIGHT
B
OFF
LID OPEN
CLICK!
ON
CLOSING THE LID AUTOMATICALLY STARTS COOLING
ALTERNATIVE
FLIPPING LID STARTS A COUNTDOWN
5MIN
BEEPS/PLAYS TUNE WHEN READY
LIFT AND TURN
C
LIGHT TO INDICATE WHEN READY
COOLING
IN COOLING
READY
COULD SAVE ENERGY, USER ROTATES AS THEY DRINK
THE 'COOLING' CAN ALSO BE TOGGLED TO 'KEEP COOL'
CHAMPAGNE
WHITE/ROSE
WHITE/ROSE
D
SPEAKER
DOCK
LID FLIPS OPEN
E
CONTROLS
OPTION TO HAVE IPOD START PLAYING WHEN WINE IS READY, LIKE RADIO ALARM
F
LID
RUBBER JACKET
KEEPS COOL, ALLOWS USER TO CHANGE STYLING, EXTRA PRODUCT TO SELL
SWITCH
CHUNKIER, MORE SOLID LID
H
LIGHTS UP WHEN READY, DECORATIVE
LABEL
CLEAR ACRYLIC, CAN SEE WINE INSIDE
WHOLE LID COMES OFF, 'RUBBER' SEAL
G
LIGHTS TURN ON AS WINE COOLS, READY WHEN IT REACHES THE TOP
ON BUTTON

Controlled Experiment Session 1 Transcript

Date:	27/11/2009

Participants

Chairperson:	CH
Scribe:	SC
Designers:	D1
	D2
	D3
	D4
	D5

Legend

ID	Identity of the speaker (initials);
Transcript	Text transcribing speech;
Time	Time when the intervention ended (minutes: seconds);
Type	Intervention type (statement (S), question (Q), answer (A), or feeling/emotion (F));
Role	Exchange role (informing (INF), exploring (EXP), resolving problems (RES), managing (MAN), evaluating (EVA), debating (DEB), digressing (DIG), clarifying (CLA), actioning (ACT) or decision making (DEC));
IT	Information type (product (PROD.), process (PROC.) Resources (RES.), or external factors (EXT));
Media	Associated Media type (Drawing (D), Image (Ia, Ib, Ic), Model (Ma, Mb, Mc), Gesture (G), Speech (S), Text (T));

Transcript Conventions

Text conventions

- Words in *italics* are approximately transcribed
- … In the text marks a pause of 10 seconds or less
- (…) In the text marks a pause of more than 10 seconds
- […] In the text marks a pause of more than 30 seconds
- <u>Underlined</u> words are those which overlap with the transcript following

Specific speaker conventions

- [ID] some or part of the intervention from this speaker was not transcribed and the reason given in the transcript encased in [ ]

ID = X, the identity of the speaker was not recognised

ID	Transcript	Time	Type	Role	IT	Media
CH	Ok... I'll give you a quick overview of the task, I have a couple of slides that I will show you and then we can maybe talk round the documents that I've given you as well, the kinda pds and design brief (...) so as you can see there are only a couple of slides... so basically what it is, is a wine chiller design, ok... eh the client, myself, is representing JIBL Domestic Appliances ok?... ehm... what we've come up with is a new... there is a niche market basically for wine chillers, you see a lot of wine chillers out there today that are in, you know, John Lewis and these kinda places that can hold one bottle and can chill it, they generally take a long time... its maybe 15 to 20 minutes and they generally only hold one bottle... the other ones that hold more than one bottle are quite expensive...ok?... so the idea behind this design, what we	03:18	S	INF	PROD	

CH	want you guys to do is to develop a rapid drinks chiller which is capable of holding around three bottles... we're not specific enough, we are not set on how many bottles it can be... it can be 3, it can be 5, it can be 2... just more than 1 bottle I think... ehm and it should chill the wine from ambient to the required drinking temperature in less than 6 minutes ... There is no preconception of how the concept, the product will look or function... ehm but we kinda envisage it to be quite a stylish bit of kit that would sit in a kitchen worktop and be quite quiet... ehm so we are looking for the output from this to be the embodiment design of the chiller... so that is a little bit more detailed than just concepts... if you look at the design brief and also the PDS you'll see that theres an ehm... we've defined a target demographic and this has been defined as a 25 to 50 year old middle to upper class urban dweller so basically your kinda, sort of standard, working professional kinda guy who likes wine, guy or girl who likes wine, the 25 to 50 is the target age but obviously there is gonna be people maybe over 50, maybe even younger than 25... above 18 of course for legal reasons, ehm who would want to buy such a					

	course, but we are aiming at householders, house owners, these are the sort of people we are aiming at... a lot of the competitor products, a couple of the ones that are shown down there ehm sell for around 50, 100... the cheapest one sell for around £30 i think so our proposed selling price is for about £50 to £60, but to offer more functionality in terms of more bottles, a better look and a faster way of chilling it. I mentioned eh John Lewis... i think sort of the expected retail outlets are John Lewis, Debenhams you know these sort of high class high end retail stores, also kinda domestic appliance stores, you know your currys, comets etc so thats the kinda market we are targeting... ehm... the product style should be modern contemporary to fit in with you know the latest fashion of... style of homes and as said the chiller should hold a minimum of two bottles at a time… so that's really it I mean if you want to have a look at the design brief you have got in front of you ehm I don't know if you've had a chance to have a look at it… has anyone?					
D4	Not yet no	03:30	A	INF	PROD	T
CH	(…) does anyone actually have a wine chiller	03:52	Q	CLA	PROD	
D4	Its called a fridge	03:54	A	INF	PROD	

CH	You call it a fridge… well its funny cause a lot of the competitors are just fridges you know the fridges at home that hold multiple bottles, the desktop ones, but what we are looking for is something that is specific just for wine… its not for beer, it's just for wine	04:09	S	INF	PROD	
D1	Does this… will it just chill the wine or for like red wine will it keep it at a nice temperature?	04:16	Q	CLA	PROD	
CH	Well I think if it's got a temperature range it could possibly just maintain the temperature. If you look at the PDS it does say it has a temperature range of between 4 and I think 20 degrees so obviously, we don't want it to be heating up the wine in the way of making it a warm drink but just really keep it at ambient temperature to get that maximum taste that you get out of wine when its at that temperature and obviously for white wine and rose wine it should be a lot cooler than what red wine.	04:45	A	DEC	PROD	T
D4	Just specifically keeping it to the wine market… you couldn't use it to put any other kind of bottle or anything else in it	04:55	Q	CLA	PROD	
CH	Well what kinda bottles do you mean?	04:57	Q	CLA	PROD	

D4	Random like even if it was cider or something else like that you know	05:02	A	CLA	PROD	
CH	I mean the design we envisaged was the, you know 750 ml bottles of wine but if you've got an idea for something else that's you know could also be used for…	05:12	A	DEC	PROD	
D4	Cocktails or something…	05:12	Q	CLA	PROD	
CH	Cider…Cocktails or whatever we are open to suggestions as I was saying. There is a lot of the competitors that do not just wine bottles but champagne bottles and things which are a little bit wider ehm so that might be something that you look at but yeah I mean cider no problem	05:30	A	DEC	PROD	
D3	So see that, see that one there that's got ice in it I mean what do most of the competitors have are they like mini refrigerators with all the chemicals and stuff in them or are some of them just.. I mean that one looks just like an ice bucket	05:43	Q	CLA	PROD	

CH	I think that's a… that one there is quite different in terms of it's a combination of ice and the temperature control so you put ice in it but you also, it's got a temperature control that you control that level of the ice, but most of them don't have ice most of them are just you know a refrigeration unit that's used to chill… but again I mean we are open to suggestions we don't have any preconceptions to what this looks like or… we just want it to work in the way that we have said and hold…	06:15	A	ACT	PROD	
D4	Does it have to be mains driven thought? Does it have to be mains powered?	06:18	Q	CLA	PROD	
CH	Yes yes it should be… the idea is that its gonna sit in a kitchen so it'll sit beside a toaster or something like that, it's not gonna be a portable thing… I think for the target demographic we are looking at that's the market that we… you know that's the kinda area we would imagine it to be sitting in a nice sorta modern looking kitchen	06:41	A	DEC	PROD	
D4	The reason why I was asking was so it could be used in a restaurant… it could be taken to a table or something like that… you like you get these buckets full of ice and they are just…	06:50	S	CLA	PROD	
D3	[inaudible] stainless steel	06:49	S	EXP	PROD	

CH	It's an interesting one I wouldn't say that the restaurant market is something we would want to target at the moment I think our expertise is with the kinda domestic appliances… uhm I mean its an interesting thought but maybe its something we could look at later on in this but I would say for this it would just really be for household use … certainly if you could use it in the back of a kitchen but I wouldn't imagine it would be taken to a table… what do you think about the price range I mean what's your kinda first impressions of that?	07:32	A	DEC	PROD	
D4	In the current market that's quite expensive, just because I know its for Christmas obviously and that's a kind a present someone would buy or for a wedding or something but I think the price, realistically in the current climate is quite high… its kind of in the top end really… top end luxury products	07:52	S	EXP	PROD	
D1	Yeah it looks sort of top of the range but I still think people would have no problems paying that amount of money	07:59	S	EXP	PROD	
D3	For the people its aimed at they will probably have a bit more money to spend… especially for… its more a kind of gift thing, you wouldn't… you probably wouldn't buy it for yourself you know	08:09	S	EXP	PROD	

D4	That's what im saying like I think I can envisage someone buying it for a wedding gift or something like that	08:14	S	EXP	PROD	
CH	Can you pass me that PDS just for a second… ehm if you look at the PDS I think it says something about the price… yeah the average cost is around £50 so we are looking for a manufacturing cost of between 20 and 40	08:37	S	INF	PROD	T
D4	There's not that much of a mark up then	08:38	S	EXP	PROD	
CH	Not really I think we, in terms of, we would have to buy a lot of the components in… we are not envisaging manufacturing the refrigeration unit and all that, we would actually try and buy something in that would do that for us and focus on the aesthetic appeal	08:54	S	ACT	PROD	
D4	So you would be looking to sell high volumes then to get a good enough return on it?	08:59	Q	CLA	PROD	
CH	I think so yeah… sorry Jie did you have a question?	09:02	A	DEC	PROD	
D5	I think the price is… uhm how many functions [inaudible]… *relates to*how many functions it has	09:16	S	EXP	PROD	

CH	Yeah I mean again the price is not fixed this is just really our first kinda thoughts on it, if you design something that's got more functions on it than anything else that is out there like you know it can sing to you as well as chill your wine… or its got a radio integrated in it… maybe that's something we could look at in developing the price… but basically we are not set on £50, that's just a kinda guide price to give you an idea of what kind of style and what	09:49	S	CLA	PROD	
D3	And it's got to be, how long does it take normally to chill about? Is it 15 mins or something?	09:54	Q	CLA	PROD	
CH	A lot of them take about 15 mins…ehm it depends on the expense of the or the price basically of the device, the high end ones take around 6 to 8 minutes but they are a wee bit more expensive, they come in about 80 to £90… the cheaper ones, the kinda £50 and under tend to be around 15 to 20 minutes	10:20	A	CLA	PROD	
D4	Would it me more kind of productive to look at the product being of multiuse and giving it a different kind of edge in the market like I mean like for example you've got here this one's got wine bottle openers and things like that, is there anything that we could look at to give it a different perspective?	10:40	Q	CLA	PROD	

CH	Again, we are open to any suggestions, as I said we really just want something that looks stylish and will look good, if there is anything that you can think of or any of the concepts that you put into it we would be more than happy to have a look at them and evaluate them… I mean certainly we wanna offer more for the money but we don't want to compromise on the style, we don't want it to have too many functions but look a lot cheaper cause then we won't sell it	11:06	A	DEC	PROD	
D4	So we will go for kinda starky styling, but IKEA practicality	11:11	Q	ACT	PROD	
CH	Stark styling?	11:11	Q	CLA	PROD	
D4	Yeah, stark styling and IKEA practicality	11:17	Q	CLA	PROD	
CH	Yeah that's a good, that's a good way of expressing it...uhm summing it up yeah, stark styling with IKEA functionality	11:24	A	DEC	PROD	
D4	That's the slogan	11:26	S	EXP	PROD	
CH	That could be, that could be a good slogan...i mean what do you think about the brief is it feasible, do you think we are... I'm kinda getting the impression you think the price is a little high	11:43	S	EXP	PROD	

D3	I think it's ok for the people you are targeting	11:47	S		PROD	
D1	I think it would be ok	11:48	S	DEC	PROD	
D2	The target market would definitely be able to afford it	11:50	S		PROD	
D4	Now I've actually seen the PDS and the cost to produce it, the actual mark up price isn't that great... so i think it's realistic for you guys to get a profit as well as getting a quality product	12:05	S	EXP	PROD	T
CH	Yeah if you look at the PDS there is a couple of sort of competitors that we have identified and unfortunately we haven't got the prices on here but i can tell you that for example the one in 6.4 the Anthony worral Thomson signature wine cooler holds 6 bottles and is £135 and its essentially a mini fridge... and thats... you know we recognise that because he is a well known chef and because its a good name people would tend to go for that especially if its a gift for a wedding or something like that but we dont wanna go down the route of a fridge, it has to...we have to focus on something that sits on a desktop or kitchen work surface and looks good essentially, looks nice, a fridge is not one of those things	12:54	S	INF	PROD	

D4	So who produces that Anthony worral thomson	12:56	Q	CLA	PROD	
CH	Ehm... im not too sure actually who manufactures it	12:59	A	INF	PROD	
D2	I thought you said who is it	13:00	S	EXP	PROD	
D4	No who produces it cause i was gonna say is that something you want to endorse, having some personality associated with this kinda product	13:09	Q	CLA	PROD	
CH	It could be, i mean it would be nice ehm obviously we would like our name on it... the company name on the device but if you've got thoughts on any celebrities	13:22	A	INF	PROD	
D4	Well i doesn't necessarily have to be a celebrity though does it, i mean like Panasonic, they use Leica lens and the association with a quality lens actually sells their product really well	13:33	S	EXP	PROD	
CH	Yeah and there is Sony as well the Carl Zeiss lens	13:35	S	EXP	PROD	
D4	Yeah i mean so there is... in particular getting a wine brand to get themselves attached to it	13:44	S	EXP	PROD	

CH	Yeah that's interesting concept i think that would be something we would certainly look at getting as pair brand	13:51	S	DEC	PROD	
D4	Thats the branding kinda aspect to it...highlight the quality	13:53	S	EXP	PROD	
CH	It could bring in revenue for us as well...reduce the cost, you get a partner essentially in it...so uhm i dunno some champagne...	14:03	S	EXP	PROD	
D4	Hardys or something	14:04	S	EXP	PROD	
CH	Hardys or some kind of champagne maker	14:06	S	EXP	PROD	
D3	I was just thinking eh if your gonna have more bottles to cool and cool them quicker is that not gonna take a huge amount more energy is that maybe why other competitors haven't done it by now? Thats eh one thing i can think of thats a big problem is the huge amount of energy needed to do that	14:25	Q	EXP	PROD	
D4	Cause then could you look at ehm cell.. actually cooling them down in cells rather than as a block	14:33	S	EXP	PROD	
D3	Would that be more energy? I mean you'd need to think about the consequences	14:41	Q	EXP	PROD	

D4	But in reality terms someone whos gonna buy this are they gonna be environmentally conscious?	14:47	Q	EXP	PROD	
D2	Mmm probably not	14:49	A	EXP	PROD	
D4	Is the consumption of energy...you know cause they are cooling wine cause they want it in an instant	14:57	Q	EXP	PROD	
CH	I think it’s a good point and it’s something that we...we don’t have the expertise to enter that design element to it, that’s where we are hoping you guys would come up with some ideas and maybe the cell idea is something you could explore a little better, I’m not sure... but yeah my initial thought is yeah maybe that is a problem... because we are hoping to run off just the standard uk 240 v mains plug so we dont anticipate its gonna be that plus any additional power and also we want it to be quite quiet	15:41	A	DEC	PROD	
D3	Yeah cause some of them can be quite noisy...	15:43	S	EXP	PROD	

CH	Yeah some of them are quite noisy I think it depends on the kinda dampening you could put on the packaging...eh not the packaging but the exterior to make it stop vibrating... i think one of the main problems is vibration, if you've got something running it will vibrate, we dont want that	16:00	S	EXP	PROD	
D4	So have we got some things in here about warranties, stuff like that and lifecycle	16:05	Q	CLA	PROD	T
CH	Lifecycle, eh yeah we do, again if you go to... where are we...	16:12	A	INF	PROD	T
D4	Life in service 10 years, minimum 5	16:14	S	INF	PROD	T
CH	We said a kinda one year guarantee but the likes of minimum 5 – 10 years	16:20	S	INF	PROD	T
D4	Could that be something that could be ehm, increased to give it that reliability factor? If you say we give it two years which is more than what the rest of the competitors give within the market, of parts or something like that we maybe could increase the value	16:39	Q	CLA	PROD	
CH	Yeah these are things we would look at yeah	16:43	A	DEC	PROD	

D3	I think with things like this there is sometime s a bit of a craze, i mean i dont know maybe you would only use it for a year or two	16:49	S	EXP	PROD	
D4	And then put it in a cupboard... like bread makers	16:50	S	EXP	PROD	
D3	Yeah it is kinda a bit like that you know it seems like a great idea at the time so maybe people wouldn't be so bothered, i don't know the...	17:00	S	EXP	PROD	
D1	I think they would probably look for any excuse to use it when they have it so if they had alike a party they would be like yes lets get it out	17:08	S	EXP	PROD	
D3	Probably if you were just sitting in the house and just you and your partner or whoever you would probably just use the fridge its maybe more for just once in a blue moon so	17:16	S	EXP	PROD	

CH	Well we did some market research and we found that a lot of people ...ehm one of the problems was especially if you have a party, a dinner party and you don't have space for 6 bottles in your fridge, so you could put 3 in there, where would you put the other 3 to keep them cool... the other thing is maybe if your buying it in a supermarket and you come home and wanting to drink it that night, you put it in the fridge, its gonna take a lot longer to cool because of the volume of area to chill etc. Where as this would be something you could	17:55	S	INF	PROD	
	put it in, 6 minutes later you are ready you know... so the.. i think the idea of it being a sort of novelty product is maybe not what we are hoping we are hoping for it to be quite, something that is going to be used again and again					
D3	So its sitting on the worktop just like the toaster	17:56	Q	CLA	PROD	
CH	Yeah	17:56	A	DEC	PROD	
D4	That's useful product for people to go ooh that's nice what's that and they go well actually it does this	18:02	S	EXP	PROD	

CH	Exactly... cause i know personally when I’ve went to the supermarket on the way home from work trying to get some wine for that evening and you get it and its at room temperature, you dont wanna drink it at room temp if its white	18:20	S	INF	PROD	
D3	Put it in the freezer	18:21	S	EXP	PROD	
D4	Yeah stick it in the freezer	18:22	S	EXP	PROD	
CH	This is exactly why we need a product like this because you know it avoids you having to put it in your freezer	18:29	S	EXP	PROD	
D4	Yeah it means you have to take the ice cream out... now you gotta eat the ice cream	18:35	S	EXP	PROD	
CH	Then other main thing i wanted to cover with you is we want to be maintenance free... ok we don’t want the users to have to do anything with it ehm...	18:47	S	INF	PROD	
D4	So maybe avoid things like ice then as you’d need to clean that out	18:49	Q	CLA	PROD	

CH	Exactly that is something you know maybe to consider... but I dont wanna limit your ...what is it...design skills or limit what what you want to do in your concepts because we want you to explore all avenues but at the same time ice is possibly something we wouldn’t want to go down	19:05	A	DEC	PROD	
D3	I suppose once you’ve got ice involved you got to be able to sort of wash it and then there electronics and stuff	19:11	S	EXP	PROD	
CH	That as well if youve got electronics and things it wouldnt be...	19:15	S	EXP	PROD	
D4	Yeah rust and everything	19:16	S	EXP	PROD	
CH	Exactly i mean a lot of the ones you can see in the images there are the kinda metallic type finishes if you do have to wash them then you have to makes sure you keep them clean and doesn’t rust or stain etc so	19:30	S	EXP	PROD	
D4	Could it... could it be disguised as... well not even disguised as but could the product become something that if as you said is just left out that wine bottles are just stored in there and then you actually just switch it on, it’s not just a product sat empty it’s something that is utilised within the kitchen in the space it is in	19:49	S	EXP	PROD	

D3	Something like a wine rack	19:52	S	EXP	PROD	
D4	Yeah you'd have, you'd put the... cause I'm looking at that there, the majority of these are all upright and to store wine properly you need the wine to moisten the cork depending on the type of cork it is, but if you had it on a angle and it just sat on its side and you just stored your wine bottles in it then you switched it on when you wanted it, so is that something that would be...	20:14	S	EXP	PROD	SLIDE
CH	Again i don't wanna limit your creativity so these are thing we would like you to explore	20:18	S	ACT	PROD	
D1	We can, we can come to these things when we get to do concepts	20:21	S	EXP	PROD	
CH	I would say... one thing i would stipulate is that we want it to be really easy to use and as stated in the PDS that the design should really be one handed operation so we are not looking for you to have to do different things it could be just put it in and push the button, that's the kinda thing we are looking for... hand operated, so eh... it's not like you have to have a computer sitting there to control it	20:44	S	DEC	PROD	

D4	A remote control from the living room	20:45	S	EXP	PROD	
D3	See if you are storing it, i mean i don't know but if you are storing a few, like say you had three bottles of wine and you end up not suing it all, does it affect wine at all, like the constant, say you chilled it then you end up not using it so then it goes back down to room temperature when you cool it i dont know does that affect wine at all?	20:59	Q	CLA	PROD	
CH	No... it shouldn't, if the wine is unopened, if it was opened it would affect the quality of the wine but if it is unopened it shouldn't because the bottles and the seals and stuff would make it so that its not really that much but I think when you really open wine you let the air into it, it does...	21:17	A	INF	PROD	
D3	Yeah...	21:18	S	EXP	PROD	
CH	So is that enough to go on then are you quite happy with that?	21:22	Q	CLA	PROD	
D1	yeah	21:22	A	DEC	PROD	
D2	yeah	21:23			PROD	

D4	yeah	21:23			PROD	
CH	Ok well in that case I'm going to head off so I'll leave you to it, are there any questions before i... do you want to clarify anything about the design anything you have to do?... No? Ok thank you very much	21:41	S	ACT	PROD	

Controlled Experiment Session 1 KEN Record

Date of Meeting: 27/11/2009 11:02

Title: Wine Cooler Meeting 1 Introduction

Attendees:

- Client
- Designer 1
- Designer 2
- Designer 3
- Designer 4
- Designer 5
- Scribe

1.	Project Introduction
Exploration	background discussion of wine chiller design
Decision	reading the design brief
Exploration	temperature range of cooling wine
Exploration	restriction in use of wine chiller - other drinks?
Decision	other drinks like cider is wine for product
Action Point	client is open to suggestions for the product use No assigned person. Status =Outstanding
Decision	target demographic - modern household kitchen
Exploration	target restaurant market route
Decision	client wants product for domestic use
Action Point	go for domestic market No assigned person. Status =Outstanding
Exploration	discussion about price
Exploration	discussion to integrate storage function for product
Decision	hand operated and easy to use
Exploration	discussion cooling cycle affect quality of wine
2.	Task Clarification
Exploration	discussion about sales and price
Decision	price is not fixed
Exploration	query about how long to chill wine
Exploration	suggestion to increase functionality of product

Decision	stark syling with ikea functionality
Exploration	PDS - discussion about competitor products
Decision	product not be like a fridge type product
Action Point	go for desktop product No assigned person. Status =Outstanding
Exploration	discussion about celebrity endorsement - e.g. sony lens
Decision	investigate branding options
Exploration	discussion about energy usage of chiller
Decision	concept options for energy issue
Decision	design quiet product
Exploration	lifecycle discussion
Exploration	justification for product need
Decision	develop useful product - not novelty
Exploration	client mentioned past experience with wine chilling
Decision	product needs to be maintence free
Decision	product should be ice free
Decision	team is happy to proceed
Exploration	discussion how to carry out brainstorming
Decision	have tea break before starting design task
Exploration	discussion about previous design experience of the product
Decision	use mind map technique
Action Point	david write/draw mind mapping process No assigned person. Status =Outstanding
Exploration	functionality - wine rack
Decision	provide second function
Decision	add radio, music, knife, corkscrew in addition to wine cooling
Exploration	suggestion to generate ice within product
Exploration	discussion about wine and mixer drinks from personal experiences
Decision	agreed not to go for mixing wine
Decision	temperature control
Exploration	other activities associtated wtih wine drinking
Exploration	discussion to hang wine glasses
Decision	detail more info about adding functions - timing
Exploration	discussion about cooling different tyoes of wine
Decision	extra functionality will increase cost of product
Action Point	limit functionality to reasonably level for price No assigned person. Status =Outstanding

Exploration	product styling discussion
Decision	integrate cable lead options
Decision	refer to PDS - go for 2 bottles
Exploration	discussion about product casing affecting function
Decision	decide upon seal for product
Exploration	discussion about interaction with product - fashion
Exploration	target market - niche or broad
Decision	go for commercial market
Exploration	material options for product
Decision	move away from stainless steel - cold to touch?
Exploration	scandinavian design could be an inspiration
Exploration	other materials - stone and ceramic
Decision	material has important role in cooling wine
Decision	need efficient cooling
Exploration	discussion about recycling of product/remanufacturing
Decision	consider modular design and disassembly in detail design
Exploration	various types of cooling process - chemical
Exploration	discussion about removing cable
Exploration	reference to new build houses, has incorporated wine cooler
Exploration	static or dynamic product - moving mechanism options
Exploration	past experience - karena attended wine tour
Exploration	orientation of wine bottle
Exploration	anecdotes about wine drinking
Exploration	location of product in kitchen
Exploration	discussion about prioritising features of the product for concept generation
Decision	agreement to focus concept generation - highlight on mind map
Decision	main points - aesthetics and cooling function to develop
Decision	function over form is agreed
Exploration	holding more bottle will increase size of product
Decision	usp - cools quicker, stylish, dual functionality something to consider in concept generation
Exploration	make usp - using natural materials?
Decision	leave the design relatively open, dont narrow down options
Decision	use post it notes for concept generation
Decision	set time limit for concept generation
Action Point	10 mins for post it note concept generation by team No assigned person. Status =Outstanding

Decision	each person explains their concepts
Action Point	karena concept explanation No assigned person. Status =Outstanding
Exploration	karena - block design (ornament and materials, exposed mechanics, natural - lily shape, functionality - triangle shape for 3 bottles, mimic design of other kitchen appliances, canon mechanism - excitement and interation with product, modular stacking idea, different sized units for 1 person, more people
Exploration	kirsty - shape design, sealing function, space saving (arrangement of bottles), rail to hang, bucket shape for different bottle sizes, extra function - kitchen feature (hide cables), ipod dock style
Exploration	gillian - aesthetic shape, locate underneath worktop , organic, rock shape, wine stopper design, wrap around cable reel, sturdy shape, dock and cooling, simple control - big buttons, music etc, upright design
Exploration	jie - simple design (block shape), plastic cover for different colours,fixture to attach to cabinet, temperature control, continuous control, detail about various types of wine
Exploration	david - digital screen recipes, ipod docking design with speakers, removable to wash, kettle type design for other drink shapes, gyroscope design rotating and cooling
Exploration	arthur - angled for ergonomics, cooling sleeve, split casing, ice function
Decision	next meeting to group similar concepts together
3.	Questions

Controlled Experiment Session 1 Minutes

ENHANCING THE DESIGN DIALOGUE

NEED A BETTER WAY OF KEEPING RECORD OF DECISIONS

MINUTES

- OVERVIEW OF TASK
  - WINE CHILLER DESIGN
  - 25-50 YEAR OLDS
  - JOHN LEWIS, DEBENHAMS, COMET ETC.
  - ONLY USED FOR WINE – POSSIBLY NO
  - CAN KEEP PRODUCTS AT A CONSTANT TEMPERATURES — (D)
  - WARM FOR RED WINE.
  - NEEDS TO BE MAINS POWERED.
  - KEEP IN DOMESTIC ENVIRONMENT — (D)
  - QUITE POSSIBLY COULD BE BOUGHT AS A PRESENT
  - USUALLY TAKES 15 MINS TO CHILL
  - OPEN TO ANY DESIGNS — (D)
  - STARCKE STYLING WITH IKEA FUNCTIONALITY — (D)
  - CELEBRITY ENDORSEMENT?
  - DOES IT USE TOO MUCH ENERGY?
  - RUN OFF STANDARD 240V UK MAINS — (D)
  - WANT IT TO BE QUIET IN SERVICE

- NOVELTY COULD BE AN ISSUE - THIS NEEDS TO BE ADDRESSED IN DESIGN
- SHOULD BE MAINTENANCE FREE — (D)

* MAYBE LIMIT ICE

- ONE HAND OPERATION. — (D)

Appendix D: Industrial Experiment Data Set

Industrial Experiment KEN Record

Date of Meeting: 24/09/2009 13:01

Title: AFRC - Compressors Project Review M5

Attendees:

University of Strathclyde

- Anderson, Magnus
- Basoalto, Hector
- Brooks, Jeffery
- Conway, Alastair
- Hutchison, Margo
- Jadhav, Prashant
- Zante, Remi

Company B

- Fortune, James
- Gallagher, Michael
- Lord, Peter
- Ruddy, Pat
- Teeling, Russell

1.	Review of Actions
Exploration	Research Agenda: A 1-hour Link call has been arranged for 25th September to collate comments
Exploration	COLLABORATIVE Project 4.3.2: as a result of this being EPSRC funded, all IP generated by the project will be shared with UoS and must enter the public domain. Background IP will be protected. This will apply to TSB-funded projects as well.
Exploration	Screw Press Update: Further discussions re press specification arranged for next week. Expect a decision before the Board meeting on 19th October to allow an order to be placed shortly after, as a certain amount of the funds must be spent by the end of 2009.
Exploration	Schuler Weingarten have given very positive indications regarding joining as Tier 1 member.
Exploration	Official opening ceremony expected to be held May 2010 and will be attended by a member of the Royal family. AFRC will be liaising with the Lord Lieutenant of Renfrewshire to arrange.
Exploration	No change to floor plan, building design currently frozen.
2.	AFRC Team members
Exploration	JB introduced Hector Basoalto

Exploration	Hector provided an overview of his experience and background related to his AFRC activities.
Exploration	JB also noted that Colin Harrison has also been appointed, his background is in mechatronics and he will be working on SPF
Exploration	Lynne O'hare will also be starting and has a background in Mechanical Engineering and material characterisation.
Exploration	Fixed date for the AFRC Inchinnan visit to be defined.
Action Point	Fixed date for the AFRC Inchinnan visit to be defined between James Fortune, Margo Hutchison and Pat Ruddy No assigned person. Status =Outstanding
Exploration	Engineering Manager will be appointed in the new year who will be responsible for the equipment.
Exploration	Company B process of finding appointments is through adverts.
3.	Review current projects
Exploration	Magnus Anderson - submitted DMAIC project, no feedback received. continuing production trials visited a number of companies, bodycote and Bohler steel
Exploration	No compound layer specified for the material
Exploration	Proposed order for W360 material from Bohler
Exploration	Order for trial dies within a week to two weeks 0.2 diffusion layer
Exploration	MG - when ordering we Need to weigh up product cost, machinability and productivity of materials.
Exploration	PL - do you have a comparison matrix for all proposed orders?
Exploration	MG - we need to ensure we discuss the options as for example Bohler are not a Company B supplier,
Exploration	Looking at different grade steel of H13 from Cooks - awaiting delivery
Exploration	MG - again need to look at the cost and other factors before decided to ensure a balanced decision.
Exploration	FEA element, difficulty in elastic dies and heat transfer, trying to arrange training for DeForm.
Exploration	Also need to do FE analysis on tool design
Exploration	MG - Need to get Sharon's input into the first issue, Kenny McGuire can help to arrange this.
Exploration	PL - we need a good balance scorecard to see what the measures are and what are the benefits.
Exploration	MA presented the current tool designs
Exploration	MG this quickly rules out material types, could be soemthing we put into our processes
Exploration	MA presented Microscopy report.
Exploration	Sample 2 shows plastic flow and different depths of nitride.
Exploration	header die 1 shows material lost and material gained and plastic flow.
Exploration	header die 2 shows the different layers and the decarbonised layer which is

	blue. the organs shows the plastic deformation.
Exploration	PL - The black dots could be cause by sample preparation, polishing pullout
Exploration	MG - John was working on N2 material and showing a completely differne failure mode and we would like to have a look at this.
Action Point	MG - Need to get Sharon's input into the first issue, Kenny McGuire can help to arrange this. No assigned person. Status =Outstanding
Action Point	MG - again need to look at the cost and other factors before decided to ensure a balanced decision. No assigned person. Status =Outstanding
Exploration	Prashant Jadhav presented an overview of his work
Exploration	Final point, Magnus has made a lot of progress
Exploration	Last week encountered some problems in Inchinnan with glassing machine
Exploration	MG - Campbell was impressed with some techniques and wishes to employ them
Exploration	Will validate experiments using the conditions used in trials
Exploration	MG - need to look at applying practicalities to this work, to ensure that we address what is practical.
Exploration	Need dates for glassing and stamping
Exploration	MG - once the parts are glassed and ready to go, dates will be arranged.
Exploration	exciting project and the potential outputs give us a greater understanding
Exploration	JB like to continue the way of working with the core research with input from Company B
Exploration	Remi slides to introduce the project since many changes have been made
Exploration	Difficult to make definitive decision about trials as there is so much background
Exploration	Unsure of input variables effect on changes. almost do what Prashant is doing but on a real time basis
Exploration	implementing monitoring system is going to be lightweight trial system to gather some data to work with
Exploration	start recording effects of die wear off the parts
Exploration	From Prashants work we hope to define the key variables and Remis work will help monitor these.
Exploration	PL - Need to invest the time upfront to get the benefit from it.
Decision	Need to develop a scaled standard of visual inspection possibly 6 point scale. Literature review of possible approaches would be good starting point.
Exploration	Curvacious geometric modelling software
Exploration	Curvacious geometric modelling software
Exploration	PL need to look at communication of the project results
Exploration	Rt - include operators as part of the project teams
Exploration	RZ - goal setting feedback system rather than a spy system, real time

	feedback
Exploration	MG _ Company B will build up a network of people to contact, Company B will develop a communication line document to allow the AFRC guys to interact with the correct people.
Exploration	PL - Number of reviews previously but now can see how the projects fit together and the associated benefits
Action Point	MG - again need to look at the cost and other factors before decided to ensure a balanced decision. No assigned person. Status =Outstanding
Action Point	MA to check sample preparation prior to experiments No assigned person. Status =Outstanding
Action Point	MA to measure and record all factors to ensure documented data set No assigned person. Status =Outstanding
Action Point	MG to provide N2 material project data set. No assigned person. Status =Outstanding
Action Point	PJ to measure and record all factors to ensure documented data set No assigned person. Status =Outstanding
Action Point	Need dates for glassing and stamping No assigned person. Status =Outstanding
Decision	Will validate experiments using the conditions used in trials
Action Point	Need to develop a scaled standard of visual inpection possibly 6 point scale. Literature review of possible approaches would be good starting point. No assigned person. Status =Outstanding
4.	Collaborative Update
Exploration	JF - number of iterations, finally approved by the steering group last week, communication isto begin working therefore adverts for staff will be going out.
Exploration	Joint planning session next Wednesday 31st at Strathclyde
Exploration	Processing modelling activity will improve current processes. other activity will look at new process models not currently being implemented
Exploration	Possibility of funding available from EPSRC to buy additional kit as AFRC kit may be used for COLLABORATIVE activities.
Exploration	PL - Interesting to see what opportunities available for Company B
Exploration	Wider COLLABORATIVE message is that the project is very close to being started.
Exploration	Ultra Fine Grain project to tune of 1million has gone through.
5.	Building and Equipment

Exploration	Building internals are now being confirmed
Exploration	Tenders for equipment being collated.
Exploration	Close to the decision on the SEM
Exploration	SE pushing to spend 600k by end of the year
Exploration	Attended meetings with Company B lab team and specifications collated from the meeting.
Exploration	Tier 2 partner Wilder Software provider and will give academic licenses. Wish to host conference in the AFRC building.
Exploration	DELCAM and ABAQUS also approached and discussions are ongoing.
Action Point	Information security systems requirements required from Company B and other partners - AMRC model No assigned person. Status =Outstanding
6.	Research Agenda
Exploration	Circulated around within Company B for comment. Basic process was drafts in May, lengthy process of getting comments from members
Exploration	All comments from Company B have been considered and integrated. in residual stress and workflow elements had a lot of input from Mettis. SPF has been mainly from Boeing - Dave heck
Action Point	Dave Bryant not present in the Tech Board. Need a Company B rep. JF to arrange No assigned person. Status =Outstanding
Exploration	Company B will discuss internally and give some feedback to Jeff. A lot of projects will be relevant to Company B
Exploration	Project Leads will be drafting out specific research plans for each, in more detail than current incarnation.
Exploration	Good review meeting, action list and 4 box charts very useful
Action Point	Company B will discuss internally and give some feedback to Jeff. A lot of projects will be relevant to Company B No assigned person. Status =Outstanding
Action Point	Project Leads will be drafting out specific research plans for each, in more detail than current incarnation. No assigned person. Status =Outstanding

Industrial Experiment Minutes

Date of Meeting: 25/09/2009 13:00

Title: AFRC - Compressors Project Review M5

Attendees:

University of Strathclyde

- Anderson, Magnus
- Hector Basoalto
- Brooks, Jeffery
- Conway, Alastair
- Hutchison, Margo
- Jadhav, Prashant
- Zante, Remi

Company B

- Fortune, James
- Michael Gallagher
- Lord, Peter
- Ruddy, Pat
- Teeling, Russell

1.	**Review of Actions from M4**
Exploration	Research Agenda: A 1-hour Link call has been arranged for 25th September to collate comments COLLABORATIVE Project 4.3.2: as a result of this being EPSRC funded, all IP generated by the project will be shared with UoS and must enter the public domain. Background IP will be protected. This will apply to TSB-funded projects as well. Screw press: Schuler Weingarten have given very positive indications regarding joining as Tier 1 member. Further discussions re press specification arranged for next week. Expect a decision before the Board meeting on 19th October to allow an order to be placed shortly after, as a certain amount of the funds must be spent by the end of 2009.
Exploration	Official opening ceremony expected to be held May 2010 and will be attended by a member of the Royal family. AFRC will be liaising with the Lord Lieutenant of Renfrewshire to arrange.
Exploration	No change to floor plan, building design currently frozen.
2	**AFRC Staffing**
	Jeff introduced Hector Basoalto (present), Colin Harrison (absent) and Lynne O'Hare (joins team at end of September). Their expertise is as follows: HB – modelling of microstructures and performance; will be Jeff's right hand man

	CH – SPF and automation LO'H – materials characterisation
Action Point	Site visit to AFRC and Company B provisionally arranged for 16th October but will be re-arranged to avoid clash with school holidays. James Fortune & Margo Hutchison Status = New
	Adverts are in preparation for additional research staff to work on COLLABORATIVE projects. Interviews will be held in November with a view to a January start date. Also, there are plans to recruit 2 more core researchers, and an engineering manager and technician, both of whom will require an unusually wide range of skills and expertise and may be a challenge to find.
3.	**Project Update - Magnus Anderson**
Exploration	MA has submitted a DMAIC proposal but has not had feedback yet.
Decision	Need to get feedback via Kenny McGuire and Sharon before November.
Action Point	Liaise with Kenny McGuire to ensure feedback before November Mick Gallagher . Status =Outstanding
Exploration	MA is examining expensive composite material from non-approved supplier (Bohler). Concerns over costs, time to prepare etc. Caution urged re balancing costs, practicality and benefits. Ideal to incorporate learning from previous similar projects, for analysis and comparison.
Action Point	Measure and record as many relevant factors as possible, from the outset, to ensure comprehensive data set for later analysis Magnus Anderson. Status =Outstanding
Action Point	Provide data from previous projects. Mick Gallagher Status =Outstanding
Exploration	Concern over black spots on samples, cause not established. May be due to (unavoidable) local softening?
Action Point	Check sample preparation to eliminate this cause Magnus Anderson Status=Outstanding
Exploration	Experienced cracking in die.
Action Point	Mick Gallagher Get recipes for the plasma process Status = Outstanding
4.	**Project Update - Prashant Jadhav**
Exploration	Campbell? wants to employ some of Prashant's techniques. The techniques will be validated in a trial using parameters specified by

	Prashant. Almost ready for final stamping. The parts will be expensive so it is important to exploit the project fully to provide as much data as possible to enhance future learning.
Action Point	Arrange for glass coating preparation to take place the day before forging Mick Gallagher Status =Outstanding
Action Point	Measure and record as many relevant factors as possible, from the outset, to ensure comprehensive data set for later analysis Prashant Jadhav Status =Outstanding
Action Point	Ensure access is possible to take measurements Mick Gallagher Status =Outstanding
<u>5.</u>	**<u>Project Update - Remi Zante</u>**
Exploration	Requirement to benchmark leads to requirement for monitoring in real-time. Project relates to both MA's and PJ's projects. Assessments of die life are currently subjective, with very little hard data available. Some recording is already taking place as part of PJ's project, from which it is hoped some objective measures will emerge.
Exploration	A scale should be used, rather than a binary (good/bad) assessment. Dedicated geometric analysis software may be considered, eg Curvaceous, as it is automatic and can be done in-situ. However scanning and measuring is time-consuming. Have to discuss with experts in instrumentation both within R-R and outwith, eg Davis Decade.
Exploration	Need to engage operators fully as part of the team, and outline possible effects, eg greater job satisfaction, improved quality, shorter task times to avoid anticipated fears about how data will be used.
Action Point	Definition of work plan and associated time-scale required in form of timeline or Gantt Chart. To be developed with Rolls Royce and AFRC. Should include quantifiable deliverables and specific outcomes. Remi Zante. Status =Outstanding
Action Point	Pull together network of contacts to facilitate communications with relevant experts. Mick Gallagher. Status =Outstanding
Exploration	CH & MG have started regular weekly meetings at UoS with researchers. This is generally reckoned to be good for progress.
<u>6.</u>	**<u>Research Topics Update – Jeff Brooks</u>**
Exploration	Collaborative 4.3.2 –Aerofoil forging (originally hot-die forging for hydraulics). Was approved by Collaborative steering group on 17th Sept. There are still questions over "additionality" and until they are resolved to the RDAs' satisfaction the rest of the funds are not certain.

	Funding of £575K will allow for 1 full-time Research Assistant (RA) for 4 years, as well as some equipment. AFRC has prepared adverts for staff, however funds have to be in place first. Internal discussions are taking place re university processes.
Exploration	Process modelling strand will focus on improving and replacing current processes. Planning session on Collaborative is scheduled for 1st& 2nd October. This should produce Level 2 plan.
Exploration	Collaborative is providing £1M for ultra fine grain technology.
7.	**Building and Equipment Update – Jeff Brooks**
Exploration	Discussions are under way re internal layout and services.
Exploration	Equipment – the tendering process is under way for some kit including mechanical test equipment (likely to be from Zwick), and a decision is expected soon on a Selective Electron Microscope (SEM). R-R providing advice on spec for SEM via Ernie Valero.
Exploration	Modelling software – A mix of full commercial and educational licences will be purchased; likely to be … AFRC may host next year's user group conference. Delcam? Abaqus?
Exploration	IT Security – part of AC's remit. AC investigating AMRC's configuration as well as R-R's compliance needs. Boeing have similarly high requirements. AFRC will improve on AMRC set-up.
Exploration	Screw Presses – awaiting data from Mettis. Likely to buy Schuler Weingarten. R-R already have multiforges. R-R wish to maintain existing capability as well as to extend capability.
8	**Core Project Proposals – Jeff Brooks**
Exploration	Drafts have been updated, incorporating comments from Tier 1 partners.
Action Point	R-R to review and provide official comments to Jeff prior to the Technical Board meeting on 1st October. James Fortune / Peter Lord Status = New
Action Point	R-R to decide on technical rep for Technical Board meeting as substitute for Dave Bryant who is unavailable James Fortune Status = New
Exploration	Clarification given that R-R will be able to provide input to and gain benefit from all core research, at least for first 2-3 years.
Action Point	JB creating matrix showing how forming and forging in R-R maps onto AFRC research to show how the research will relate to R-R business interests. Jeff Brooks. Status =New