2 Literature review

Dr. Terence Love (drawn from 1998 PhD thesis) Social, Environmental and Ethical Factors in Engineering Design Theory: A Post-positivist Approach

2.1 Introduction

Chapter 1 introduced the practical problem that underlies this research and laid the foundations for the thesis. In this chapter, the description of the practical problem is first transformed into a theoretically defined research problem, and then the literature relating to addressing the research problem is reviewed. This review leads to the definition of the research questions that form the basis of this research.

Identifying and defining the research *questions* is commenced by first classifying the literature into 'background' and 'focal' literature, as recommended by Phillips and Pugh (1987). Then the research *problem* is positioned, in the manner suggested by Perry (1996), relative to both the wider body of background knowledge and to its immediate focal field of inquiry (see Figure 1).

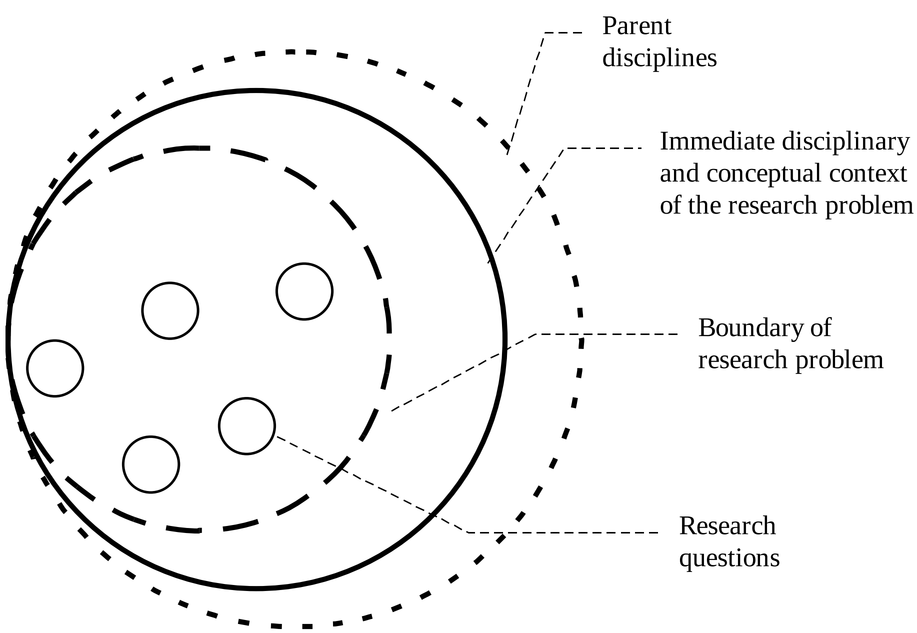

Figure 1: Perry's model of relationships between research problem, research questions and disciplinary context

The final definitions of the research questions, whose answers enable the research problem to be addressed, are consequent on the analysis and investigation of the immediate disciplinary and conceptual context of the research problem in the concluding sections of this chapter.

Graphical models are used in this review of literature to clarify and add structure to the different aspects of the analyses of the literature. This is necessary because of the problems presented by the combination of cross-disciplinary terminology, the complexity of the relationships between the different fields, disciplines and perspectives involved in the study of design, and the terminological problems of design research and engineering design research referred to in Chapter 1.

2.2 Overarching disciplinary contexts of the research problem

The practical aim of this research is to address the problem,

> *How can social, environmental and ethical matters, be better included in designing?*

The consequences of resolving this problem lie in practical changes to designers' activities. Researching and resolving the problem, however, lies in the realm of design theory. This research focuses on updating design theory in this area to take account of advances in research into alternative foundations of theory-making. Hence, the research question addressed in this thesis is,

> *Can social, environmental and ethical matter be better included in theories about designing engineering artefacts by applying a post-positivist perspective?*

2.2.1 Parent fields of the research problem

The theoretical position from which this research is undertaken lies outside the disciplinary areas of the research problem. The theoretical position of the researcher, and the source of the theoretical tools used in this research, are mainly drawn from the field of philosophy of knowledge. This philosophical basis is necessary to include those philosophical aspects of the disciplines that relate to the practical aspects of the research problem.

The research problem is grounded in five parent fields:

- Engineering
- Design research
- Social aspects of technology
- Environmental aspects of technology
- Ethical aspects of technology

For brevity, the latter three are combined together into 'social, environmental and ethical aspects of technology'. The issues relating to the research problem lie in the area of overlap between the three fields of engineering, design research and the social, environmental and ethical impacts of technology represented in Figure 2 below.

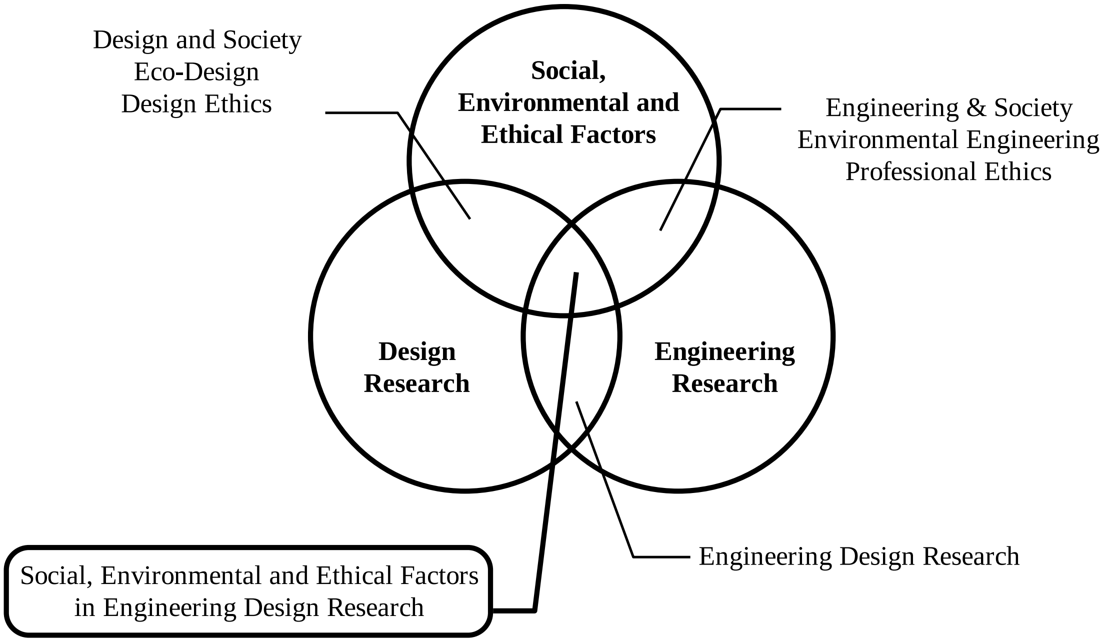

Figure 2: Centrality of research area in relation to parent fields of research problem.

Figure 2 illustrates the centrality of the area of the research problem relative to its parent fields. It is necessary, however, to clarify which aspects of the literature of these parent fields provides a background to the research problem, which areas are focal, and which areas of literature are not immediately relevant. The relationships between the parent fields and the research problem are better illustrated in Figure 3. This figure is a topological transformation of Figure 2 that emphasises the linkages between disciplines and the research problem rather than the overlaps of knowledge between the main disciplines.

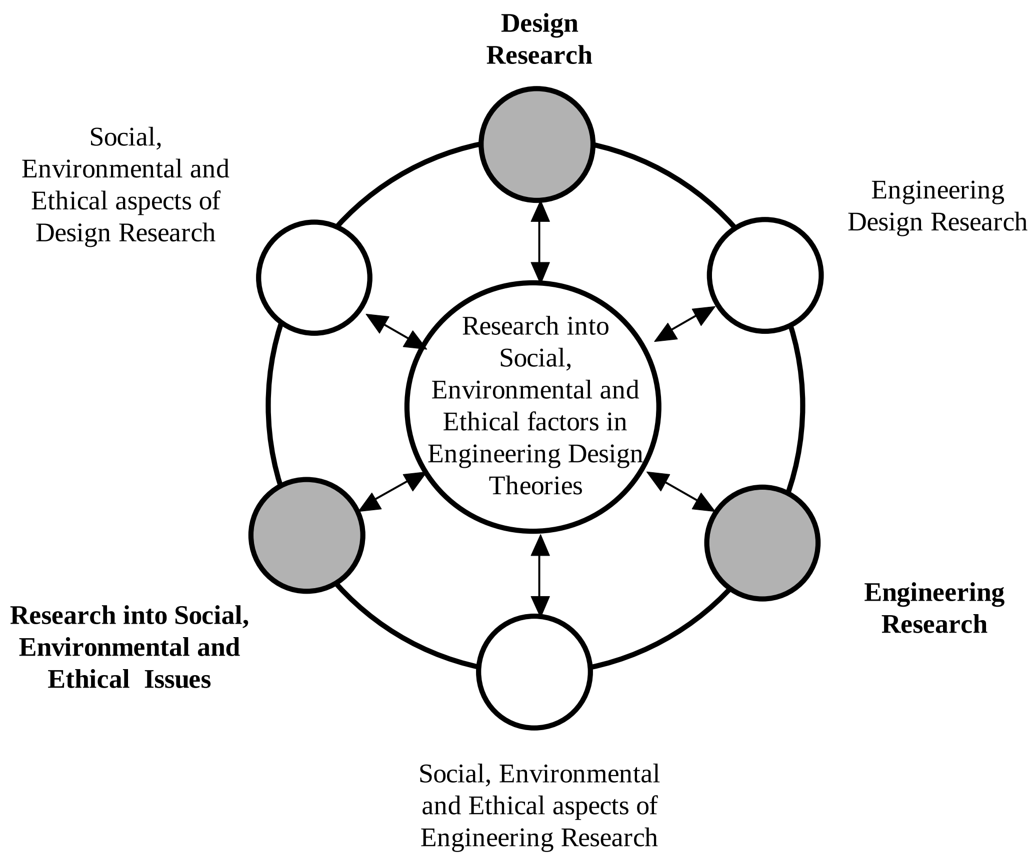

Figure 3: Centrality of social, environmental and ethical factors in engineering design theory

In this thesis, the research problem is considered in the context of theories about design cognition, and consequently the disciplines in the upper half of Figure 3 are more relevant to the central research area than those disciplines in the lower half of the figure. The literature of engineering research is directed towards modelling the physical behaviour of artefacts rather than the cognitive environment in which the specifications of artefacts are created, and thus is peripheral to this research. Research into the social, environmental and ethical aspects of engineering research focuses more on the ethics of engaging in particular aspects of engineering research, for example, the commercialisation of research into medical and food technologies such as artificial human conception and genetic modification of plants and animals. Neither of these disciplinary perspectives is of direct relevance to the formulation of theories of design cognition which are the essence here. The delimitations and assumptions of this research defined in Chapter 1 mean that the literature concerning 'research into social, environmental and ethical issues' is also not of direct relevance because its main focus is the *consequences* of particular technological implementations, as is evident from the focus in the field on 'environmental impacts' and 'social impacts'.

The purpose of this research is to improve the social, environmental and ethical consequences of technology and its design by improving design theory related to how the consequences of technology influence designers as described in section 1.3. Hence, the sources of literature that are of primary interest are found in the fields of design research and engineering design research. This means that, although the central area of interest is related to all of the above six fields, only the literatures of the fields design research, engineering design research and social, environmental and ethical aspects of design research are of direct significance. Thus, the 'background' and 'focal' literature structure of this research is as illustrated in Figure 4 below.

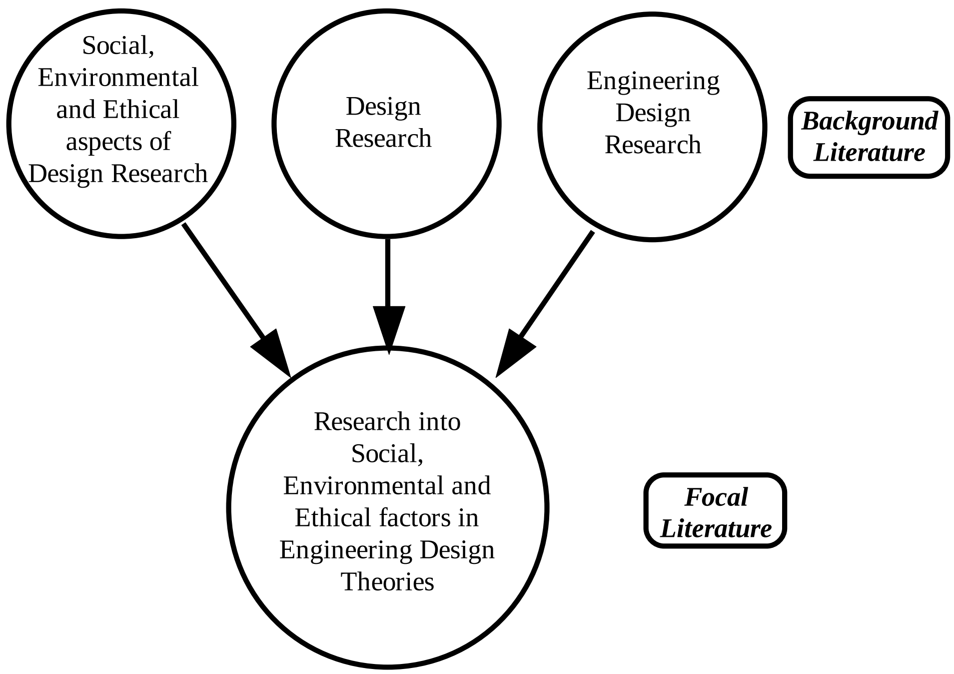

Figure 4 The disciplinary context of the background and focal literature

2.2.1.1 Literatures of design research, engineering design research and the social, environmental and ethical aspects of design research

It is first necessary to clarify some issues about the background literature relating to this research, and about the relationships between the background disciplines to the research problem. First, the terms 'design research' and 'engineering design research' are primarily used in this section in the senses that are most commonly found in the literature. For example, 'design research' is used by the Design Research Society's Journal *Design Studies,* to mean 'design research in engineering, architecture, products and systems' (see also, for example, the goals of the Design Research Society and the aims of the journal *Research in Engineering Design)* (*Design Studies* 1996a; Durling 1996b; Finger, 1991)). Secondly, the literature on the social, environmental and ethical aspects of design research is not discussed here separately from the literatures of design research and engineering design research because it is effectively subsumed into them. Third, the extensive overlap between research into design and research into engineering design has meant that research and theories relating to design research are frequently referenced to texts, conference proceedings and journals that are predominantly associated with engineering design research and vice versa.

The explanation for the overlap of the literatures of 'design research' and 'engineering design research' is found in the history of the development of research into these areas. The modern English language literature of design research is grounded in an academic tradition that started in the English speaking world in the 1950s. The Design Research Society, founded after the Conference on Design Methods in 1962, has been the main bearer of this tradition, particularly in the UK. In North America, the Design Methods Group, founded at the University of Waterloo in Canada in 1966, has a similar role with similar interests and methodologies (Jones and Thornley 1963; Pahl and Beitz 1984). The Design Research Society publishes *Design Studies*, the electronic *DRS_News* and the *Design Research Newsletter*, and the Design Methods Group publishes the *DMG Newsletter*. Researchers associated with these organisations are responsible for the majority of the literature in both fields. Although the scope of design research extends, in theory, beyond the design of technical objects to the role of design in Art, both of these English language research streams have been characterised by a focus on technical artefacts designed for commercial purposes (Cross 1984d, 1993).

Predating the above two English language traditions is the German research into systematic design. The German approach originated in the 19th century and is firmly based on a scientific deterministic hierarchical model of design process (Pahl and Beitz 1984; Matousek 1963). Associated with this systematic approach is the development of the VDI 2221 German Standard design guidelines, the publications of the German WDK design research group founded by W. E. Eder and V. Hubka, and the International Conferences on Engineering Design (ICED) organised by the WDK group (Eder 1981; Hubka and Eder 1981; Pahl and Beitz 1984; VDI 2221 1985; Wallace 1987). This German systematic approach emphasises procedural methods of designing and is founded on the intention that design research will result in a science of design. This systematic and scientistic research perspective focuses on the artefact and problem characteristics rather than the activity of designing, and provides a strong contrast to the traditional style of design research dating back at least to Vetruvius that involves bringing together insights from a variety of disciplinary sources (Cross 1993; Dasgupta 1992). In Cross' (1995) terms, the systematic tradition focuses on 'research *for* design' rather than 'research *into* design'.

In addition to the English and German literature of design research and engineering design research are the occasional translated publications from the former USSR colonies. These translations indicate the existence in the former USSR colonies of research programs focusing on systematic methods of addressing design problems in a similar manner to the WDK group and on research into the praxiological nature of designing, that is aimed at clarifying the issues surrounding the duality of theory and practice in design (see, for example, Altshuller 1984; Gasparski 1979; Stupniker 1994; Tempczyk 1986).

In all of the above research histories, the origins of the academic interest in researching into design is found in the development of mathematical methods for complex decision-making and the applications of the newly coined 'systems' perspectives (Love 1995). During the 1960s, the application of theories of systems and cognitive science to the more technical design disciplines led to a dream that a way might be found to automate designing and to the start of interest in research into design by academics and commercial organisations. In 1970, Jones reported on the development of several theories of design from which the human designer had been completely removed: design had become conceived as a process that related problem and solution. At the same time, ‘design research’ had become ‘research into how satisfactory solutions might be deterministically identified and defined’ and ‘engineering design research’ had become well established as ‘research into technical and theoretical tools to help designers choose and evaluate design attributes’ (Beck 1966; Duggan 1970; Eder 1966; Himmelblau 1974; Wong 1974).

There are three trends evident in the development of the literatures of design research and engineering design research. Firstly, the literature of both design research and engineering design research is dominated by research aimed at automating some or all aspects of designing in the more technical domains (Coyne and Snodgrass 1993). Secondly, both literatures emphasise the role of science as a paradigm with differing levels of support for the idea that the aim of research into design is the establishment of a design science or science of design. These differences relating to the role of science are illustrated in Table 1 below, where the column concerning design research is based on the role that *Design Studies* defines for itself, and the column relating to engineering design research is drawn from statements made by prominent researchers in engineering design (*Design Studies*, 1996b; Dasgupta 1992; Dixon 1987; Hubka and Eder 1990; Pugh 1990). Thirdly, ‘design research’ has been reduced in scope to refer only to research into designing artefacts associated with scientifically based technologies, and this appears to be due to the lack of formal attention that has been paid to research into the less technical design domains especially the Arts (Newbury 1996; Allison, 1995; Cross, 1995).

Design Research	Engineering Design Research
Discussion and development of the theoretical aspects of design including its methodology and values	Design science is ‘an integral system of logically related insights and knowledge that should contain complete knowledge about and for designing.’ (Hubka and Eder 1990)
An understanding of design from comparison of its application in all areas, including engineering, architecture, planning and industrial design	‘Design researchers are viewed as a single communicating community searching for *scientific* theories of engineering design; that is, theories that can be tested by formal methods of hypothesis testing.’ (Dixon 1987)
New developments, techniques, knowledge and applications in the practice of design	‘Explanations of design process must satisfy the programmatic aims of science.’ (Dasgupta 1992)
Design education: how design techniques may be taught, the approach to ill-defined problems and the impact of new technologies	Engineering design research is the ‘Interaction between design process research and applied engineering research.’ (Pugh 1990)

Table 1 Science in design research and engineering design research

Whilst these trends clarify the roles of design research and engineering design research, the complexity of the issues involved in research into or for design, and the terminological problems referred to in Chapter 1, have led to substantial overlaps between the disciplines. In addition, the boundaries between design research and engineering design research are made more complex by the overlapping claims about the scope of each discipline that can be inferred from Table 1. From the perspective of design research, topics addressed in engineering design research are either subsumed within design research, or relate to engineering rather than design. From the viewpoint of many engineering design researchers, however, *all* design research is completely subsumed within a science of design that is based on similar scientific principles to those used in engineering analysis.

These differences in outlook mean that there is a substantial overlap in the literature of both disciplines in terms of the topics that are addressed. More importantly, however, it means that the activity of designing engineering artefacts is rarely viewed as a human activity with all that that entails. This is because from the perspective of engineering, engineering design research is seen as research into a technical process, and from the perspective of design research, engineering design research is a subdiscipline that investigates the peculiarities of designing in the domain of engineering. In both disciplines, the literature relating to how theories of engineering design include social, environmental and ethical considerations reflects these assumptions that design can be scientifically modelled as an ahuman process.

To recap,

- Research into the social, environmental and ethical aspects of design research is embedded in the literatures of design research and engineering design research.
- Both design research and engineering design research are based on systems theory and the theories of cognitive science.
- Both design research and engineering design research are mainly concerned with the design of artefacts associated with the more technical domains and this has led to substantial overlaps in the literature.
- The literature of design research is less dominated by scientism than the literature of engineering design research.
- Researchers involved in both design research and engineering design research lay claim to their perspective encompassing all and every aspect of research into design.
- Both design research and engineering design research are mainly focused at automating design and hence are concerned with developing ahuman design theory that is suited to that end.

The above analysis of the background literature in design research, engineering design research and social, environmental and ethical aspects of design research outlines their content and relationships as seen from a general perspective. The perspective of this research, however, is defined by the way social, environmental and ethical factors are incorporated into theories about human design cognition, and hence it is necessary to review how the background literature relates to this perspective.

Firstly, the overlapping characteristics of the literatures of design research and engineering design research mean that identifying the literature relating to a particular specialism is not as straightforward as the above general analysis might imply. For example, the dichotomy between the human-centred and ahuman perspectives on design does not result in a clear separation of the literature and, in fact, much of the literature relating to the development of mechanistic and deterministic ahuman theories of designing also contradictorily implies or states that design is an essentially human activity (see Chapter 3 and Appendix 1). There is an imbalance in which the majority of the literature focuses on the artefactual design solution at the expense of research into the human side of designing. Analogically, it is as if research into English literature ignored issues of æsthetics, semantics and truth and focused only on grammar, punctuation, logic and syntax. This imbalance in the literature means that many of the references that are relevant to this thesis are found in literature whose primary focus is only distantly connected to it. Secondly, issues concerning social, environmental and ethical factors are more particularly concerned with theories of design cognition than theories of the characteristics of objects. This is because what is needed is to extend theory in this area of engineering design research beyond the simple quantisation of social, environmental and ethical factors as technical factors so that it also encompasses how designers include these factors in their partial and internal conceptualisations and evaluations. Publications relating to design cognition are mainly found in the literature of design research. Thirdly, the analytical tools that are utilised in this research for investigating engineering design cognition originate in the field of philosophy, but the issues surrounding their choice and the epistemological detail of their use that are discussed in Chapter 3 are based mainly on the literature of design research. Fourthly, the problems associated with disciplinary structure, referred to in Chapter 1, have meant that Dewey and similar library classification systems do not contain a specific classification structure for the literature of design research and engineering design research (see Appendix 3). Consequently, the literature of engineering design research and design research is unevenly distributed across libraries and has mainly been classified according to the domain of interest of its purchaser. This presents difficulties of both location and access for research in this area.

In summary, the main source of background literature for this research is to be found in the literature associated with the discipline of design research, but, because the disciplines of design research and engineering design research do not translate to unique library classifications, this gives rise to difficulties in identifying and obtaining relevant texts.

The above difficulties associated with a lack of appropriate library classifications which in turn are based on problems with the structure and bounds of relevant disciplines means that the background and focal literatures of this thesis cannot be easily and uniquely identified from electronic catalogue searches undertaken within a particular domain. Therefore, the literature for this review has been drawn from the contents of the journals *Design Studies* and *Research in Engineering Design*, along with the texts found by manual library catalogue searches across many domains and from related bibliographic references.

2.2.2 Research problem and the literature

The discussion of issues relating to the social, environmental and ethical aspects of designing is rare in the design research and engineering design research literature and, in general, these discussions only come to light when one of them is focal to a design problem. For examples, the environmental implications of leaded motor fuel, the social implications of high rise housing, or the ethical implications of armament design. The focus remains, however, on the problem and its solution, and in general what is addressed in the engineering design research literature is 'How can the social/ environmental/ ethical side of this particular design problem be satisfactorily resolved?'. In this thesis the focus is moved from the design problem to the theories and assumptions that underpin how design problems are viewed. That is, what is being investigated in this thesis are alternative post-positivist paradigms and perspectives that might form a new basis for engineering design research and theories of engineering design.

Social, environmental and ethical considerations are especially important to reviewing the basis of design research and formulating theory about designing because designing is an activity that is socially, environmentally and ethically situated (Coyne, Rosenman, Radford, Balachandran and Gero 1990; Dilnot 1982; Gasparski 1979; Konda,, Monarch, Sargent, Subrahmanian 1992; Simon 1981). This is a key point in this thesis and it, and its implications, are discussed in detail in Chapters 3, 4 and 5. What viewing designing as a socially, environmentally and ethically situated activity implies is an inversion of the accepted relationship between theories concerning the social, environmental and ethical aspects of design and theories of design. The argument is that:

- Designing is a human activity that is socially purposeful and is intended to result in changes to social situations, for example, by making money for its sponsors.
- Designers do this by modifying environments with their designs, not only because of manufacturing inefficiencies, but also because designers intend to create new artefacts and technologies that change the user's environment.
- The activity of designing is grounded in ethical judgements by designers and others about design solutions and social and environmental problems associated with both of the two points above.

If the above argument is accepted, then theories of designing would be expected to be derived from, and evaluated with respect to, research and theories relating to the social, environmental and ethical situation of designing. What has happened instead is that, in most of the literature, the social, environmental and ethical aspects of designing have been assigned a minor role in theories whose primary purpose is to define the physical relationships between a scientifically defined problem and its technically defined solution. Most research into designing results in theories of designing as an ahuman process and this means that social, environmental and ethical factors are dealt with in this context as information—preferably quantified—and the implications for human design cognition are lost (Court 1995; Dorst and Dijkhuis 1995; Joseph 1996; Oxman 1995). There are exceptions. For example, Dilnot (1982) has drawn out in detail the argument against the primacy of the technical perspective in design research with respect to design and society. Recent work by Coyne and Snodgrass (1991, 1992a, 1992b, 1993), Reich (1994a, 1995) and Franz (1994) and other researchers who espouse a constructed or phenomenological view of reality have this alternative human-based view of design research implicit in their arguments. From these perspectives any theory of the technical must reduce to one about individual human circumstance with the concomitant implications concerning social, environmental and ethical consideration. Similarly, but more distantly, the argument for reversing the privilege given to object-based engineering design theory is implicit in the work of Cross, Cross and Glynn (1986) on hemispheric brain specialisation and 'designerly ways of knowing'. Finally, implicit support for this inversion of the relationship between the theories about the social, environmental and ethical aspects of design and human-based theories of design is found distributed throughout the works of researchers who view designing as an essentially human activity and whose research reflects this focus (see, for example, Cross and Cross, 1995; Goldschmidt 1995; Peng 1994; Reich et al. 1996; Sharrock and Anderson 1994; Wong and Shriram 1993).

The idea that design is essentially a human process is rarely explicitly stated in the design literature, but is more often implicit in either the topic being discussed or in the detail of analyses. Design research was founded on the disciplines of architecture, industrial design and to some extent the craft design traditions (Alexander 1979, 1964, 1963; Archer 1979, 1965; Broadbent 1973, 1966; Jones 1970; Jones and Thornley 1963). In each of these disciplines the idea of a 'designer as creative genius' was dominant and this has carried through, albeit as a minor strand of the literature, into contemporary design research (Roy 1993; Coyne And Snodgrass 1992b; Tovey 1992a, 1992b; Buchanan 1990). The idea of design as a human activity is also strongly implicit in theories relating to 'human error in designing', 'participatory design', 'design for the user', 'designer as "prosumer"', 'computer supported co-operative work', 'design thinking' and the research into design that uses protocol analysis as its research method (see, for example, de Bont, Schoormans and Wessel 1992; Bowers 1991; Cross and Cross, 1995; Goldschmidt 1995; Gunther 1992; Krouwel 1992; Magee 1987; Peng 1994; Petroski 1991, Reich et al. 1996; Sharrock and Anderson 1994; Sonnenwald 1996; Stewart 1992; Tang and Leifer 1991; Toffler 1990; Wong and Shriram 1993).

2.3 Immediate disciplinary and conceptual context of the research problem

In section 2.2, the way that the disciplines of design research and engineering design research provide a general background to the research problem was discussed. The conceptual background to the research problem now needs to be exposed in sufficient detail to draw out the research questions that must be answered to address the research problem. This section starts that process by exploring the immediate context of the research problem.

The breadth and depth of concepts and theories about design have been mapped out in a variety ways, but some of these mappings are more appropriate to domains other than engineering, for example, to Graphic Art or Sculpture. Significant overviews of concepts and theories of design research are those on:

- Design methods (see, for example, Chandrasekaran 1990; Cross 1984d, 1989, 1993; Jones 1970; Pahl and Beitz 1984; Rittel and Webber 1984, 1974, 1973, 1972; Ullman 1992).
- Types of design research (see, for example, Cross 1995).
- Design theories (see, for example, Cross 1993; Hubka and Eder 1990; Konda, Monarch, Sargent and Subrahmanian 1992; Ullman 1992).
- Design research methodologies and issues of epistemology and ontology (see, for example, Coyne and Snodgrass 1992; Franz 1994; Reich 1994).

The conceptual mappings or overviews that are discussed in the following have been chosen because they represent the main aspects of research into design that has a technological or engineering focus. These overviews and taxonomies of the literature and the design research effort coexist, however, with the ubiquitous classification by domain and subdomain, echoed in how design research and design theory is catalogued in libraries (Appendix 3). There are several explanations for the dominance of the domain based taxonomies of design research, but it will be argued later, in Chapters 3, 4, and 5, that one of the most important reasons for the failure of proposals for a structure of design theory that is not based on domains is the lack of attention to epistemological assumptions in design research, especially where those assumptions relate to design cognition.

2.3.1 Theoretical approaches to design research: Overviews, taxonomies and classifications

It is necessary to bound this research by defining which aspects of the literature are not addressed by this review. In this thesis, the research problem is viewed in terms of theory-making and conceptualisation and this means that the study of the history of design methods lies outside its scope. Similarly, the study of the relationships between particular design methods is not considered here in detail. In spite of these general exclusions, some concepts that originated in design methods research are useful for developing design theory, for example, the ideas of classifying designing in terms of its 'wickedness' or its novelty are useful in separating activities that are 'pure' design from associated routine activities (Love 1996a, 1996b; Pahl and Beitz 1984; Rittel and Webber 1984, 1974, 1973,1972).

In this section, six different classifications of the concepts and theories of research relating to design are reviewed with the intention of establishing the historical backdrop of the developments of design theory for the theoretical investigations of this research. The six classification systems are,

- Hubka and Eder's (1990) taxonomy of design research.
- Ullman's (1992) taxonomy of design research in mechanical engineering.
- Konda, Monarch, Sargent and Subrahmanian's (1992) taxonomy of design research.
- Cross' (1995, 1993 and 1984b) historical reviews of the literature relating to research into design, design science and science of design.

- Franz'(1994) taxonomy of design research in the domain of architecture.
- Reich's (1994) layered taxonomy of research methodology in engineering design research.

Hubka and Eder's (1990) taxonomy of design focuses on design knowledge and is based on a paradigm of research and theory-making that is drawn exclusively from the natural sciences. Their scientific perspective on design depends on the activity of designing being adequately described by theories of information processing and the structure of their taxonomy reflects this assumption, see Figure 5.

Figure 5 Taxonomy of Design Science (Hubka and Eder 1990)

In 1992, Ullman proposed an hierarchical taxonomy or, rather, a set of hierarchical frameworks to classify design research in the mechanical domain. The top level of this taxonomy is reproduced in Figure 6 below. The purpose of Ullman's taxonomy is to classify design methods and tools and it is set firmly in the context of establishing a design science. The taxonomy differentiates between research relating to an artefactual view of design and research relating to design process, and, unusually, includes a category for classifying research into design environment, that is, the environment in which a design is created.

Figure 6 Taxonomy of Mechanical Design (Ullman 1992)

Ullman put forward the above model for classifying design methods and tools in the domain of mechanical engineering, but it is clear that it has wider application. What Ullman achieved was to separate many aspects of research into design that were commonly conflated, and in doing this the structure of his taxonomy draws attention to several aspects of design research that are often overlooked, for example design environment and individual designers' backgrounds. According to Ullman, one of the main purposes of his taxonomy was to provide a basis to avoid the problems associated with the lack of terminological and conceptual agreement in design research and to support the critical analysis of theories and research results. It is clear that he has separated and differentiated between overlapping areas and concepts, and in this his taxonomy provides a useful tool for the deconstruction of design theory. What he has not addressed, however, is how alternative ontological and epistemological perspectives change the basis for design research and hence, change his taxonometric structure. Ullman's taxonomy provides a well developed taxonometric 'snapshot' of a positivist perspective of engineering design research which although initially grounded in his research into mechanical engineering design is likely to apply to most engineering design (Nagy, Ullman and Deiterrich 1992).

Ullman's taxonomy of design method shares many features with Hubka and Eder's (1990) taxonomy of design science. The main differences between the two taxonomies are due to their difference in purpose. Hubka and Eder aimed to classify design knowledge whereas Ullman's purpose was to classify means of design assistance. The similarities between the two taxonomies extend to detail, for example, Ullman's environmental category is paralleled in Hubka and Eder's taxonomy by a combination of their 'current fields' and 'general' knowledge classifications.

Konda, Monarch, Sargent and Subrahmanian (1992) derived a graphically structured taxonomy indicating the relationships between different elements of research into the design of technology (see Figure 7). Their taxonomy is important because it encompasses all aspects of design theory and it situates designing in a social, environmental and ethical context. The universal scope of this taxonomy, therefore, extends beyond the taxonomies of Hubka and Eder and Ullman whose foci are limited to design knowledge and design aids.

Figure 7 'Shared Memory' taxonomy of design research (Konda et al 1992)

The position of Konda et al that underpins their taxonomy parallels the arguments used in this thesis for focusing on design theory qua theory rather than its content, and in terms of viewing design as a socially, environmentally and ethically situated phenomenon. They take a social constructivist perspective on design, and in this sense view designing as an activity undertaken between humans. This position leads naturally to the concept of 'shared memory' in which the focus of design theory expands to include all the shared human knowledge that is contextual to the creation and implementation of a design. This concept provides the underlying basis for their classification of design theories and research and the basis of their proposals that shared memory is suited as a unifying theme for design research and practice.

For Konda et al, the idea of 'shared memory' has two roles: On one hand it offers the means of introducing a constructed view of reality into design research and provides a basis for enabling design research to move beyond its positivist beginnings so that it may encompass the implications of the social constructionist perspectives on knowledge. On the other hand, it keeps design theory tightly connected with the mathematically computerisable informatic perspectives of engineering design research. The 'shared memory' proposals are important because they are a milestone in the acceptance, by one of the main groups of artificial intelligence based researchers, that the non-technical human aspects of designing are what differentiate design from engineering and that it is necessary to address issues relating to the construction and interpretation of reality by designers and researchers alike.

The findings of Konda et al are important but not central to this thesis because their post-positivist perspective is tied to social constructivism, and therefore, leads to a structuralist outlook whereby the activity of designing is described in terms of the structural constraints defined by social and cultural considerations. This research is also post-positivist, but its central focus is on theory relating to individuals' design cognition because the aim of this research is to investigate the best way to express in theory how individual engineering designers' cognitions are influenced by non-technical external factors.

In 1993, Cross took an overview of design theory and design research in a way that followed on from his review of a decade before (Cross 1984b). Both reviews used the same categories, but differed in their focus. In 1984, Cross' focus was on the history of research into design methods and methodology, whereas, in 1993, his emphasis was on the details of the relationship between scientific research and design research and the implications this has for design theory. In both overviews, rather than using conceptual structures in the manner of Ullman or Hubka and Eder, Cross classified design research into themes that were almost identical for both 1984 and 1993. In 1993, the themes he proposed that represented the main streams of design research were:

- The development of design methods.
- The management of the design process.
- The structure of design problems.
- The nature of design activity.
- The philosophy of design method.

These themes are coherent with the taxonomies of both Ullman (1992) and Konda et al (1992) in the following ways,

- Themes 1 and 3 refer to artefactual matters.
- Themes 2 and 4 refer to design process.
- Theme 5 is essentially part of the epistemological consideration that is necessary for establishing a coherent research methodology.

What is omitted from Cross' overview is any explicit reference to research into the environment of designing, but this is not surprising in view of its paucity in the literature.

Two years later, in 1995, Cross suggested a three-fold classification of 'types' of design research. These were:

- Research *into* design
- Research *for* design

- Research *through* design

In Cross' terms, 'research *into* design' includes all aspects of investigations of the design activity, processes, knowledge. Its purpose is to increase knowledge about designing. 'Research *for* design' is that research intended to assist designers or to improve design outcomes in some other way. Research aimed at the development of design methods is an example of research *for* design. 'Research *through* design' refers to research that necessarily occurs in the course of designing. That is, 'research *through* design' occurs when a sculpture, or a dance, or a design of whatever sort not only represents itself, or a solution to a problem, but also represents the inquiry—the research—that led to its appearance.

Cross' categorising razor cuts the field of design research in a way that is important from several standpoints. Firstly, Cross' classification outlook is important because it clarifies and differentiates between different types of research in terms of the *purpose* for which it was undertaken. This is useful because the field until recently has overlooked the ways that the reasons for doing research influence not only on what research is undertaken, but how it is undertaken. Cross' classifications bring these issues of purpose to the fore and open the way for further clarification of the assumptions that underpin particular theories and concepts. Secondly, Cross' three classifications reflect the differences between the work of those involved in domain-independent research, domain-dependent research and practitioner-focused research. Finally, Cross' classifications inadvertently illustrate an endemic problem in the design theory literature relating to the way that different design research perspectives can result in apparently contradictory conclusions. An example of this is that classifying this thesis according to Cross' categories at first implies that the research that underpins it is primarily 'research *into* design'. This research is, however, intended to be useful to designers, which means that it might also be viewed as 'research *for* design'. In addition, because this research and thesis have been designed—in Schon's (1984) sense of 'design as a process of enquiry'—it is also 'research *through* design'. The implication of the above example is that the usefulness of Cross' classifications are at least partially neutralised by the multiplicity of purposes to which design research can be applied.

The ephemerally changing 'Design Web' taxonomy (a 1997 version of which is listed in Appendix 4) contrasts with the above carefully derived taxonomies and reviews of design research (see *DesignWeb Researchers' Database* 1997). The taxonomy of design research contained in the *DesignWeb Researchers' Database* is defined moment to moment as design researchers enter their areas of interest onto a World Wide Web database held at the University of Bath in the UK. It appears that the *DesignWeb Researchers' Database* includes an experimental classificatory system that is used to structure a database of design researchers' areas of interest as design research keywords. As additional researchers add their interests, the taxonomic structure is changed to reflect the new input. The structure of the 1997 *DesignWeb* taxonomy in Appendix 4 is dominated by research relating to information for designers, design science and artificial intelligence, which is perhaps to be expected since those who put entries in *DesignWeb* are likely to be familiar with computers. The taxonomy of *DesignWeb* is not reviewed in detail here because of its ephemerality and because of its experimental purpose. Its value, however, is that it reflects a composite of researchers' preferences as to what they would like the structure of design research to be like in the conceptual vicinity of their particular research interests.

Design methods, design knowledge, theories about artefact definition, theories about design cognition and models of design process have all been well addressed by design researchers. The epistemological considerations that theory-making about design depends upon, however, have been relatively neglected (Coyne and Snodgrass 1992, 1993; Franz 1994; Reich 1994a). This means that those researchers who focus on the ontological and epistemological foundations of design theories are in a position of trying to bring the field of design research up to date with contemporary advances in these philosophically based areas. Coyne and Snodgrass, Franz and Reich concur that design theory has been inappropriately dominated by a positivist perspective, and in consequence, a major emphasis of their taxonomies is to provide a structure to guide the development of new design theory that is based on post-positivist perspectives, rather than classifying existing design theory, methods or knowledge.

Franz (1994) developed her taxonomy of all design research from within the domain of architecture. Franz' research is significant in terms of research into engineering design because architecture, like engineering design is a technical discipline that is socially, environmentally and ethically situated and, perhaps more importantly, the field of architecture provides many of the foundational concepts of design research on which engineering design research draws. Franz' taxonomy separated the technical, conceptual and philosophical aspects of design research, and divided the literature into the following categories:

- Technically oriented research (systematic frame of reference)
- Technically oriented research (computational frame of reference)
- Technically oriented research (management frame of reference)
- Conceptually oriented research (psychological frame of reference)
- Conceptually oriented research (person-environment frame of reference)
- Philosophically oriented research (epistemological frame of reference)
- Philosophically oriented research (ontological frame of reference)

This taxonomy of Franz has many similarities with Cross' (1984b, 1993) themes and with Ullman's (1992) taxonomy of mechanical design. Her separation of design research into 'technical', 'conceptual' and 'philosophical' orientations aligns with the terminological structure developed in Chapter 1, where 'engineering theory' includes most of the 'technical' aspects of design research; 'engineering design theory' parallels 'conceptually oriented research'; and 'the philosophy of design' is equivalent to Franz' 'philosophically oriented research'. The main difference in the first category is that Franz' 'technically oriented research' also includes research relating to the management of engineering design. What is evident in both Franz' taxonomy and the terminology defined in Chapter 1 is a concept of meta-theoretical 'layers' where the theories and concepts in any one layer are informed by and inform the layers above and below them.

This idea of layers is developed further in Chapter 3 to provide a methodology for deconstructing design theories and, in Chapter 5, the layered model of Chapter 3 is used together with the findings from the research questions to sketch out a new structure for design theory and the discipline of design research.

In 1994, Reich suggested a different taxonomy of research methodology that also had a layered structure. In this layered model, Reich focused on theories as theoretical entities in their own right rather than on the objects to which theories refer (see Table 2)..

Layer	Examples
World views	• Practicism • Scientism
Research heuristics (sources of theories or hypotheses)	• Cognitive science • Decision science • Formal methods • Human-centred • Software engineering • Systems science
Specific issues (evaluation or goodness criteria)	• Formal representation • Parsimony • Practical relevance

Table 2: A layered model of research methodology (Reich 1994a)

Reich's layered model formalises a view of theory similar to that which underlies Kuhn's concept of 'paradigms' because it locates theory within a ground of research methodology and beliefs (Kuhn 1962; Stegmüller 1976). In essence, Reich is arguing that the choice of concepts and theories for any thesis or investigation, and their validity, depend on the background assumptions that underpin the research. That is, theories and concepts that arise in a research project depend on:

- The researchers' beliefs about the world and about knowledge.
- The belief systems espoused by the academic disciplines through which the research task is approached.
- The choice of methodology and specific methods that are used in the research.

In Table 2, these beliefs, assumptions and choices are coalesced into 'world views', 'Research heuristics' and 'specific issues'. In Reich's layered model, each 'World view' defines and bounds the available choice of 'research heuristic', and each 'research heuristic' then, in its turn, influences which 'specific issues' become relevant in research method.

The above section broadly reviews the immediate context of the research problem using a selection of overviews and taxonomies of design research drawn from the literature. To summarise this review:

- The overviews of design research and the taxonomies of design theory of the researchers presented here are substantially coherent with each other with the exception of some aspects of the taxonomy of design knowledge proposed by Hubka and Eder (1990) that depend on an exclusively scientistic perspective in a way that is argued against by Reich (1994a), Franz (1994) and Coyne and Snodgrass.
- The main foci of design research in the literature are:

1. The designed object (artefactual view)
2. The design process (process view)

- There is agreement that design related human and environmental issues are a part of design research although the literature is sparse.
- Ontological and epistemological aspects of design research and design theory need addressing more adequately, and post-positivist perspectives need to be applied to design research to replace the positivist or rationalist perspectives that inappropriately underpin many existing design theories.
- The layered deconstruction of research methodology which underlies much of the above literature is valuable because it points beyond methodology to the need to investigate the role of the assumptions and foundations of design research which are relevant to deconstructing engineering design theory to resolve the research problem in this thesis.

- Because this thesis is concerned with improving the way that social, environmental and ethical factors are incorporated into theories of design cognition, research relating to prescriptive methods or design aids is peripheral to the main task and is not considered here in detail.

2.3.2 Research problem and its immediate theoretical contexts

In the previous section, the broad theoretical context of the research problem was explored, particularly in terms of the theoretical assumptions that underpin any research into design. In this section, the theoretical contexts of three aspects of the research problem are investigated:

- Matters of ontology and epistemology relating to the validity and coherence of engineering design theory. These issues are important because it is necessary that any new theory is based on adequate foundations, and also because there are problems with the ontological and epistemological foundations of design research and engineering design research as identified in this chapter and Chapter 1.

- Theories of design cognition. This aspect of engineering design theory is important because the research problem is addressed in terms of *theory* and *designers' internal processes.*

- The representation of social, environmental and ethical matters in theoretical terms and concepts. This is necessary because the research problem is addressed in the realm of *theory*.

The literature relating to these three aspects of the research problem are reviewed in more detail in the following sections.

2.3.2.1 Matters of ontology and epistemology relating to the validity and coherence of engineering design theory

The most prolific writing relating to the philosophical foundations of design research and design theory has come from Coyne and his associates (Coyne 1991b, 1990a, 1990c; Coyne and Snodgrass 1993, 1992a, 1991; Coyne, Snodgrass and Martin 1992; Newton and Coyne 1992). This literature emphasises the role of metaphor in design research and theory-making and points towards positivism as a limiting factor in the quality of design research. More specifically, Coyne and associates identify the 'rationalist' aspects of positivism that are to be challenged, although they do not spell out the relationship between positivism and rationalism in detail. Coyne and associates have chosen to argue against 'rationalism' in design research, perhaps because of the emphasis on 'rationality' in research into artificial intelligence and design, but many of their criticism apply to both positivism and rationalism, and the demise of rationalism brings the demise of positivism due to positivism's necessary reliance on rationality. For example, in *Problem Setting Within Prevalent Metaphors of Design*, Coyne and Snodgrass (1992) explored the implications of rationalist and post-rationalist perspectives on problem regimes in design theory. They use the six categories of problem first defined by Alexander (1964) in his *Notes on the Synthesis of Form:*

- Coping with complexity.
- Being systematic.
- Enabling communication.
- Enabling the processing of information.
- Formulating methods and models.
- Capturing knowledge.

Coyne and Snodgrass claimed that these problem regimes were created and defined in the discipline of design research as a consequence of researchers' dependence on a rationalist basis for research and theory making. They argued that many problems of design research are pseudo-problems, consequential to rationalist epistemologies and created by the choice of metaphor which have been used to represent the activity of design and which, in consequence, disappear or are transformed when different metaphors are applied.

What Coyne and Snodgrass have done is to interpose an additional layer in the picture of the relationship between design research and its theories. They argued that the problems, solutions and theories of design research are not objectively found, and by bringing attention to the role of metaphor, Coyne and Snodgrass have dispelled the claim to obviousness of design problems. Coyne and Snodgrass claimed that different metaphors result in different problems and different sorts of solutions, that is, the claim that the agreement in the field about the range of problems that design researchers 'see' are a direct consequence of researchers' dependence on positivism, scientism, and more specifically, rationalism, as the source of their ontological and epistemological assumptions. Consequently, Coyne and Snodgrass argued it is necessary for post-rationalist metaphors to replace the existing dominance of the metaphors of rationalism, positivism and scientism.

In Coyne and Snodgrass' view, metaphors of design based on post-rationalist perspectives change the disciplines of design research in two ways. Firstly, they cast doubt on the validity of many existing design theories. Secondly, they point to problems of relativity in establishing positions from which to theorise or research: in Coyne and Snodgrass words 'Postrationalism is characterised by an impermanent set of metaphors'. They suggest that the way forward is through deconstructing and re-examining existing concepts and theory using a critical methodology.

Coyne and Snodgrass' conclusions align with those of Franz (1994) about the problems of design research and who also suggested critical methods as the way forward in resolving those problems that are founded in ontological and epistemological issues. This is in spite of using a different analytical approach to Coyne and Snodgrass and originating her inquiries in the field of architecture rather than artificial intelligence. From her position in architectural design research she noted that philosophical inquiry in design research has been limited to 'a meagre collection of epistemological and ontological studies' and claimed that this is due to four positivist assumptions:

- The conception of the world as atomistic.
- The conception of research as primarily prescriptive and interventionist.
- The conception of designing as rationalistic.
- The conception of design in purely physical or formal terms.

Franz claims that these assumptions have led to less than adequate design methods, but, more importantly, they underpin many of the difficulties concerning the inclusion of human and environmental issues in design theories. Essentially, she suggests that many of these difficulties can be overcome by changing from a dualist view of design to a dialectical view that designers and researchers exist in and as part of the world that they influence. This change from a dualist perspective to one of dialectic has been expressed by Coyne (1991b) and Coyne and Snodgrass (1991) previously and they have come to similar conclusions. Its effect would probably be most radical in the research into design undertaken from a perspective of artificial intelligence because the literature, theory and concepts in this area depend heavily on dualism (Coyne and Snodgrass 1993). This change of view from dualism to dialecticism, of including the existential aspects of design cognition in design theory, requires different research methodologies and methods. Specifically, it requires theories and concepts to be relativistically validated via a critical methodology because research methodologies and methods that depend on assumptions of objective validity and truth are inappropriate in this theoretical arena.

The criticisms of existing design research and the proposals for changes to research practice made by Coyne and Snodgrass and Franz are also supported by Reich (1994). Reich explored the area of research methodology in the application of artificial intelligence theory in engineering design research. This area of engineering design research is significant because of late it has become possibly the largest area across all design research (Coyne and Snodgrass 1993). In exploring issues of research methodology, Reich drew attention to the importance of considering ontological and epistemological issues alongside methodological ones and to the importance of coherency between the ontological, epistemological and methodological foundations of a research project. In establishing the epistemological relationships between these three aspects of research, Reich developed the layered model of research methodology that was referred to in the previous section. The analyses that led to Reich’s layered model imply an essentially pragmatic position: that different ontological, epistemological and methodological combinations are suited to different research situations with some combinations being fundamentally incompatible, for example, the combination of scientism and a human-centred perspective. Reich argued that the ontological and epistemological assumptions that have driven research methodology in the realm of artificial intelligence are flawed: an important issue because design research has come to align itself with the study of artificial intelligence theories as researchers attempt to automate design cognition. With respect to other matters of ontology and epistemology, Reich’s position is similar to Coyne and Snodgrass and Franz. He proposed that more consideration should be given to moving design research beyond its dependence on positivism and addressing theory, theory-making and research from post-positivist or post-rational perspectives. In particular, Reich emphasised what he referred to as *practicism*, a constructivist position drawn from the work of Guba (1990) and Reason and Rowan (1981). Also in line with Coyne and Snodgrass and Franz is the implicit assumption underlying Reich’s discussions of the importance of ontological and epistemological considerations in resolving problems of theoretical validity and coherence in artificial intelligence research, and that advances in design theory and design research depend on the application of a critical methodology.

To summarise so far; researchers investigating the ontological, epistemological and methodological assumptions that design research and design theory are based on conclude:

- Post-positivist/post-rationalist epistemologies and ontologies provide better ways of addressing many of the issues that are central and fundamental to design research, especially issues relating to the interface between designers and reality that are either avoided, neglected or less than optimally addressed in research based on positivist or rationalist perspectives.
- That design research needs to be based on theoretical foundations that allow that reality is individually interpreted and constructed and hence, in many ways is relative and subjective rather than objective. Much of design theory has been inappropriately based on positivist and rationalist perspectives.
- The application of post-positivist / post rationalist perspectives necessitates the use of a critical methodology in design research. This is especially true for research that involves the study of the relative and interpreted nature of reality in design and the interpretation of design theories in this light, particularly those theories relating to design cognition,

If the above summary is combined with the problems of design research raised in Chapter 1, they define the problems of analysing existing design theories and developing new theory as follows:

- A lack of terminological agreement in the field.
- No established and widely agreed fundamental concepts.
- A lack of attention to epistemological and ontological issues which has lead to inadequate definition of terminology and under-justification of concepts and theories.
- The inappropriate application of positivist and rationalist perspectives in areas of investigation that may be more satisfactorily addressed from other theoretical vantage points.
- The neglect of issues relating to the essentially human nature of designing with all that that entails in terms of reality being individually interpreted and constructed.
- A shortage of well established literature, language and concepts relating to the application of post-positivist/post-rationalist epistemologies and ontologies in design research.
- Unresolved problems relating to the interpretation of existing design theories which have been proposed and accepted as established without being critically analysed in terms of their epistemological validity. This is especially relevant in the area of theories relating to design cognition.

The combination of the above problems means that establishing a coherent theoretical structure of engineering design research in terms of the existing theoretical perspectives is especially difficult because it cannot easily be achieved within the existing language and concepts of the field. What is needed first in this research is to identify an adequate means of analysing and validating design theories: in effect a means of deciding privilege in the different theoretical circumstances of engineering design research and design research (Coyne, Snodgrass and Martin 1992). This issue of privilege and validation has precedence over other aspects of this inquiry because further analysis and theory-making depends on it. It raises the first research question,

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Research question 1.

How can design theories be evaluated and compared?

The wide ranging implications of this question have led to its discussion being distributed through this thesis. Different aspects of that discussion are found in Chapter 1, in justifying this research; in this chapter, Chapter 2; in Chapter 3, where the establishment of the theoretical framework of this research is undertaken; in Chapter 4, where the question is formally analysed; and in Chapter 5, where the analysis of the research question in Chapter 4 and its implications for resolving the research problem within its wider disciplinary context are discussed.

2.3.2.2 Theories of design cognition

The positivist information-processing idiom stands out as the most widely utilised perspective of research into design cognition. It is this information-processing view of design cognition that lies behind the ubiquitous 'analysis'—'synthesis'—'evaluation' (ASE) model of design process and which has led to the widespread assumption that design can be satisfactorily described as a rational problem-solving activity represented in terms of the informatic management of a world seen as patterns of information (see, for example, Bañares-Alcántara 1992, Bieniawski 1993; Chakrabarti and Bligh 1994; Chandrasekaran 1993; Court 1995; Coyne, Rosenman, Radford, Balachandran and Gero 1990; Culley, MacMahon and Court 1995; Dasgupta 1991; Visser 1992, 1996; Wong and Shriram 1993).

The literature relating to design cognition that focuses on designing by humans is substantially smaller than the above informatic literature. That is, the literature of design cognition rather unequally divides between what Cross, Dorst and Roozenburg (1992) have called 'the "artificial" and "natural" intelligence of design' which in this thesis are referred to as 'artificial design cognition' and 'human design cognition'. In this thesis, because this research focuses on human design cognition, the balance of emphasis between the reviews of the literatures of 'artificial design' and 'human design' is reversed; a brief overview of the literature on artificial design cognition is followed by a more detailed review of the literature on human design cognition. These reviews of the design cognition literature lead to the development of two more of the research questions that guide this thesis.

2.3.2.2.1 Artificial cognition

The informatic position on design cognition is reflected in the common perceptions of designing as 'problem solving' or 'satisfying requirements' (Dasgupta 1992; Wallace 1992; Simon 1981; Thomas and Carroll 1979; Newell and Simon 1972). Viewing designing as problem solving, in this manner, has been attractive to design researchers on three grounds. Firstly, because it brings the theories that have been derived from research relating to methods of scientific problem-solving and rational decision-making into engineering design theory and is thus coherent with the engineering background of many engineering design researchers. Secondly, a scientific, logically based theory of design problem-solving matches well with the development of a science of design. Thirdly, a logical model of designing offers a basis for computerising the engineering design process and thus gives rise to the conceptually and economically attractive possibility of automating designing.

The cognitive theories that are implicit in general 'artificial' design theories are not hidden; it is more that they are assumed rather than being discussed in detail (Akin 1992; Reich 1995, 1994a, 1992). For example, the 'General Design Theory' of Yoshikawa (1981) has no model of human design cognition. Instead it assumes that design cognition is a theoretical relationship between problem and solution characteristics that can be mathematically defined (Reich 1995; Tomiyama 1994). Similarly, in the 'Axiomatic Design Theory' of Suh (1990) the theoretical model of design cognition is reduced to a set of axioms for developing solution characteristics of relatively well-defined design problems. The concept of 'design science' implies a mechanistic model of design cognition because 'design science' is based on a scientistic paradigm of design research that carries with it the assumptions of science and positivism and hence defines design cognition as an objective, deterministic and mechanistic process (see, for example, Cross 1993; Eder 1989; Dixon 1989; Finger 1991; Hubka 1985 and Hubka and Eder 1988 1990). The field of artificial intelligence has a variety of models or theories of design cognition because artificial intelligence and the associated models of design cognition have been based on one or more of the following: logic and 'fuzzy' logic theories, rationality and bounded rationality, linguistic grammars of design attributes, biological models of connectionism, neural nets and genetic development theories. Artificial intelligence research provides sufficient theoretical basis for Oxman (1990) to suggest that creativity can be explained by a scientific theory that has knowledge defined in terms of precedents and procedures, and Hertz (1992) to build a general design theory on empiricism via logic although this latter is possibly positivism under a different name. The underlying characteristics of each of the models of design cognition associated with the above theories are defined by the overall aim that the models of design cognition are intended to be computerisable (Coyne 1990b; Coyne and Yokozawa 1992; Purcell, Mallen and Gourmain 1974).. Consequently, the main epistemological characteristics of artificial intelligence models of design cognition are that they are mechanistic, objectively deterministic, based on an information-processing paradigm and an assumption that all relevant knowledge can be adequately represented quantitatively.

An alternative slant on the role of artificial design cognition is offered by Tomiyama and Yoshikawa (1985) who claim that computer aided design systems give designers more time for thinking more deeply about the products. This is supported by Coyne and Snodgrass (1993) who in addition claim that the rationality that underpins artificial intelligence based research into CAD cannot address many aspects of human designing. What is implied by this is that artificial intelligence based theories of design cognition leading to CAD design solutions are ***not*** theories of human design cognition but instead are theories about those aspects of human cognitive design activity that can be mechanised and in this way are useful in freeing the human designer to undertake essentially human aspects of designing. This deconstruction of design activity into that which can be automated and that which cannot has been pointed to in Chapter 1 and earlier in this chapter, and is discussed further in Chapter 5.

Predating the above artificial intelligence theories are older models of artificial design process that were mainly developed in the 1950's and 1960's but are still in common use (see, for example, Ertas and Jones 1993). These older models of design process are based on concepts drawn from early systems theory and include the 'Analysis- Synthesis- Evaluation' feedback model, and the 'black box' and 'glass box' perspectives on design cognition (Jones 1970). Descriptions of designing in texts containing these early models of artificial design cognition frequently refer to 'feeling', 'intuition' and 'insight' as essential aspects of designing, but the models of design cognition are mechanistic and positivist, and contain little that is adequate to address concerns about the individually interpretive basis of understanding and designers' creativity (see, for example, Alexander 1964; Asimow 1962; Gregory 1996a; Jones 1970; Jones and Thornley 1964a; Mann 1963; Matousek 1963; Roe, Soulis and Handa 1966).

2.3.2.2.2 Research into human design cognition

Many researchers have gone to great lengths to emphasise the difference between scientific activity and design activity (see, for example, Abel, 1981; Cathain, 1982; French, 1985; Joseph, 1996; Lyle, 1985; Sancar 1996; Tovey 1997, 1992b; Wray, 1992). In terms of design research, their arguments centre on the need to include in design theory those aspects of design activity that depend upon human internal activities such as cognition, judgement, creativity, valuing, feeling, guessing, intuiting and insight. Research into this essentially human side of design cognition is represented in the literature by four main fields,

- Models of design cognition that include an appreciative process parallel to a rational cognitive process (see, for example, Abel 1981; Bastick 1982; Dilnot 1982; Motard 1974; Porter 1988;; Schön 1984, Sneed (in Stegmuller 1976); Stegmuller 1976; Thomas and Carroll 1979; Weiskrantz 1987).
- Design cognition theory based on brain research (see, for example, Cross 1984d, 1990; Cross, Cross and Glynn 1986; Lera 1981a; Smets and Overbeeke 1994; Takala 1993; Ward 1984).
- Theories of cognition based on including the role of human values (see, for example, Alexander 1980; Bono (in Lawson) 1993; Cooper and Powell 1984; Cross 1984d; Dilnot 1982; Gordon 1961; Lera 1981b, 1983; Protzen 1980).
- The role of intuition and insight in theories of cognition (see, for example, Bastick 1982; Cross 1989, 1990; Davies 1985 (in Cross 1989); Davies and Talbot 1987; Glegg 1971; Rosen 1980; Simmonds (in Lera) 1983).

The individual literature relating to the above fields overlaps considerably, but in the main is bounded by the seven conceptual areas illustrated below in Figure 8.

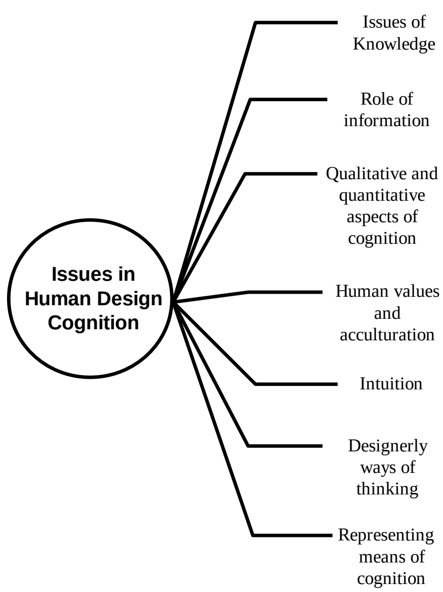

Figure 8: Issues in human design cognition

In addition to the above four fields of literature of design cognition and the seven conceptual areas of Figure 8, is the study of the epistemological and ontological issues that underpin them (see, for example, Coyne 1990c; Coyne, Snodgrass 1991; Cross 1983, 1984c, 1991; Cross, Cross and Glynn 1986; Daley 1982; Davies and Talbot 1987; Franz 1994; Hamlyn 1990; Reich 1992, 1994a, 1994b, 1995; Reich et al 1996; Rosen 1980). There is substantial agreement between researchers about the human attributes that are important or essential for design cognition, and what emerges is a picture of human design cognition that is partly rational, partly intuitive and dependent upon designers' feelings (see, for example, the lists of characteristics and skills of Cross 1989; Eder 1995; Glegg 1971 and Neville and Crowe 1974 in Appendix 5).

The rational aspect of human design cognition has been subjected to considerable attention because it readily relates to the outlooks, theories and methodologies of the field of cognitive science (see, for example, Akin 1992; Baljon 1997; Chandrasekaran 1990; Dasgupta 1992; Faltings 1991; Gero 1991b; Hubka 1985; Newell and Simon 1972; Newell 1990; Ramscar, Lea and Pain 1996; Salminen and Verho 1989; Simon 1982; Soufi and Edmnds 1996; Visser 1991; Zeleny 1994). Of the non-rational aspects of design cognition, it is *intuition* and *feeling* that are most frequently referred to by both designers and design researchers alike. For example, Spencer-Chapman (1993) believed that designers should aim to develop a *feel* for the relationships between engineering artefacts and social and natural systems, and repeated Ferguson's question of 'how we can foster the ***intuitive feel*** [emphasis added] for physical behaviour'. Similarly, Motard (1974) pointed to the importance of the role of feelings and experience in design cognition and the importance of biologically sensual aspects of design memory claiming that,

> *. . . an engineer would be hampered in his ability to design things if he had not experienced the material world first hand and distilled this experience through a kind of contemplation until it penetrated his entire being. The more perceptive the individual and the more sensitive, the more effective potentially, in the multidimensional pattern of design under constraints. Discovery and intuition might then have a physiological enhancement elicited from the fabric of the visual, aural and tactile experience and the 'feel' of physical situations.*

In addition, both feeling and intuition are commonly associated with creativity, synthesis and understanding—all essential aspects of what marks designing as distinct from other human activities—and additionally, these 'intuitive' and 'feeling' aspects of designing are implicit in suggestions that design is both science and art (Deiter 1983; Eder 1995; Jones 1970; Matchett 1981; Wray 1992).

Some researchers have attempted to bridge the gap between the rational and non-rational aspects of human design cognition by suggesting that designers have particular ways of thinking that are different from 'normal' thinking. For example, Cross, Cross and Glynn (1986) have suggested that designers have 'designerly ways of thinking') and Goldschmidt (1994), Liu (1995) and Tovey (1992a) have pointed to the importance for designers of 'visual thinking'. These 'particular way of thinking' models of design cognition open the door to including other aspects of cognition than the purely logical and connect well with the work of those researchers who maintain that it is subconscious processes that are essential to explaining design cognition (see, for example, Davies 1995; Davies and Talbot 1987; Dorst 1995; Gasparski 1979; Glegg 1971; Jones 1971; Kern (quoted in Gregory1981b); Lawson 1990, 1994; Purcell and Gero 1996; Soufi and Edmonds 1996; Stoltermann 1974).

In the main, however, where intuition or feeling has been included in theories of design cognition it has generally been via theories about the designed object or models of design process (see, for example, Akin and Akin 1996; Galle and Kovács 1996; Kolodner and Wills 1996; Lawson 1990, 1993, 1994; Liu 1996; Lloyd and Scott 1994). Epistemologically, these ways of including intuition, feeling and other non-rational aspects of human cognition are unsatisfactory because of their lack of scope and because they do not adequately include the essence of what it is for a human to design. Dilnot (1982) and Joseph (1996) have argued that viewing design cognition through either the designed object or through an ahuman definition of design process effectively moves the objects of research out of sight of the research method. In addition, Coyne and Snodgrass (1993), Franz (1994), Reich (1994a) and (1980) argued that scientific and positivist based design research is epistemologically insufficient for addressing many issues that are central to exploring the human aspects of design cognition. This means that those aspects of human design cognition involving intuition and feeling have either been ignored at the outset or addressed using research methods whose theoretical perspective is inappropriate.

Biologically based theories of design cognition that included intuition and feeling were proposed early in the history of design research. In 1970, Jones argued that designers are similar to artists, using 'the capacity of a skilled nervous system to respond quickly to an intuitively held picture of the real world . . . when they have to find their way through a number of alternatives while searching for a new and consistent pattern upon which to base their decisions.' By this proposal, Jones opened the theoretical foundation of design cognition to include research in neurology and the new field of psychoneurobiology. In a similar vein, Motard (1974) maintained that, 'design as a human activity includes ***behavioural*** [emphasis added] phenomena as well as cognitive inputs' and argued that good designers were good because they had 'the ability to ***integrate experience*** [emphasis added] as well as to generate conditions for experience to occur' and were also able to 'mature in their ability to condense states of knowledge into useful rules of thumb.' Motard argued that the raw material for internal patterns of thought comes from physiological experiencing and that the abstraction of this experience is then linked via cognition to the abstracted but also physiologically based experience of others. Motard's is a sophisticated empirical view that avoids the more obvious epistemological and practical problems of biological determinism by its reference to cognitive abstraction. Had these biological proposals been adopted they would have connected well with the work of contemporary post-positivist and post-rationalist design researchers and the following three avenues of research into design cognition:

- The development of models of design cognition based on ideas of biological determinism. This option, developed via the field of artificial intelligence, has led to the development of connectionist, neural net and genetic algorithms of artificial design cognition (see, for example, Brown and Hwang 1993; Bullock et al 1995; Coyne et al 1990; Gero 1991b; Gero and Maher 1993; Hills 1995; Liu 1996; Newton And Coyne 1992; Woodbury 1992).

- The exploration of post-positivist epistemologies for design research (see, for example, Coyne 1990c, 1991b; Coyne and Newton 1992; Coyne and Snodgrass 1991, 1992a, 1993; Coyne, Snodgrass and Martin 1992, Dilnot 1982; Dorst and Dijkhuis 1995; Franz 1994; Reich 1994).

- The exploration of research into similar problems in other disciplines, for example, left and right brain hemisphere research (Cross 1984d, 1990; Cross, Cross and Glynn 1986; Lera 1981a; Smets and Overbeeke 1994; Springer and Deutsch 1993; Ward 1984).

To summarise, researchers have explored several avenues investigating human design cognition across a variety of concept areas. There is substantial agreement in the field about the human attributes that contribute to human design cognition, but there are disagreements about the epistemological validity of some aspects of research in this area.

2.3.2.2.3 Discussion of the importance of theories of human design cognition

This section contains an overview of the epistemological merits of grounding this research in the research into human design cognition rather than artificial design cognition.

In spite of the explicit and implicit dominance of the informatic or 'artificial' basis of design research many researchers have had doubts about its adequacy as a basis for research into all aspects of design cognition, particularly with respect to the role of humans in designing (see, for example, Coyne and Snodgrass 1991, 1992a, 1993; Cross 1992; Daley 1982; Dasgupta 1993; Dilnot 1982; Franz 1994; Glegg 1971; Hamlyn 1990; Lera, Cooper and Powell 1984; Newell 1990; Porter 1988; Reich 1994; Roozenburg 1992; Simon 1981, 1982; Stolterman 1994; Thomas and Carroll 1979). Cross (1992), supported by one of the first collections of papers on design thinking (Cross, Dorst and Roozenburg 1992), argued that design cognition had been inadequately addressed in the literature to that time, that is,

> *Those simplifying paradigms* [of design thinking] *which have been attempted in the past - such as viewing design simply as problem-solving, or information-processing, or decision-making, or pattern-recognition - have failed to capture the full complexity of design thinking.*

This lack of adequacy or completeness of the artificial view of design cognition has been raised by other researchers presenting the following arguments,

- That the scientific, rational, informatic, problem-solving model of designing does not adequately address many aspects of the humanness of designers and theories of design cognition need to be able to address the vagaries of human intelligence, ignorance and intuition (Chakrabarti and Bligh, 1994; Glegg 1971; Lera, Cooper and Powell 1984; Petroski, 1992; Porter 1988; Simon 1981; Wong and Shriram, 1993).

- That the concept of abductive logic, used to underpin artificial intelligence models of artificial design cognition, is unsatisfactory and that a model of design cognition must replace it which includes 'innovative abduction' which cannot be expressed in formal logic (Roozenburg 1992).

- That designing is essentially a human activity, and when viewed as complex language-game or a Wittgensteinian 'form of life', it depends on other humans for its proper functioning (Konda, Monarch, Sargent and Subrahmanian 1992; Liddament 1996).

- That the claims of Yoshikawa's General Design Theory and similar informatic theories to be complete theories of design were overstated in relation to human designing (Reich1995).
- That an hermeneutic approach to research into design cognition is necessary to address existential issues of meaning relating to human design cognition (Coyne and Snodgrass 1991, 1992a).
- That designing is not purely rational but depends also on intuitive considerations, for example, Glegg (1971) maintained that,

  ...we must beware of . . . . regarding all design as a strictly logical exercise. It is no substitute for the inventive or the artistic... Logic is not enough; a sense of fitness of things is needed too.

- That theories of design cognition must adequately include qualitative design considerations, for example, Sharpe (1995) claimed that around 2500 million qualitative design decisions are made in designing an item of major plant and that this was approximately the same as the number of quantitative decisions.
- That design cognition cannot be adequately described from a rational verbal perspective because this perspective does not satisfactorily encompass the visual aspects of thinking. Tovey (1992a) offered objective evidence that automotive stylists have their own rich *visual* style of cognition accompanied by its own evolving language that enables the communication of that visual cognition
- That information-processing models of artificial design cognition ignore aspects of human functioning such as belief (Hamlyn, 1990), or make their adequate inclusion impossible (Newell, 1990). This is an important failing in terms of research into design cognition because theorising about designers' internalised processing of the validity of partially conceptualised creations is one of the most important issues which an information based model of designing would be expected to address and modelling all aspects of human cognitive process is necessary to that task.
- That intuition was a necessary aspect of the theoretical description of analysis and rational activities previously assumed to lie solely in the province of logic (Rosen 1980).
- That much of the theoretical inaccessibility of the intuitive aspects of cognition are connected with the widespread use of the 'central information-processing models' of thought and cognition that underpin theories of artificial design cognition (Hamlyn 1990).
- That issues of meaning and values underpin the problems of representation in theories of artificial cognition (Newell 1982, 1990). This means that the theoretical foundation of theories of design information and knowledge are challenged because they depend on a satisfactory theory of representation that cannot be construed using the same epistemological perspective.

- That design must be viewed primarily as a human activity rather than an ahuman process (Nakata 1996; Bieniawski 1993; Dasgupta 1993; Lawson 1993; Konda et al 1992; Petroski 1992; Piela, Katzenberg and McKelvey 1992; Ullman 1992; Cross 1984a, 1990; Ward 1984; Wilde 1983; Abel 1981; Thomas and Carroll 1979).
- That the focus on the designed object or the design process, common in research into artificial design cognition, leads to fundamental problems with respect to the validity of research methodology and the theory developed from it (Dilnot 1982).

Conceptually, the idea of ‘artificial’ intelligence assumes that there exists ‘real’ human intelligence. Likewise, ‘artificial’ models of designing, that are intended to automate design processes, depend upon an assumption of the existence of ‘real’ human designing. If this was not so, there would be no need to make the distinction that underlies the title of the journal *Artificial Intelligence in Engineering Design, Analysis and Manufacture*. The fact that the ‘artificial’ or mechanistic models of designing are theoretical *models* of an activity that exists in actuality has been overlooked in some research, and consequently models of designing and design process that have been created to simulate designing as an *artificial* process have come to be regarded as accurate representations of the *real* human activity. This confusion between the artificial and the real has led to an assumption, implicit in much of the literature on design cognition, that human designing can be understood and represented by concepts and models relating to artificial design processes (Cross 1992).

Epistemologically, the study of human designing and the study of artificial design processes are theoretically different. One is the study of a human activity which has objectively observable and subjectively hidden aspects. The other is the study of a theoretical structure. In Popper’s (1976) terms they lie in different ‘worlds’ of research and theory-making. By using models of artificial design process based on formalising the links between problem definitions and designed outcomes, the activity under study, *design cognition,* is opaquely reconceptualised from the realm of designing to the realm of the mechanical. This reconceptualisation means that designing, in this sense, cannot be automated because what is then referred to as ‘designing’ has become a determinable mechanical process. This latter point implies that theories created about automatic or routine design processes are not theories about *designing*, regardless of whether they are based on the techniques of artificial intelligence or any other body of knowledge.

A similar point was argued by Dilnot (1982) with respect to researchers’ convergence on the designed object and the information transformations of a design process. He suggested that this way of viewing design through the design problem and its solution not only takes precedence over other perspectives, but results in the exclusion from investigation of other essential aspects of design cognition. One implication of Dilnot’s argument is that, in a general theory of engineering design or a discipline of engineering design, the view of ‘design as human activity’ should have precedence over other design research outlooks, because the latter can be subsumed within the former but not vice versa.

The biological perspectives proposed by Bastick (1982), Jones (1970) and Motard (1974) offered a means of including human attributes alongside an informatic approach to design cognition by using biology as the theoretical interface between feeling and thinking. These biological perspectives on design cognition, based on the assumptions that design was a human activity and that human biology was part of the human process that led to the creation and conception of designs, were well suited to being one of the cornerstones of human-centred theories of design.

Instead, alternative approaches more suited to computerisable theories of design have evolved where theoretical models of general biological and neurological process are used as a basis for the computerised synthetic deterministic development of design solutions to Well-defined and structured problems. This latter biological contribution relates to artificial design cognition rather than human design cognition and depends upon researchers giving privilege to a definition of design as 'an objectively determinable search process through solution space' in order that algorithms that imitate biology or neurology may be viewed as adequate means of mechanising the search for 'biologically determinable' solutions. Restricting the conceptual view of design to that of 'mechanically searching for solutions' means that issues concerning those essential aspects of human design and decision-making that relate to creativity, individually constructed realities and value judgements are neglected and remain unaddressed.

Value judgements and other human aspects of design cognition are excluded from the logical analysis that underpins many theories of artificial design cognition and creativity (see, for example, Alexander 1964; Altshuller 1984; Coyne, Newton and Sudweeks 1993; Hertz 1992; Liu 1996; Mitchell 1993). This exclusion of the human aspects of cognition gives rise to the problem of representation. Briefly, the problem of representation is the difficulty in establishing an adequate epistemology for theories that insist on objectivity and contain a circularity due to knowledge being derived from representation, and knowledge in its turn existing as a further representation. This issue of representation presents potentially insurmountable difficulties relating to the validation of core theories and concepts for those working in the fields of cognitive science and artificial intelligence. Newell (1982) identified the importance of the representation problem in the first presidential address of the American Association for Artificial Intelligence and it emerged again in Newell's later attempt to establish a comprehensive framework for a unified theory of artificial cognition (Newell, 1990). Theories of human design cognition that allow subjectivity and human values into the semantic aspect of cognition avoid those aspects of the representation problem that are present in theories of artificial cognition because the problem of representation arises due to attempts to locate 'meaning' independently of individual human conceptualisation.

In addition to the epistemological problems of representation Rosen (1980) raised two other issues relating to the foundations of analysis that are relevant to theory-making about both artificial and human design cognition. Rosen pointed to intuition being epistemologically foundational in any explanation of creativity and synthesis and he implicated intuition, creativity and synthesis in activities which are commonly regarded as being rational or non-intuitive. After critically analysing the foundations of theories of analysis and synthesis, he concluded that intuition was fundamentally important to such theories because of its roles in:

- Justifying the closure which is necessary for validating theory (see also Walton 1996).

- Differentiating between creative activities and processes that can be routinised or formalised.
- Explaining activity which is not routine.

According to Rosen, intuition is dependent on individual human values, and this implies that it is essential to include human values in explanations and theories of analysis, synthesis and human judgement. Rosen’s inclusion of intuition and human values as essential aspects of theories of analysis and creativity is directly and indirectly supported by a variety of viewpoints. For example:

- Hamlyn (1990) critically analysed the foundations of theories of cognition and concluded that intuition was an essential aspect of theories of design cognition and also that it is neither explained nor explicable in the rational and bounded rational views of cognition (Newell 1990; Simon 1982).
- Lai (1989) claimed that humans use an interpretive ‘investigative strategy’ for analytical problem solving.
- Rittel and Webber (1974) brought human values and intuition into design by arguing that the information needed to *understand* a problem depended upon one’s idea for *solving* it.
- Dym (1994) included human values and intuition by arguing that design is a human activity or process with all that that entails about context and language.
- Stolterman (1994) claimed that there is objective evidence that designer’s do not function rationally, and that it is the ideals and values of the designer that give a ‘hidden rationality’ to the design process.

The arguments that have been presented in this section point to artificial design cognition being epistemologically inadequate both in terms of representing design cognition in general and in its own concepts and methodology. In consequence, it is human design cognition that has been chosen to form the basis of this research. This choice of a human rather than an artificial focus has an additional benefit of assisting with circumnavigating the terminology problem discussed in Chapter 1. The terminology and theory from the tradition of engineering design research which relates directly to this human perspective is sparse, and researchers have tended to use the better-established concepts and terminology of other disciplines (Abel 1981; Davies and Talbot 1987; Lawson 1993; Schon 1984; Thomas and Carroll 1979; Ullman 1992).

Viewing design as a creative human activity that includes human values does not itself, however, lead to any easy theoretical solutions. Issues of human value give rise to problems in any theories of design cognition because of the difficulties associated with trying to explain. The consequences of individual designers having different underlying assumptions about reality, and how designers’ values influence how they perceive both reality and their new conceptualisations (Magee, 1987; Protzen, 1980; Alexander, 1980). In addition, there are problems related to theorising about creativity because of the tautological difficulties in explaining the origin of new ideas (Hamlyn, 1990; Rosen, 1980).

The positivist information-processing basis for research into design cognition has depended on knowledge being represented as ‘facts’ that are objectively verifiable and independent of human values. This separation of facts from values has been argued against by researchers who maintain that facts and values, and knowledge and values, are closely coupled and that theories of design must reflect this (see, for example, Coyne 1991; Coyne and Newton 1992; Coyne and Snodgrass 1991, 1992a, 1992b; Coyne, Snodgrass and Martin 1992; Crane 1989; Dorst and Dijkhuis 1995; Margolis 1989; Pacey 1983; Reich 1994; Sargent 1994). Crane (1989) drew attention to the acceptance in philosophy of the demise of the fact-value dichotomy in the 1930s’, and commented that this acceptance seems to have been slow to have been absorbed by the technical community. It is assumed in this thesis that facts and values are inseparable and, hence, it is inferred that there is a lack of credibility and completeness in the ontological and epistemological bases for theories of engineering design cognition that exclude human values and depend on facts and values being viewed as independent. These assumptions that facts and values are closely linked and that human values are a necessary part of theories of engineering design lead to the next research question.

Research Question 2:

> *What are the implications of including human values in theories of human design cognition?*

To date, most researchers have used positivist methodologies and theories which present fundamental problems, as discussed earlier, because research into human design cognition involves many issues that are explicitly or implicitly excluded by the primary definitions of both positivism and science (Coyne and Snodgrass 1992b, 1993; Franz 1994; Guba 1990a; Reich 1994a, 1994b). The values issue is only one of the epistemological problems of positivist theories of design cognition which, when deconstructed, show weaknesses in the areas of intuition, cognitive styles, creative thought, meta-cognition, the role of feelings, individuation, evaluation, fixation, social influences on design, representation and perception (Akin and Akin 1996; Baljon 1997; Berger and Luckman 1987; Coyne 1990c, 1991b; Coyne and Snodgrass 1991, 1992a, 1992b, 1993; Crane 1989; Cross 1983, 1990; Cross and Cross 1995; Cross, Cross and Glynn 1986; Hamlyn 1990; Holt 1997; Indurkhya 1992; Kitchener and Brenner 1990; Kolodner and Wills 1996; Newell 1982, 1990; Oxman 1995; Purcell and Gero 1996; Ramscar, Lee and Pain 1996; Rosen 1980; Sternberg 1990; Tovey 1997; Visser 1995). What is needed is a research perspective that provides an epistemologically adequate basis for including non-rational subjective aspects of cognition in researching and theorising about design, but without needing to reduce the cognitive phenomena into ahuman concepts and processes. This is particularly important for developing any general theory of design cognition where it is necessary for researchers to be able to theorise about those aspects of cognition that exist prior to a designer’s conscious cognitive conceptualisation of a partial solution or ‘design’ and to take account of how the ‘design’ and its context are dealt with in ‘fantasised design worlds’ within designers’ minds (Schon 1992; Schon and Wiggins 1992).

Several researchers have argued that it is epistemologically more appropriate to use post-positivist perspectives for research that focuses on design as a human activity because it is possible to include the subjective human considerations that the positivist perspectives cannot (Coyne 1991b; Coyne and Newton 1992; Coyne and Snodgrass 1992a, 1992b, 1993; Dorst and Dijkhuis 1995; Franz 1994; Guba 1990a; Harre 1981; Lincoln 1990;.Phillips 1990; Popper 1976; Reason and Rowan 1981b; Reich 1994a, 1994b, Rowan and Reason 1981a; Schwandt, 1990). This research explores the use of post-positivist perspectives to address the research problem, and this leads to next research question.

Research Question 3:

> *What are the implications of using post-positive perspectives for research and theory-building in the area of engineering design cognition?*

2.3.2.2.4 The representation of social, environmental and ethical matters in theories of design cognition

It has been argued earlier in this chapter and in Chapter 1 that social, environmental and ethical factors are central to developing an epistemologically satisfactory basis for theories of engineering design cognition. To summarise the position, design research needs to include social, environmental and ethical issues because of the role of design as definer of technology (Nicholls 1990; Wallace and Burgess 1995) and because the use of technology leads to,

- Changes in the *circumstances* of individuals and societies; if circumstances did not change then a particular technology would not have any utility.
- Changes in *attitudes* of individuals and societies; it is widely argued that technology changes users’ attitudes by those involved in the study of technology transfer (see, for example, Harrison 1987; Illich 1974; Kipnis 1990; Klagge 1989; Mak 1995; Mamat 1991; Spencer 1991). In addition, the main purpose of some technology is to change users’ attitudes and behaviour, and the technology is designed to those ends (Goggin 1994; Smets and Overbeeke 1994; and Woolley 1991).
- Changes to the underlying individual and societal *assumptions* that guide thoughts and actions (Benn 1974; Carpenter 1989; Frankel 1987; Margolis 1989; Norman 1992; Rapp 1989; Roszak 1974; Smets and Overbeeke 1995; Toffler 1973)

These issues are important in design research and the development of theories of design cognition because designers themselves are individuals affected by the technology they use, by the societies they live in, and by the activity of designing itself because thinking about new technology causes changes to an individual’s attitudes and assumptions (Eno

1996; Margolis 1989; Schon 1983, 1987, 1992; Visser 1995). Hence, social, environmental and ethical issues are an important aspect of engineering design theory because of the ways that they necessarily influence engineering designers' cognition and the designs that they create. In this section, an overview is taken of the main themes concerning the inclusion of social, environmental and ethical matters in engineering design. The section concludes with a discussion of the characteristics of social, environmental and ethical factors and presents additional research questions.

The conceptual topology of the study of social, environmental and ethical issues relating to technology is convoluted. The epistemological relationships between social and environmental concerns are confused and delineating a boundary between which issues relate to environmental effects of technology and which are best studied as social effects of technology is often difficult. This overlap and the difficulties that it presents is shown in, for example, the spread of topics in the contents list of *Social Impact* (Autumn 1992) and Fookes (1992) discussion of the New Zealand Resource Management Act.

The dominant view of the disciplinary relations in this area is that the study of the social effects of technology are subsumed within the study of the environmental effects of technology. This outlook may be because the study of the environmental effects of technology predates the study of its social effects: the time lag between the commencement of environmental and biophysical impact studies, and the study of socio-economic and cultural impacts was about six years in the United States and social factors were included because of an emphasis on 'secondary factors' in the 1973 National Environmental Protection Acts and Guidelines (Canter 1996),. In Western Australia, the work of the Social Impact Unit was relayed via the Environmental Protection Authority to the State Government, which illustrates a similar dominance of environmental considerations over social ones (Social Impact, vol. 1, no. 1, p. 2). The minority view on the disciplinary relations between environmental and social concerns reverses the above situation and has the environmental effects of technology subsumed as part of the social effects of technology, and this is justified on the grounds that environmental changes cause human consequences by changing the human environment (see, for example, I. E. Aust. 1992). A more even handed position is reflected in the literature on the evaluation of program impacts where the effects of technology are partitioned into social and non-social environmental effects (Mohr 1988).

When ethical considerations are added to the above social and environmental relationships, the situation becomes more complex. Theories about ethical issues relating to technology have a reflexive epistemological relationship with the studies of the social and environmental effects of technology. Both social and environmental consequences of technology have an ethical aspect, yet the study of ethics is concerned with nothing other than social and environmental issues because of its role as the study of the 'rightness' of human beings' actions. Ethical actions have external and/ or internal consequences: if they are external, they affect the environment and hence, potentially, have social effects; and if the actions affect the actor internally, then, taken objectively, it is a social matter.˙ Hence, it is not clear whether social and environmental factors are a subset of ethical factors, or whether, by completely addressing the social and environmental consequences of technology, ethical analysis becomes redundant. Finally, in addition to these complexities, there is a temporal relationship between social, environmental and ethical matters that needs to be taken into account. Not only do social and environmental issues depend on ethical values, but, over time, ethical values themselves evolve within human societies, and these exist within, and are dependent on, a wider environmental ecology (Berger and Luckmann 1987).

The lack of clarity with respect to each of the terms ‘social’, ‘environmental’ and ‘ethical’ has led to a need to address this issue epistemologically in this research. In this thesis, the knowledge relating to social, environmental and ethical matters that are relevant to a particular design situation are viewed as *factors* which are similar to technical *factors* because they are influences on designers’ cognition (see Chapter 1). Therefore, what is needed is epistemological clarification of the relationship between these social, environmental and ethical factors and the theories of engineering design cognition that are intended to include them. That is,

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Research Question 4:

> *What are the theoretical characteristics of social, environmental and ethical factors?*

The last thirty or so years has seen increasing pressure on designers and the organisations which employ them to produce designs which reduce or avoid particular social and environmental effects. Design researchers have responded with Eco-Design, Life Cycle Analysis, Design for Recycling, Design for Environment, Sustainable Design and other research and design methods that have been intended to improve the social, environmental and ethical consequences of technology (Chick 1997). Superficially, the philosophical basis of these new design developments appears to be clear, but on closer inspection it is a conceptual morass of different theoretical perspectives. For example, Hallen (1990) identified eight ethical ontological positions in relation to research concerning the environment that ranged from self-interested egoism, through the *grey green* outlooks of Bunge (1989), to the holism of the ‘deep ecologists’ or ‘dark greens’ (see, also Hollick 1995). Alongside these problems of ontological and epistemological perspective are terminological difficulties. For example, the definition of ‘Ecodesign’ that emerged from the 1994 Eco-Design Forum was,

> *Design which addresses all environmental impacts of a product throughout its complete life-cycle, without unduly compromising other criteria such as function, quality, cost and appearance* (ECO2-IRN forum, 16th November 1994).

Underlying this definition was an understanding that a designer’s consciousness of environmental issues influences their designing. The definition assumed that designers would have the ‘right sorts of values’, but the above definition does not preclude a designer consciously aiming to produce negative environmental impacts. Similar difficulties were noted by Brennan (1993) especially in relation to the number of meanings of the term ‘sustainable’ in circulation.

So far, engineering design theories have included social, environmental and ethical matters in one of the following ways:

- A design solution is first developed to satisfy technical constraints and it is then evaluated as to whether it satisfies social, environmental and ethical considerations. This is the most common perspective in the training of engineering designers and is represented in the methodology of environmental and social impact assessments (Booker 1962, Canter 1996; Ertas and Jones 1993; Konda, Monarch, Sargent and Subrahmanian 1992).

- Social, environmental and ethical factors are quantified and included as if they are *technical* factors (Ertas and Jones 1993; Fenves and Grossman 1992; Piela, Katzenberg and McKelvey 1992; Otto and Antonsson 1994; Traub 1996)

- Social, environmental and ethical factors are reduced to the form of satisficing constraints. In terms of design theory, this perspective of bounding design solutions by quantifying social, environmental and ethical issues originated in the 1960s (Alexander 1963, 1964). The satisficing outlook on social, environmental and ethical factors is found in national and international technical standards that have social and environmental factors implicit in their specifications, and also in the guidance of national Environmental Protection Agencies where, for example, a requirement for good air quality might be reduced conceptually into a limitation on the proportion of sulphur dioxide that the air contains (Canter 1996).

- Social, environmental and ethical issues are included during the design process by recursively cycling through a design process model that divides the process into many interrelated parts (see, for example, the 'Total Design' model of design process of Pugh (1991)). In effect, this method brings social, environmental and ethical issues into the design process earlier than otherwise by using the above three methods at a micro level of designing.
- By bringing together the stake-holders in a design, informing them with quantitative data and allowing the design solution to evolve through a 'political process' (see, for example, Hollick 1993; Piela, Katzenberg and McKelvey 1992).

The underlying perspectives on how the social and environmental effects of technology are incorporated into models of design process are similar in all of the above except the last item. Practically, most perspectives assume a model of design cognition that depends on objectively quantifying the parameters of the design situation and then making decisions about these parameters by using a weighting method such as cost-benefit-risk or one of the more recent methods of magnitude scaling, multi-variable or multi attribute weighting that have been developed for use in multi-criteria optimisation (Crane 1989; Singer 1995; Zeleny 1994). The model of design process that is based on the interactions between stakeholders being described in terms of political process explains the creation of a design via ideologies and publicly declared values. It does not, however, address issues concerning individual designers' cognition, particularly, how those quantitative and qualitative factors are brought together in creative cognition.

What each of the above situations illustrates is a lack of epistemological attention to the issues that underlie the representation of social, environmental and ethical matters in design theories. The epistemology of social, environmental and ethical issues in engineering design theory has been neglected in the literature of engineering design theory because the focus of mainstream positivist and post-positivist research has lain elsewhere. Positivist engineering design research has focused on artefact outcomes, engineering analyses, methods, knowledge, processes and techniques and from this positivist perspective, social, environmental and ethical matters are either quantified and included as if they were technical factors or are viewed as extraneous to the engineering design process. In both cases, the study of social, environmental and ethical factors is peripheral because the epistemological issues relating to the quantification of social, environmental and ethical factors are assumed to lie outside the province of engineers. In post-positivist engineering design research, the main themes have been:

- The application of post-positivist epistemologies from the Social Sciences.
- The establishment of arguments against positivist models of design cognition by exploring the weaknesses in the models of design cognition based on Cognitive Science.
- Bringing into design research the critical research perspectives of the post-positivist literature from the field of Philosophy of Knowledge.

Social, environmental and ethical factors are peripheral to each of the above post-positivist research directions, and the above analyses indicate that, for a variety of reasons, social, environmental and ethical factors have not been a significant concern of positivist and post-positivist engineering design research or design research.

It may be useful here to draw attention to a classification of research perspectives into what Phillips (1987) called 'hard headed' and 'soft headed'. The 'hard headed' perspective is positivist, based on quantitative information, and assumes that everything is amenable to mathematical representation. The 'soft headed' perspective has design as a human fundamentally unknowable activity. Ertas and Jones' (1993) outlook on social, environmental and ethical issues, whilst epistemologically unsophisticated, is 'hard headed' because their underlying epistemology is positivist. It contrasts with, for example, the 'soft headed' romantic metaphor of design described by Coyne, Snodgrass and Martin (1992). Potentially bridging both hard and soft headed approaches is the 'Total design' of Pugh (1991) which has a 'hard headed' line about technological matters but does not preclude the possibility of a more 'soft headed' approach to matters which cannot be managed in a 'hard headed' manner. One explanation of why the literature of engineering design research has been predominantly 'hard headed' is that there has been a shortage of alternative and more complex models of practical design that includes the human attributes. This has led to social, environmental and ethical factors being regarded as peripheral to the technical purpose of engineering (Beder 1989a, 1989b, 1990; Gregory 1981; Jonas 1982; Martin and Schinzinger 1983). As early as 1981, Gregory claimed that the lack of literature on design cognition relating to groups, organisations and social and environmental pressures was because of the shortage of alternative human models of design that could address human issues such as motivation, communication and negotiation. In other words, the technical emphasis in the design literature has led to a positivist perspective on social, environmental and ethical issues in engineering design cognition that is unable to incorporate the necessary values-based explanation of the cognition of human designers whose individual value systems are different and whose realities are relativistically constructed. Consequently, in this thesis, it is taken that the 'hard headed' outlook is inadequate for addressing social, environmental and ethical factors and this research explores the application of a 'soft' post-positivist perspective on engineering design cognition.

The above theoretical issues relating to social, environmental and ethical matters impinge on most engineers via the prescriptions of the professional engineering institutions (Beder 1990, Ertas and Jones 1993; Jonas 1982; Layton 1971; Martin and Schinzinger 1983). The guidelines from professional institutions about how engineers should conduct themselves contain ethical advice on social and environmental issues in engineering (see, for example, *Code of Ethics,* I.E. Aust. 1988; *Environmental Principles for Engineers,* I. E. Aust., 1992; *Supplemental Charter and Byelaws,* I. E, Aust., 1991; *I.Mech.E.: Royal Charter, By-laws and Regulations for Voting* 1989). In the United States, most of the major engineering professions and professional institutions have adopted codes of ethics based on the code of ethics of the National Society for Professional Engineers (NSPE), and this trend has been followed by state legislators who have included some elements of the NSPE code in laws related to professional engineering registration (Ertas and Jones 1993; Martin and Schinzinger 1983). In Australia, in spite of close linkages with the United Kingdom, engineering institutions have in the main followed American engineering institutions in terms of their ethical codes. In the case of the Institution of Engineers Australia, which has a 'Code of Ethics' defined separately from its Royal Charter, its environmental code of practice, currently titled 'Environmental Principles for Engineers', was derived via the codes of ethics of the Institution of Professional Engineers, New Zealand, (I. E. Aust. 1988; 1991, 1992). In the UK, however, those institutions founded by Royal Charter are more likely to have their ethical strictures contained within their Royal Charter provisions (see, for example, I. Mech. E. 1989).

The contents of institutions' codes of social, environmental and ethical behaviour reflect the underlying assumptions and values of the institutions and the professional engineers that have joined them. This cultural gestalt of engineering institutions' ethical advice and prescriptions has been criticised by some researchers. For example, Jonas (1982) expressed concern that institutional prescriptions for professional engineering practice appeared to emphasise the ethics of professional relationships at the expense of social and environmental matters. His argument is supported by the environmental case studies of Caldwell, Hayes and MacWhirter (1976) and the historical overview of the American engineering institutions by Layton (1971). Beder (1990) claimed that there can be serious difficulties for engineers who attempt to satisfy professional engineering institutions' ethical requirements relating to social and environmental issues because of the pressures on individual engineers to be compliant with an employer's wishes. She points out the hegemonic difficulties for an individual engineer taking a stance against their employers or other professionals on social, ethical or environmental grounds where there is no institutional or professional support for engineers and observes that action has been taken against engineers by professional institutions who have viewed an engineer's actions as a breach of professional ethics. In addition, Beder notes that the future employment prospects of an engineer who goes against an employer or other engineers are adversely affected. These analyses of Jonas and Beder of the practical and ontological difficulties of compliance with professional engineering institutions' advice on social, environmental and ethical matters are further supported by Layton's (1971) review of the institutional behaviour of engineers and Martin and Schinzinger's (1983) historical critiques of engineering ethics.

The issues raised by Beder, Jonas and Martin and Schinzinger relating to the underlying epistemological and ontological positions of engineering institutions are evident in the professional codes of the Institution of Engineers Australia (I. E. Aust.). The Institution of Engineers Australia has been chosen for this example because of the ready availability of its documentation rather than any assumption that its ethical position is less well considered than any other professional engineering institution. Historically, the professional engineering institutions have addressed social matters as a matter of priority and environmental matters as a consequence of the social emphasis which is in contrast to standards bodies concerned with environmental legislation and guidance who usually include social issues as a subset of environmental ones (Hollick 1995). In its *Environmental Principles for Engineers*, the I. E. Aust. (1992) indicates its intention that its engineers should attribute some ethical value to natural phenomena and give 'nature a standing which recognises maintenance of ecosystem independencies [sic] and diversity'. This potentially wide reaching definition of environmental ethics is then humanistically limited by the I. E. Aust, giving primacy to social ethics over environmental ethics as follows,

> *This* [environmental ethic] *does not accord nature an ethical standing similar to that of humans. Any recognition that all forms of nature have an inherent value unrelated to any utility would present new challenges to impact assessment and project evaluation.*

The description has bounded the Institution's position on technological impact assessment and project evaluation by implying that design optimisation and decision-making methodologies should assume some criteria of human utility such as financial value and, in addition, the I. E. Aust. code of environmental practice has effectively excluded from consideration all arguments that insist on aspects of the environment having intrinsic worth.

The *Code of Ethics* of the I. E. Aust. (1988) avoids Jonas' concerns that institutions' advice to engineers emphasise professional and financial issues at the expense of social and environmental matters insisting that::

> *The responsibility of engineers for the welfare, health and safety of the community shall at all times come before their responsibility to the profession, to sectional or private interests, or to other engineers.*

There is no indication, however, of the Institution providing any additional support for engineers who are disadvantaged by following its ethical directives and this leaves unanswered Beder's claims that such prescriptions are worthless.

Finally, the Institution requires that its members 'develop and promote a sustainability ethic'. There are problems with the terminology of this directive due to the lack of clarity about the exact meaning of 'sustainable' as noted by Brennan (1993) but, more importantly, the Institution gives no clear indication as to how 'developing and promoting a sustainability ethic' might be done by engineers whose training does not include any of the necessary conceptual skills or knowledge to enable them to embark on such a task (I.E.Aust. 1992).

The above discussions indicate that social, environmental and ethical issues are not conceptually well addressed in engineering design research and in the directives of professional institutions. More, the discussions point again to a shortage of epistemological analysis and a lack of conceptual and terminological clarity. For this research to address the research problem some of these epistemological and conceptual problems must be resolved first. Court (1995) has argued that the most crucial aspect of understanding designing and designers' behaviour is understanding how a designer uses information. Technical factors are easily expressed as quantitative information and because it is assumed in this thesis that social, environmental and ethical *factors* influence designers' thoughts and behaviour in a similar way to technical factors, then it implies that social, environmental and ethical factors, like technical factors, should be seen as information. This position would fit well with the established quantitatively informatic view of design and with the design research literature that depends on the paradigms of Artificial Intelligence and Cognitive Science. To follow this direction, however, would be to go uncritically against the arguments that have been established earlier in this thesis that a positivist outlook on engineering design research is inadequate for addressing matters of design cognition relating to social, environmental and ethical factors. If social, environmental and ethical factors are to be included in design theory it is necessary to identify pertinent abstract characteristics about these factors which enable meaningful conceptualisation and communication. This argument is supported by Court (1995) who emphasised the extensive use of individual memory, knowledge and experience by engineering designers across all design activities and concluded that 'future research should also be directed to study the processes and developments involved in creating the memory/ knowledge and experience of engineering designers'. It is necessary to have concepts, theory and terminology which enable the possibility of answers to epistemological questions such as, 'What are the implications for this conceptualisation of social factors of a deterministic theory of engineering design?'. It may be that social, environmental and ethical factors are best conceived of as information, but, by using a post-positivist research perspective, issues relating to human values, and the subjective aspects of designers' behaviour and thought can also be included. In other words, the post-positivist perspective provides a more complete basis for investigating how human designers include social, environmental and ethical factors in their designing rather than investigating how social, environmental and ethical factors can be included in models of artificial design cognition.

The above considerations lead to the final research question concerning engineering designers' use of social, environmental and ethical factors.

Research Question 5:

> *How do designers use information and knowledge about social, environmental and ethical factors?*

2.4 Conclusion

In this chapter, the background and focal literature that relates to the research problem has been reviewed. This has led to; the clarification of relationships between the background disciplines of the research problem; the identification of the need for satisfactory epistemological and ontological foundations for engineering design research and design research; and the identification of weaknesses in existing design theory, particularly with regard to cognition and social, environmental and ethical factors. In addition, the boundaries of the main conceptual areas of this research, (design theory, design cognition and the role of social, environmental and ethical factors) have been extended into areas that better relate to the human construction and interpretation of knowledge.

2.4.1 Summary list of research questions

Consideration of the research problem against the background and focal literature reviewed in this chapter has led to the five research questions that form the basis of this thesis.

1. *How can design theories be evaluated and compared?*
2. *What are the implications of including human values in theories of human design cognition?*
3. *What are the implications of using post-positive perspectives for research and theory-building in the area of engineering design cognition?*
4. *What are the theoretical characteristics of social, environmental and ethical factors?*
5. *How do designers use information and knowledge about social, environmental and ethical factors?*

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