Annotated bibliography relating to definitions of the term 'Design' 1962–1995.

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1.1 Introduction

Within the disciplines of design research and the disciplines in which designing takes place, there have been many attempts to define design, designing and design process. The first wave of publications in this area in English was not seen until the early 1960s, although the groundwork for this interest in design as a focus for research and theorymaking occurred earlier (Jones 1970; Pahl and Beitz 1984). In this appendix, the focus is on how 'design' is conceptualised and defined by researchers and theorists. This overview is not intended to be exhaustive, but it is, however, intended to be extensive and to give an adequate representation of the thoughts and writings of those researching into or theorising about engineering design throughout this period. Judgment has been made at various points as to the importance of texts relative to their accessibility. Simaqi (in Shah, 1979, p. 166) offered the following advice around a thousand years ago to those involved in design,

> *If you take what is relative to be what is absolute, you may be lost. Take nothing, rather than risk this.*

Bearing in mind Simaqi's advice, a relativist perspective on concepts and terminology is used in this review. That is, this review allows that other researchers use terms and concepts in a variety of ways, but analyses the work of others by using the terminology defined in Chapter 1 of this thesis.

The literature being reviewed is from the period 1962 to 1995. The review is undertaken historically, commencing with 1962, and is divided into the periods 1962-1969, 1970-1979, 1980-1989 and 1990-1995. The only significance in this division is that there appear to me to be phases in the literature which change approximately as the decades change. This is supported by Cross (1984, 1993) who also sees trends in design research that change at around the same times. By separating the review at these points it offers the opportunity to comment on any obvious changes in research direction.

1.2 The 1960s: systematic methods, design as a process and the world of the ‘artificial’

The first UK conference on design methods in 1962 included papers on many different aspects of the study of designing (Jones and Thornley, 1963). In this first conference there was little attention paid to clarifying basic issues such as what different participants meant by design and it appears to have been considered sufficient, by the participants and organisers, to have established some kind of discussion at whatever level, with whatever content, provided it was related to the designing or planning of technology (Jones and Thornley, 1963). As Jones (1970) was to comment later, ‘it was sufficient to know that designing was what architects, engineers, industrial designers and others did in order to produce the drawings needed by their clients and by manufacturers’. In a foreword to the proceedings, Slann (1963) argued that the collected papers might be seen as ‘a collection of works of exploration, to test the existence and quality of the “bedrock” on which it is hoped to construct a sound system for design’. There was obviously enough common ground to be built upon by the researchers, although there was little to indicate that the participants of the 1962 conference were addressing problems of epistemology and semantics.

In the same year as this groundbreaking conference, Matousek’s (1963) German text on systematic design was translated and edited for the English-speaking market. Unlike the speculative proposals of most English-speaking design theorists, Matousek’s text arrived with its theoretical proposals full blown—due to the length of time that the systematic technological design paradigm had been gestating and developing on the Continent and particularly in Germany (Pahl and Beitz 1984). Matousek’s work fits coherently with the work of other German researchers in this idiom (see, for example, Eder 1966; Hubka 1985; Hubka and Eder 1988; Pahl and Beitz 1984).

In the following year in Northern America, Alexander (1964) published a detailed description of a deterministic computational method of design that was based on his earlier analysis of the design of an Indian village (Alexander 1963). Alexander viewed design as the activity necessary to match 'form' to its 'context' and used the 'misfit' between form and context as the basis for a probabilistic computer assisted procedure to decompose a problem into well conditioned sub-problems.

In the UK, research into design proceeded apace after the 1962 conference. There was sufficient progress for another conference in 1965 bringing together the work of design theorists and researchers to provide a 'state of the art' description of this new field (Gregory 1966a). This conference was no small scale academic affair. According to Gregory (1966a), theorists and researchers presented their work at the University of Aston at Birmingham in the UK to an audience of around two hundred persons who were 'drawn from the most diverse branches of technology and design'. The title of the proceedings, 'The Design Method', reflects the focus on method of theorists and researchers at that time (Cross 1984, 1984b, 1993). The papers of this conference show that both design researchers and design theorists were, on one hand, developing techniques aimed at improving design outcomes and, on the other, hoping to discover a theoretical basis for automating design in a way which would replace human designers (Gregory 1966a).

Jones (1966) reviewed design research and his review offers a basis for grouping the definitions of design of that time into the following categories:

- Design as creative activity (see, for example, Broadbent 1966; Jones 1966; Reswick 1965).

- Design as a template for replicating goods or services (see, for example, Asimow 1962; O'Doherty 1966).

- Design as simulation and modelling (see, for example, Booker 1964)
- Design as working in the future with elements of the present (see, for example, Esherick 1963; Jones 1966).
- Design as working with complexity and uncertainty (see, for example, Alexander, 1964; Asimow 1962; Mann 1963; Matchett 1963,).
- Design as scientific activity (see, for example, Broadbent 1966; Eder 1966; McRory 1966).
- Design as a process (see, for example, Eder 1966; McCrory 1966; Watts 1966)

The definitions of design that emerged in this 1965 conference were often multifaceted. For example, McCrory (1966) defined design in terms of ethics, science and technology:

> *Design is considered as the process of selectively applying the total spectrum of science and technology to the attainment of an end result which serves a valuable purpose.*

Like McCrory, Eder (1966) also implicated science and defined design as,

> *the use of scientific principles, technical information and imagination in the definition of a mechanical structure, machine or system to perform pre-specified functions with the maximum economy and efficiency.*

At the same time, however, Eder also emphasised the human aspect of design stating that 'in essence, it is this human power of imagining something that did not exist before that is termed "design"'. Concluding his review, Jones argued that it is necessary to view design and science as different activities, and suggested that the most promising definition of designing is an artistic one.

As editor of the proceedings of the 1966 conference on 'The Design Method', Gregory provided much of the material linking the work of other contributors and addressing obvious conceptual shortfalls. For example, Gregory's definition of design brought together the work in different domains by proposing that, ‘to design is to plan for the fulfilment of human satisfaction’ (Gregory, 1966b). The difficulties that researchers found in defining design at this time are indicated by Gregory asking ‘What is design?’, before circumscribing it without attempting to define it. Later, Gregory showed a preference for a process-based definition of design by focusing on ‘design itself as a process’, ‘design as a psychological process’ and design as a sociological process’.

In 1969, MIT Press published Simon’s re-envisioning of technological creation, titled *The Sciences of the Artificial*. Grounded in research in the field of artificial intelligence, Simon addressed issues in engineering design theory in a new way, bringing topic areas from the social sciences into centre stage in design theorymaking. In apparent contrast to the vigorously expressed informatic rationalism which underpins the bulk of Simon’s work, his definition of design here extended beyond the purely technical (see, for example, Newell and Simon 1972; Simon 1982). In arguing for a science of the artificial, a science of making artifices, Simon claimed that the activity of design is the core of professional training in all fields and marks out the professions from the sciences. Further, ‘everybody designs who devises courses of action aimed at changing existing situations into preferred ones.’ This latter definition of design implied that design is essentially a human activity that spans domains and supported arguments for a domain-independent basis for design research.

The role of domain dependency and independency is extensively implicit in the literature in this decade and one obvious attribute of the literature is the way that design is described in similar terms and concepts to those used in the field with which it is associated. This understandable tendency for designers from particular domains, especially engineering domains, to envisage design theory in concepts drawn from those domains is indicated in Eder (1966) and illustrated by Beck’s (1966) use of a ‘breadboarding’ model of designing as the basis for the planning and organisation of the 1965 conference on electronics design. ‘Breadboarding ’ is the colloquial terminology for the development of an ad hoc functional mock-up of an electronic circuit on generic circuitboard material.

In this first decade of modern design research, many authors, in addition to those already mentioned, made important contributions both in rejuvenating traditional engineering design practice with the newfound design methods and in promoting a new perspective on design (see, for example, Archer 1965, 1968; Asimow 1962; Booker 1962; Duggan 1970; Gordon 1961; Mann 1963; Matchett 1963; Middendorf 1969; Moore 1970; Page 1963; Pye 1964; Rapoport 1969; Rittel 1967a, 1967b; Roe, Soulis and Honda 1966). Many of these also created definitions of design as part of developing their new design methods and theories. For example, Middendorf (1969) claimed to define design in the broadest terms as,

> *The activity wherein various techniques and scientific principles are employed to make decisions regarding the selection of materials and the placement of these materials to form a system or device which satisfies a set of specified and implied requirements.*

Middendorf's 'broad' definition appears restrictive and dated compared to the definitions of Jones (1970) and Simon (1969), but underlying it was the assumption that designers should consider the whole life of a product when designing; that is, raw materials, finished product, product in use, and scrap (salvage) or waste. This perspective predated the contemporary focus on environmentally conscious design through Life Cycle Analysis by a quarter century.

1.3 The 1970s: domain dependency and independency, 'wicked' problems, intuition

During the 1970s the terminological and conceptual 'free for all' in engineering design theory continued, but, in England at least, there were differences between the 1970s and the 1960s. In the tertiary teaching of engineering, there were signs of a confidence in the idea of design as a separate subject of study, and several universities changed their syllabi to reflect this change of attitude. For example, Lancaster University offered a 'thin sandwich' engineering course which was multidisciplinary and held together by its focus on designing. This enthusiasm was relatively short-lived, however, and many of these design-based courses evolved back into separate traditional courses in civil, mechanical and electrical engineering. This was perhaps due to problems related to professionalism, along with the difficulties of maintaining the accreditation required by engineering institutions (Langrish 1988; French 1991). This greater credibility of design led eventually, however, to the establishment in the 1980s of tertiary design centres whose focus is mainly postgraduate research relating to engineering design (see, Hills 1995; Sharpe 1993, 1995; Tovey 1995; Wallace and Burgess 1995). The most obvious feeling of the decade of the 1970s was that researching design and developing design methods, although unusual, was, academically at least, a respectable thing to do.

This academic respectability did not, however, extend to the detail of design theory, particularly to a widely-agreed definition of design. There were changes as the decade progressed, and the best choice of boundaries for the discipline of design became more evident. A clear separation started to emerge between those definitions of design that related to design as a human activity and those that defined design as an ahuman process. Much of the research and theorymaking of this decade does not specifically define the term design, and hence it must be inferred from the context. This is difficult because much of the literature of this decade is marked by an epistemological looseness and lack of consistency. These problems are addressed in this review by focusing on the analysis of individual contributions rather than by comparing and contrasting different aspects of the definition of design across the field. By reviewing individual contributions, the internal inconsistencies in the perspectives that underpin the definitions of design of each can be explored and the outcomes of these explorations can then be classified as the main themes of the decade.

The start of the 1970s was marked by the publication of Jones' *Design Methods,* an influential systematic overview of the design research field from the perspective of method that Gasparski (1995) referred to as the development of a 'methodics' of design (Jones 1970). In Part 1 of *Design Methods*, Jones analysed the activity of designing, discussing how it might be improved, and in Part 2 he collected together the design methods developed up to that time, classified them and discussed their use. In Part 1, Jones argued that there was a diversity of opinion as to what design is, and quoted some definitions:

- *Finding the right physical components of a physical structure*

- *A goal directed problem solving activity*
- *Decision making, in the face of uncertainty, with high penalties for error*
- *Simulating what we want to make (or do) before we make (or do) it as many times as may be necessary to feel confident in the final result*
- *The conditioning factor for those parts of a product which come into contact with people*
- *Engineering design is the use of scientific principles, technical information and imagination in the definition of a mechanical structure, machine or system to perform pre-specified functions with the maximum economy and efficiency*
- *Relating product with situation to give satisfaction*
- *The performing of a very complicated act of faith*
- *The optimum solution to a set of true needs of a particular set of circumstances.*
- *The imaginative leap from present facts to future possibilities.*
- *A creative activity - it involves bringing into being something new and useful that has not existed previously.*

Jones noted the variety in the definitions and surmised that it may be better to look outside them and try to define designing by its results. In a similar manner to Simon (1969), he concluded that design is a means of changing the artificial aspects of the world and devised his 'ultimate' definition of design on the basis that:

> *The effect of designing is to initiate change in man made things.*

Taking this definition, Jones then explored how the definition implicates additional issues and suggested that research into design and the consideration of the implications of that research involve many other disciplines. Jones concluded that, *As soon as we think about this ultimate definition, we see that it applies not only to the work of engineers, architects and other design professionals but also to the activities of economic planners, legislators, managers, publicists, applied researchers, protesters, politicians, and pressure groups who are in the business of getting products, markets, urban areas, public services, opinions, laws, and the like, to change in form and content.*

Like Simon (1969) before him, Jones is defining design not in terms of the domain-centred focus of specific professional actions, but in terms of the wider creation and management of the 'artificial' world. In Pacey's (1983) terms, both Jones' and Simon's definitions place design in the wider scenario of human technology practice.

It was at the start of the 1970s that design researchers began to get the measure of the phenomenon of designing and reviewed their use of the simpler systematic outlooks. Researchers began to comment on the complexity of design as a concept. For example, Duggan (1970) pointed out that, 'engineering design is a complex activity which is not easy to define comprehensively'. Taking an overview of designing from what Coyne, Snodgrass and Martin (1992) refer to as a 'Romantic' position on design, Duggan suggested that,

Design is essentially a creative activity, requiring a certain amount of what might be termed native wit. It is this creative aspect which makes it different from most other subjects of engineering science, for it means that there is no unique answer to a specific problem.

Whilst moving from an overview to a more limited specific view, however, Duggan changed direction with his definition, placing it firmly into a framework emphasising analysis,

It (design) requires a systematic and scientific approach (drawing on the engineers knowledge of mathematics, mechanics, stress analysis, manufacturing processes, and mechanical behaviour and properties of materials) and an appreciation of aesthetics and ergonomics . . .

Bringing all of the above aspects of his inquiry together, Duggan moved towards a materialist position and concluded that:

> *Engineering design is of a complicated nature, involving making decisions based on sound knowledge and good judgement, and the application of analysis and synthesis in transforming an idea into a manufactured component or machine.*

Duggan's conclusion echoes Simon's (1969) definition of 'ill-structured' problems and foreshadows the influential, and better argued ideas of Rittel and Webber (1972, 1974, 1984) on 'wicked' problems.

During 1972 and 1973 Rittel and Webber published descriptions of some practical design situations in planning which were not obviously amenable to any amount of 'applying of a systematic perspective' (Rittel and Webber, 1972, 1973). They named this type of problem 'wicked' and described its general characteristics (Rittel and Webber, 1974, 1984). By drawing attention to these 'wicked' problems they effectively extended the definition of design beyond the well-defined and well-structured circumstances that were implicit in many formal theories of design. This outlook, therefore, challenged a discipline of design research based on the development of design methods because it implied that the more designerly problems lay outside what can be addressed via deterministic or systematic design methods. Rittel avoided this crisis, however, by proposing that wicked problems require a new generation of design methods that would be different to those developed during the 1960s (Rittel, 1972a, 1972b, 1984). That is, although the first generation of design theories (i.e. the systematic methods for dealing with fairly well-defined or well-understood engineering problems and the simple process models of design) did not address some design problems, the second (or a later) generation may well do so. This generational idea was supported by researchers because not only did it free them from attachment to prior methods, it also allowed the focus of design theory-making to remain methodological (Cross 1993). The avoidance of this early crisis in the development of design theory meant that researchers and theorists could also avoid the necessity of reviewing the epistemological and ontological basis of research and theory making relating to the phenomenon of design with all that that implied for defining design.

Instead, this generational perspective allowed them to avoid defining design, skirt the philosophical questions, and continue viewing design and design process in terms of the development of design methods based on positivist perspectives.

Rittel and Webber's concept of 'wicked' problems had additional benefits in bounding definitions of design because it differentiated between 'the routine mechanistic definition of determinable solutions to design problems via systematic methods' and 'the human activity of designing that addresses wicked problems that are ill-defined and ill-structured'. This differentiation leads to the possibility of discussing how much the concept of design should encompass each of these situations. Whilst it is almost universally agreed that dealing with 'wicked' problems is an essential aspect of designing, it is not clear that it is appropriate for the term 'design' to also include the routine identification of information that results in the technical definitions needed to produce appropriate artefacts. If this were so, then a stock management system would be a designer.

During the next few years the main trend in the literature of design research was the consolidation of the systematic position. Although Jones, Rittel, Webber and others were already seeing the limitations of systematic methods there remained an almost universally held hope amongst design researchers and theorists for the development of a mathematically definable representation of a design process which would enable the automatic production of optimal design solutions. The following definitions of design from the 1970s show both sides of this situation. On one hand, the theoretically constricting process models of the 1960s and earlier were used as a theoretical base, and, on the other hand, researchers were attempting to define design in a way that offered possibilities for new theory in the future. This combination, whilst providing a conceptual stepping stone, laid the basis of much of the conceptual and terminological confusion that was forecast by O'Doherty (1963) and identified as an ongoing problem by Hollins (1994), Pugh (1990) and Ullman (1992).

Sensing that the study of designing was being seen as theoretically problematical, that many researchers were attempting to address some of these problems, and that the concept of design was broadening, Spillers (1974) attempted to bring the questions and answers together in 1974 by holding a symposium on the basic questions of design theory at Columbia University, New York. The contributors to this symposium were drawn from diverse technical design domains, but, surprisingly, many of them proposed definitions of design from within the domain of chemical engineering, a field not otherwise renowned for its level of output on design theory. Difficulties were still surfacing, however, in relation to epistemological issues and terminology in particular. These issues were not in the main seen as important in the field, but rather they were viewed as troublesome and unnecessary complications to developing theories of design. For example, Mullen (1974) suggested that it was not necessary to specifically define the term 'design' because,

> *...the word design is in fact a convenient label, a Lewis Carroll portmanteau, for the early stages of that very complex process which takes place whenever a perceived need is consciously turned into a fulfilled need.*

It is not obvious, however, that the use of a word as a label is very different from the ordinary use of a word. The purpose of a label is to describe or classify, and it is necessary to know what a label includes in its description and what it does not. Denigrating the mode of use of the term 'design' does not mean that it becomes semantically insignificant. Similarly, a lack of care about well argued coherent epistemological foundations is found, for example, in Himmelblau (1974) and Director (1974). On one hand, their research focused on developing mathematically based theories of design and design optimisation, whilst at the same time referring to the importance of human creativity and intuition in the resolution of complex design issues.

Himmelblau (1974) focused on process and equipment design in Chemical Engineering and claimed that suitable procedures oriented towards computer implementation of conventional design had been proposed, but not fully tested, in that domain. He addressed the problem of defining design by circumscribing its context and looking at it from several perspectives, including attempting to identify all the underlying common features of design theory among different disciplines. It appears that Himmelblau was seeking a 'scientific' model of design because firstly, he expressed concern that there did not appear to be a theory of design, in any discipline, which was analogous to the physical theory of conservation of momentum, and, secondly, he discussed mathematically-based optimisation analyses in detail. Himmelblau was also interested in non-routine design problems, and he separated design methods which were used to produce novel designs from those which had more conventional or prosaic results. He concluded, however, that, as far as he could ascertain, no acceptable theory had been suggested for creative or innovative design. Thus, Himmelblau's underlying definition of design is one that has a scientific epistemology for routine design, but, beyond identifying a class of design outcomes as novel, is not otherwise epistemologically or terminologically defined.

Director (1974), from the domain of Electronic Engineering, followed much the same journey as Himmelblau on possible advances in automating design. He suggested that, because there is a uniform mathematical framework in which the analysis of engineering systems can be undertaken, it seemed reasonable that a common mathematical and numerical basis existed for design. By this, Director, like Himmelblau, set his definition of design in a scientistic, mathematical, rationalist, empiricist framework. He ignored difficulties of the sort identified by Motard (1974) relating to the phenomenological issues associated with human designers learning about a problem as they synthesise a solution to it. Epistemological contradictions are found in Director's position. Firstly, contradictions exist between his intention to develop scientistic, deterministic methods and his understanding that design procedures are not always clearly defined but based on intuition and experience to a large extent. Secondly, his assumption that designing can be computationally modelled is contradicted by his observation that,

> *Even in automated design the human designer must be actively involved in the design process to make those engineering decisions based upon reasoning which computers are incapable of doing.*

The above contradictions imply that Director is using several definitions of design because his implicit definition of design must otherwise be simultaneously deterministic and relativistic, and scientific and imbued with human values. One explanation of Director's position is as follows. Integrated circuit design is concerned with discrete electronic elements whose characteristics and forms can be almost fully modelled mathematically. Hence, electronic devices can be synthesised using one or more of a variety of mathematically-based methods. This provides some practical justification for a mathematical basis for a definition of design in this domain in spite of the epistemological problems.

Graham's (1974) background was in the design of computer-programming languages, which is similar to that of Director in that integrated electronic circuit elements and computer programming elements are both mathematically definable. However, her view of design was very different from Director's. She described programming-language design as very much more an art than a science and emphasised human skills in design rather than the mathematical and quantifiable aspects of design information. For Graham:

> *Good language design is a somewhat subjective characteristic and even objective criteria are more qualitative than quantitative.*

By referring to 'good' design, Graham introduced aesthetic and ethical issues into her definition of designing. Hence, her definition is not only based on design as a human activity but is also underpinned by a qualitative and relativist epistemology.

Although much of the design research in the 1970s is positivist and aims at developing deterministic design theory, Graham's human-centred perspective is also found explicitly or implicitly in almost all of the literature relating to design research in the 1970s. Most commonly, it is allied to a view of designing as 'problem solving'. For example, Wong (1974) discussing bio-engineering design, stated that,

> *Bio-engineering design . . . . is a purposeful activity stemming from our technological culture, with the fulfilling of the ever increasing human needs as its ultimate teleological goal.*

and that,

Design may be described simply as a progression from the abstract to the concrete, but it is often thought of as a goal-directed heuristic problem-solving process.

Making problem-solving one of the main aspects of a definition of design automatically brings in issues relating to the characteristics of problems. For example, the picture of design as a human problem-solving activity sketched out by Akin in 1979 segregated designing into 'intuitive' and 'non-intuitive' processes and his separation of the intuitive from the non-intuitive has many connections to 'wicked'/'routine'/'ill-defined'/'ill-structured' classifications of problems.

Thomas and Carroll (1979) focused on design as human problem-solving because of their backgrounds in cognitive psychology. Unlike Akin, they restricted their definition of design to dealing with problems in which 'the goal, the initial condition and the allowable transformations were 'ill-defined'. Their concept of ill-definedness was attributed to Reitmann (1965) and is somewhat similar to the idea of 'wickedness' of Rittel and Webber (1972, 1973, and 1974), but they appear to use the term 'ill-structured' to mean much the same as ill-defined. An important aspect of their definition is the way that they chose to separate 'what is design' from 'what is not design' by considering the implications of how designers look at problems. In defining design Thomas and Carroll argued that,

Much of what we call technological progress may be viewed as a process of rendering ill-structured design problems as more well structured procedures for accomplishing the same ends—without requiring design.

Thomas and Carroll concluded that design is a type of problem solving and that whether it is design or not depends on how the problem-solver treats the situation. That is, design happens when a problem-solver

views his/her problem or acts as though there is some ill-definedness in the goals, initial conditions or allowable transformations'.

This particular outlook leads to a definition of design that is human centred, individualistic and relativistic: a constructivist definition. In addition, and at least as significant, this position leads to the conclusion that much of what is at present considered design and design research is inappropriately classified as such.

From an architectural perspective, Bazjanac (1974) followed a similar path towards a human centred vision of design that avoided many of the philosophical difficulties associated with both the positivist 'analysis/synthesis/evaluation' models of design process, and the early 'systems' based models of the design (see, for example, Alexander 1964, 1971; Broadbent 1973; Dasgupta 1991; Page 1963; Rittel 1967a, 1967b, 1972b). Bazjanak proposed a definition of design as a learning process in which problem definition, problem solution and documentation cannot be separated. Bazjanac believed that it was Rittel's definition of 'wicked' problems which best casts light on what is wrong with the early models of the design process. In Rittel's terms, Bazanak saw his learning model of design process as a second generation model. This puts Bazjanak's outlook in the same class as the perspectives that underpin the 'wicked' models of Rittel and Webber (1973) and the later 'Pattern Language' models of Alexander and associates (Alexander et al. 1977; Alexander 1979). This definition of 'design as learning' is one of the early pointers to the later 'reflective' definitions and theories of design of Schön (Schön 1983, 1984, 1987, 1992; Schon and Wiggins 1992).

Motard (1974) assumed a human perspective on design and differentiated between routine and inventive design. He suggested that successful routine designs emanated from imaginative and informed people steeped in the technological state of the art in which they operate. Inventive design he regarded differently and echoing Bazjanac stated that,

> *Design by invention is a learning process . . . . design as a human activity includes behavioural phenomena as well as cognitive inputs.*

Motard also differentiated between design and analysis. He regarded design as innovation or invention where, 'design as an engineering art is certainly more than the application of scientific and technological concepts'. By contrast and where analysis is an essential but different activity that is part of evaluation,. He suggested that the benefits of computers in design lies not in their potential for generating new designs, but as a means of emphasising and developing human professional judgement. Motard's discussions relating to these side issues confirm his position on design as an essentially human phenomenon.

Powers and Rudd (1974) took a similar human-centred position to Motard and also differentiated between routine and non-routine design. They based their position on research into improving design outcomes in chemical engineering, reporting that the outcomes of this research had been more successful when applied to automating the analysis of processing systems rather than improving understanding of the design of the basic configuration of such systems. At that time, this latter problem of the choice of processing system and its basic configuration was not a routine problem, and depended on human intuition and judgement.

The management of design, particularly in commercial situations, formed the basis of several definitions of design. For example, Leech (1972) took an instrumental view of the role of the designer within a business perspective, and emphasised the commercial situation of designing. He suggested that the best designer is one who makes the most profit for the employer. Leech avoided defining design directly and instead characterised it in terms of the following circumstances,

- *Having a customer who wants something and is prepared to pay for it.*
- *A manufacturing organisation which will make what the customer wants and sell it to him.*
- *A designer who supplies the manufacturer with what instructions are necessary to manufacture his product.*

The definition of design implicit in the above circumstances is one that is instrumental and informatic. Essentially, Leech's definition of design is whatever process produces the information necessary to manufacture a product for which a customer pays. In Leech's sense of design, the activity of designing overlaps with market research.

Contrasting with Leech's commercial view is the management view of design proposed by Siddall (1972). From this perspective, Siddall inferred that design consists of four main components; identification of need, innovation, decision making and detail design. The domain-based nature of Siddall's view is shown by the way that these four components reflect the roles of departments in many organisational structures.

Three years later, in the area of planning and management, Ostrofsky (1977) argued for a similar view of design to that used by Jones (1970) and Simon (1969). He used the following definition drawn from Websters International Dictionary:

> *Design is defined as purposeful planning as revealed in, or inferred from the adaptation of a means to an end or the relation of parts to a whole...*

Ostrofsky suggested that designing and planning should be considered synonymous, and proposed the title of designer-planner. In Ostrofsky's words,

> *The lack of interchange between planners and designers is anomalous. If planning and designing include the same basic processes, the methods of each should be applicable to the other.*

Ostrofsky's definition of design is filled out by his picture of the designer-planner as one who moves to meet a need in the most effective manner possible. He argued that the designer-planner must have much the same mastery over disciplinary content as a scientist but must have additional skills.

> *The designer-planner must achieve a useful solution to meet the needs within his resources even though absolute rigour may be (and often is) sacrificed for the good of overall performance.*

This predates Pugh (1989) in trading scientific correctness for pragmatic gains and extends Ostrofsky's definition of design beyond the scientific. The underlying definition of design that is found in Ostrofsky's proposals is human-centred problem-solving and includes an ethical element via the 'purposefulness' of the planning.

In summary, the main points that emerged in the explicit and implicit definitions of design found in the design research literature of the 1970s relate to:

- Human aspects of designing including creativity, inventiveness and intuition.

- Characteristics of problems including ‘wickedness’, ill- defined and ill-structured.
- Routine and non-routine aspects of designing.
- Commercial and management aspects of design theory.

The end of the decade of the 1970s marked a new phase for design research in the UK. In 1979 the Design Research Society started the journal Design Studies. It was intended to be the international forum for research into technological design. The first edition marked another new beginning: that design should be a discipline itself rather than being seen as a subsidiary aspect of many other disciplines. Gregory (1979), as editor, argued that,

> *One of the principal assumptions behind the launching of this new journal is that Design can be identified as a subject in its own right, independent of the various areas in which it is applied to practical effect.*

Yet all this was proposed without a definition of design that was epistemologically coherent and well-agreed across the field.

In essence, the literature of the 1970s shows that design researchers made token efforts to define the concept of design whilst they explored the practical aspects of building theories but neglected epistemological and terminological difficulties relating to fundamental concepts.

1.4 The 1980s: design as information processing, design as problem-solving, design management, designing as an aspect of being

The start of the 1980s was the start of the public face of the study of design as described in the first edition of *Design Studies* (Editorial 1979). Computer assistance for designers was now well known if not available on many designer’s desktops. Later in the decade, with the widespread proliferation of personal computers, computer aided drafting (CAD) became de rigeour for many designers, particularly in Engineering and Architecture. The onset of the computerisation of drawing, together with use of computers for computationally complex tasks and for managing large amounts of data, led to changes in the direction of research into engineering design towards a focus on manipulating and transforming information. These areas became the 'preoccupations of the scientific research community' at that time (Lera, Cooper and Powell 1984). Those involved in research into design in this period were to see the implementation of expert systems, knowledge based systems, design decision support systems and a burgeoning connection between the 'design of the artefact' and its manufacture through the bringing together of CAD and computer aided manufacturing (CAM) into the catch all 'computer aided engineering' (CAE). Many of these systems were implemented on readily available computers at prices that were acceptable to most technical organisations. These developments are most readily found in the literature of engineering design research, perhaps because engineering design lent itself more readily to the application of computers. The proceedings of two of the more significant design research events in the 1980s, the *International Symposium on Design and Synthesis* in 1985 and the *International Conference on Engineering Design* in 1989 illustrate the breadth of this trend towards informatic computational perspectives on design.

The International Symposium on Design and Synthesis (ISDS) of 1985 in Tokyo was a milestone in the collecting together of the state of the art in design theory in the 1980s. Although restricted in its outlook, it captured the mood of technological design theory at that time. An overview of the topics indicates that the proceedings were drawn from around one hundred and twenty papers of which more than one hundred described advances in engineering theory and technological advances. Although most of the remaining papers related to engineering design theory, the majority of these described technical aids for designers. Few were concerned with epistemological issues relating to design research or developed design theory in the sense that it is defined in Chapter 1 of this thesis. In part, this imbalance towards engineering issues appears to be due to the domain distribution of the contributors to this symposium because they were drawn almost exclusively from the field of mechanical engineering. This is considerably different to the *Symposium on Basic Questions of Design Theory* in 1974 in which the papers reflected a wider range of technological domains. According to Yoshikawa (1985), this bias towards mechanical engineering is a consequence of the interests of organisations that sponsored the conference, in which case, it may have been academically more satisfactory if the title of the symposium had reflected this limitation.

The proceedings of ISDS provide strong evidence of the trend in the 1980s towards an information-processing focus for research into designing. Yoshikawa (1985), chairman of the symposium, noted that information-processing had become an issue in design by the mid-1980s because, by then, designers needed to use computers, or, more specifically, to process information. He suggested that those involved in information-processing had begun to view designing as one of the typical intelligent processes of the brain, and many of the papers at this symposium came from perspectives that were closely related to those used in research into artificial intelligence. That is, they either proposed that design is information-processing or they described techniques developed from this field for use in designing. What was not evident in the papers of this symposium, however, was an understanding that there are important epistemological differences between viewing information-processing as a tool to be used by designers, and viewing designing as information processing. Hegemonic analysis of the situation suggests that the development of information-processing techniques by those most involved in design research leads, in turn, to defining design in a manner which supports the acceptance of these information-processing techniques.

Another major element of the literature on engineering design of this period is the proceedings of the International Conferences on Engineering Design. These international conferences, which started in Rome in 1981, are organised by the WDK (Workshop-Design-Konstruktion) group founded by Hubka with support from Eder and Andreasen (Wallace and Burgess 1995). Although WDK organise the ICED conferences and the main publisher for the WDK group is Heurista in Zurich, the proceedings of ICED are published by a variety of organisations, for example, ICED 87 was published by the American Society of Mechanical Engineers; ICED 1989, which Hollins (1994) considers the best of these conferences, was sponsored by Institution of Mechanical Engineers, UK and the proceedings were published by MEP Ltd, their publishing arm. There were ninety seven papers included in the proceedings of ICED 89 which were grouped by the organisers into seven main categories,

- Keynote papers (4 papers).
- Management (27 papers).
- Methods (27 papers).
- Computer Application (9 papers).
- Education (19 papers).
- Reliability (3 papers).
- Information (7 papers).
- Late papers (1) by Hubka, on 'quality in design', which would otherwise have been placed either in 'Management' or 'Methods'.

As can be seen from the above list of categories there were no papers dealing specifically with the philosophy of design, design theory or epistemological issues in design theory. There was a considerable amount of theorising of one form or another in the proceedings, but the confusion between engineering theory and engineering design theory was widespread. The term 'design theory' was not only loosely applied to engineering theory, but was also applied to a variety of theories from other disciplines that had a connection with designing. For example, theories of management relating to design situations became design theories, and, similarly, 'information theories', 'marketing theories', 'psychological theories' and even 'social theories' were passed off as design theories.

In spite of the wide variety of disciplines involved with the creation of technological artefacts, ICED 89, like the *International Symposium on Design and Synthesis* was dominated by papers with a mechanical engineering focus. This cannot be attributed to a possibility that it is only mechanical engineers who are interested in engineering design because engineering design research from other domains was being published elsewhere (see, for example, Altshuller 1984; Cross 1984; Langrish 1988; Lera 1981a, 1981b; McDermott 1982; Nadler 1989; Parnas and Clements 1986; Wilde 1983). What it does indicate is that the organisers, WDK and the

Institution of Mechanical Engineers, were unable or unwilling to attract papers on design from other technological domains. This is unfortunate on two counts. Firstly, some other domains have a strong history of design theorisation and, secondly, the rich picture offered by the contrasts in the paradigms of design research of differing domains was not available. In the following reviews, the focus is on the definitions of design that underpin the arguments, research and theoretical proposals of the authors.

Haugen (1980) took a socially beneficent view that to design was 'to formulate a plan for the fulfilment of a human need'. He focused on mechanical engineering design and regarded it as being concerned particularly with component strength, stiffness, thermal behaviour and economic factors. Implicit in his perspective was the assumption that theories of mechanical engineering design should be based on physics, mathematics, engineering science and engineering theory. Haugen's main proposal was probabilistic theory of design which required that all design factors be expressed in quantitative form, and assumed that structural design is the most significant aspect of designing in the mechanical engineering domain. Haugen's theory is suited, for example, to analysing the probabilities relating to the difference between the stresses in a component and the actual strength of that component. In terms of the definitions of Chapter 1 of this thesis, Haugen's theory is an engineering theory rather than a design theory.

Dieter (1983) noted that there are numerous definitions of design, and argued that Webster's dictionary definition 'design is to fashion after a plan' is incomplete as it does not include the temporal idea that to design is to create something that has never been. That is, that,

> *Design establishes and defines solutions to and pertinent structures for problems not solved before, or new solutions to, problems which have previously been solved in a different way.*

Deiter's definition is positivist and deterministic because of its dependence on analysis and synthesis.

Clausing and Ragsdell (1985) also emphasised 'synthesis' in the sense of 'the assembling of separate or subordinate parts into a new form' (*Webster Comprehensive Dictionary* 1986) in describing their understanding of what design is. This position on synthesis led them naturally to a definition of design which implied that all products are assemblies of independent sub-systems and, consequently, that design is a constructive activity where previously disassociated elements are brought together to form that which previously did not exist.

Spur, Krause and Dassler (1985) defined the *act* of designing as the processing of geometry under functional and physical demands to find an optimal solution under the given circumstances. There are, however, epistemological difficulties about equating the concept of an 'act'—presumed to be human from its context—and the idea of a 'complex processing of geometric data'. An important difference is that 'complex processing' is something that may be undertaken in a variety of ways by a variety of means but an 'act' must be done by a human being. To co-join them in the sense that an 'act' is identical to a 'process' is to take away or ignore some of the difference in meaning that the terms 'act' and 'process' indicate. This difference in meaning reveals the hidden and inappropriate epistemological shift that enabled Spur, Krause and Dassler to equate 'the human act of designing' and the potentially mechanisable 'design as processing of geometry' to support the development of a computerised model of designing.

Hubka (1985) defined engineering design from an information-processing perspective as 'a process in which the designed problem (based on demands) is transformed into a description of technical systems (technical product)'. Hubka also assumes that designing is an activity undertaken by humans and therefore his process based definition of designing is subject to the same epistemological criticism as that laid against Spur, Krause and Dassler above. This epistemologically inconsistent situation in which researchers assume or define design as both a human activity and a mechanisable process is widespread. It depends on a positivist approach to design research that excludes many of the epistemologically and conceptually essential aspects of designing. The arguments as to why the positivist position is insufficient and inappropriate to design research are described in detail in Chapters 1, 2 and 3 of the thesis. For brevity, these issues are not discussed further in this appendix and it is assumed that they apply whenever design is defined in positivist, scientific or deterministic terms.

In 1981 Yoshikawa proposed a mathematical theory of design which he called 'General Design Theory' (GDT). GDT moved the focus of the definition of design to the finite attributes of the designed object rather than the activity of designing, and thus effectively excluded human action from the definition of design. GDT has practical benefits as an information theory or an engineering theory in terms of adding value to information and supporting the development of computerised engineering assistance for designers. The main theoretical benefit of the ahuman perspective of GDT is that it offers an intimate correspondence between the concepts and theories of artificial intelligence, knowledge engineering, computer aided design and design, but its claim as a theory of designing is epistemologically limited by being unable to address the more human issues of design cognition (Reich 1995; Tomiyama and Yoshikawa 1985).

Wallace and Hales (1989) identified research areas in engineering design on the basis of the information-processing paradigm described by Yoshikawa (1984). For Wallace and Hales, designing was seen as transforming information and from this point of view the purpose of design research was to provide 'structured knowledge which can be used by design engineers'. Their perspective on design was that of a mechanically-defined rational designer applying transformations that are definable in prescriptive and normative terms to descriptive information about 'specifications of needs' in order to create 'specifications of solutions'. Wallace and Hales' model of design did not include the role of human valuing in conceptualisation, interpretation, creation, evaluation or decision-making. The definition of design that underlies Wallace and Hales' work is positivist, mechanistic and informatic in the sense that design is the logical and deterministic transformation of objectively defined information.

The description of design proffered by Hongo (1985) echoed that of Tomiyama and Yoshikawa (1985) and Hubka (1985) with respect to design as knowledge processing and the use of a model of design based on mathematical set theory. Hongo's analyses place him firmly in the logical positivist camp because he defined 'theory of design' as design science or the scientific study of design activities, and claimed that he identified his theory of design as a description of truth from (sic) design activities. There are many parts of Hongo's paper which are written in a manner which requires interpretation, and some parts which appear not to make sense. For example, defined within his 'design science' is the sub-category 'technical information of design science' which tautologically includes the 'theory of design processes'. Hongo's position presents some epistemological inconsistencies. Firstly, his observation that intuitive designing is a very powerful method which should not be disturbed by forced methodologies does not accord with his insistence on an all-inclusive scientific paradigm of design research that does not include intuitive designing. Secondly, a further contradiction exists between his argument that designing consists of unconscious and conscious activities because it is not obvious how Hongo proposed to define these scientifically. In summary, Hongo's definition(s) of design are contradictory and reflect the underlying epistemological difficulties with trying to simultaneously recognise that design is a human activity, with all that that entails about human values and the internal workings of the human psyche, and hold that design can be described as logically definable in mathematical or scientific terms

In contrast to the mathematical theorisation of Hongo, Andreasen's (1985) underlying definition of design was based on Danish designers' practical experience with systematic methods of design. In Denmark, according to Andreasen, design is seen as both problem-solving and, unusually, as an integrated product development process. This combination necessitates a broader definition of design than otherwise. Definitions that relate purely to problem-solving can more justifiably adopt a mechanistic and deterministic approach, but integrating design into the product development process implies the inclusion of those human considerations that enable value judgements to be made. This latter corresponds with Lyle (1985) who contrasted science and design, and claimed that, unlike science, 'design is ultimately an integrative activity'. Andreasen's description of the Danish perspective on design has many similar characteristics to the concept of Total Design developed by Pugh

(1991) which emerged fully developed some five years later but which is apparent in Pugh and associates earlier work at about the same time as Andreasen's text (see, for example, Hollins and Pugh 1989; Pugh 1985; Pugh and Morley 1989).

Dittmayer and Sata (1985) also described the use of systematic product development that was integrated to some extent into the product-development process, in this case, at the University of Tokyo. They used an axiomatic model of design similar to that later described by Suh (1990), but ascribed it to Glegg (1971), and linked it to a model of planning to provide a system to support decision-making in design by choosing the details of the design process. This is an unusual theoretical step because in this Dittmayer and Sata allowed that there might be many different design processes that could be used in designing, whereas most authors define a particular model of design process that relates to their particular definition of design. Their inclusion of 'planning the design process' introduces a meta-analysis, and adds additional conceptual and cognitive levels to their model. The 'design process planning model' Dittmayer and Sata used resembled many of the design process models of the previous twenty years, but was differentiated from them by the inclusion, of a data or 'a-priori knowledge' store. The inclusion of this store moves the emphasis of their model towards the cybernetic system and information-processing perspectives on design. By the above means, however, Dittmayer and Sata avoided treating all aspects of design in the same way and thus pioneered the clarification of epistemological issues via meta-theoretical analysis in order that each of these different aspects might be addressed in an epistemologically appropriate manner. In essence, Dittmayer and Sata's definition of design is primarily rationalist and consequently has the contradictions described earlier in relation to the human aspects of designing. It divides design into epistemologically different aspects, however, and this points to the possibility of resolving some of the conceptual contradictions.

The outlooks developed by Dittmayer and Sata above fit well with Slusher, Ebert and Ragsdell's (1989) proposals for improving the management of design. They suggested classifying design situations into incremental design, complex design, creative design and intensive design, and argued that these situations should be managed differently because they represent different creative contexts of artefact and problem situations. Dittmayer and Sata’s approach is useful because it provides the basis for developing appropriate design processes that suit each situation. From a perspective of design research, however, if Slusher, Ebert and Ragsdell address these situations differently it implies that they are using different theoretical perspectives on design. Hence, definitions of design that are different in detail.

The most comprehensively developed systematic basis for designing is the German VDI 2221 design guidelines. Ehrlenspiel and Dylla (1985, 1987) used these as the basis for their theories of design. They based their theories on the analysis-synthesis-evaluation definition of design implicit in VDI 2221, and identified, collected and classified their experimental data in terms of the same definition. By using this experimental process they excluded the possibility of identifying and collecting information that would contradict their thesis about what design is. It is not obvious that Ehrlenspiel and Dylla identified this difficulty. Similar underlying epistemological problems relating to the definition of design can be found in the work of Salminen and Verho (1989), which was also based on the German model of systematic design.

The broad picture of engineering design, as what happens between identifying a potential need and supplying it profitably, was synchronistically developed by several design researchers in the late 1980s. Neilsen and Valbak (1989) developed a means of defining design by classifying design activity. They used a wide ranging industrial perspective and, from this perspective, derived a model of design that focused on the dynamics of the design situation and included,

- The areas of design and production.
- Strategic, tactical and operational levels.
- The positioning of any act with respect to what it depends on in the past and what it influences in the future.
- The way that ‘actors’,. consumers and those passively involved result in co-ordinated joint activity and its consequences.

- The way that development acts on and in the environment.

By opening out the perspective of what is involved in designing and drawing attention to the temporality of the relationships involved, Neilsen and Valbak offered a new perspective on designing which sits on the boundary between positivist and post-positivist positions. The above perspectives imply a constructivist definition of design as a human activity, yet, at the same time, focus on the details of problems, solutions, contexts, situations and processes. These factors suggest that their position has internal contradictions on the lines argued by Dilnot (1982) (see Chapter 2). There are some similarities between Neilsen and Valbak's view, and Stauffer's (1989) emphasis on the domain-independent nature of design in that the 'dynamic approach' of Nielsen and Valbak and the idea of 'domain independence of designing' both depend on dealing with aspects of designing which cannot easily be described, or manipulated by mechanistic models of design activity.

Eder (1989) continued the 'design is information processing' theme and proposed the following definition of engineering design that connects needs to solutions from that standpoint:

> *Engineering design is a process performed by humans aided by technical means through which information in the form of REQUIREMENTS is converted into information in the form of descriptions of TECHNICAL SYSTEMS, such that this technical system meets the needs of mankind.*

The model of design process on which he based this premise relegates other factors involved in design to sub-systems acting as operators on the above forms of information. Eder defined design as a 'process performed by humans' and his focus was on identifying the external details of that process as perceived from an informatic perspective. This view of design, however, neglects all those aspects of designing that are internal to the human designer and on which externally observable process depends. That is, Eder has focused on what happens to information, an engineering issue, rather than the human activity. In this sense, it may be more appropriate that Eder's theories are classified under engineering research rather than design research.

A pragmatic definition of engineering design that was based on planning and management considerations was provided by Coplin (1989):

> *Engineering design is essentially a detailed planning process backed by analysis and demonstration. It is used to control the means by which we satisfy both customer and shareholder.*

Coplin's definition is instrumental in that it defines design as a process that is used to control. By this, Coplin does not exclude human participation in that process but he has defined engineering design in terms of that ahuman process rather than the human activity.

Rhodes and Smith (1989) provided an almost identical definition of design in their work and although both the theories of Coplin (1989), and Rhodes and Smith (1989) predate Pugh (1991) and his development of 'Total Design' they are obviously similar in direction and content. Phrases characteristic of Pugh's work on Total Design occur frequently and diagrams of a similar structural format are used. Rhodes and Smith viewed design as,

> *The total activity necessary to provide an artefact to meet a market need that commences with the identification of that need and is not complete until the product is in use, providing an acceptable level of performance.*

This definition precludes any inclusion within the design process of disposal of the used artefact or for full life-cycle design within a wide-scale ecological framework. That is, their definition, although providing a basis for the definitions of 'Eco-Design' and similar environmentally focused developments in design theory, has insufficient scope to include their implementation.

French (1985) offered a definition of design that focused on the form of the product and this reflects his mechanical engineering background.

'Design' is taken to mean all the process of conception, invention, visualisation, calculation, marshalling, refinement, and specifying of details which determines the form of an engineering product.

In spite of this focus on form and the 'needs' that necessitate its creation, French's definition has a similar conceptual breadth to the theories of Andreasen (1985) and Pugh (1991), but does not extend into the detail of the manufacturing, sales and management arenas in the way of those other proposals. French discussed the role of conceptual design 'schemas' in design theory and tied the values of these schemas to the overarching commercial purpose of design, maintaining that:

A scheme should be sufficiently worked out in detail for it to be possible to supply approximate costs, weights and overall dimensions, and the feasibility should have been assured as far as circumstances allow.

French's definition of design is functional and pragmatic. From his position, the purpose of defining design is to develop conceptual and mathematical tools and analyses that can aid designers, and it is sufficient for these purposes to define design in terms of 'needs' and 'solutions' (see, for example, French 1985, 1988). In this sense, French's definition of design does not directly relate to the concepts of design theory and design research as defined in Chapter 1 of the thesis because in most cases French's focus is on information about the physical attributes and behaviour of objects. French's outlook was later to form the basis of a well-funded research program to develop 'Schemebuilder', a computerised expert system intended to assist with the conceptual design of mechanical and mechatronic devices (French 1990; Oh, Langdon and Sharpe 1994; Sharpe 1995).

In a similar manner to French (1985), Starkey (1988) put the focus on design as dealing with problems and 'needs'. He defined design as follows,

It [design] is the recognition and understanding of a basic need and the creation of a system to satisfy that need. Put more simply, design is problem finding followed by problem-solving.

Later, Starkey changed tack to an educational model of design in which 'design is a learn-by-doing activity'. Starkey's definition of design is essentially human-focused and tightly tied to the problem-based theories of cognition.

Lewis and Samuel (1989) followed Starkey (1988) in focusing on 'problem-solving' and 'needs' as the main characteristics of their view of engineering design. Their definition echoes that of Duggan (1970) with respect to its mention of the complexity of design, and extends to a stance very close to that proposed by Coplin (1989) above. Lewis and Samuel concluded that, in general, design is 'directed towards satisfying some human want or need' and defined engineering design as follows:

> *Engineering design is a complex problem-solving activity. In essence it comprises the planning of engineering systems, devices, products and components in order to satisfy some human need.*

The 1980s focus on information in design research necessitated and allowed advances in mathematics as the 'needs', processes and technical outcomes of design became specified in quantitative physically measureable terms. In 1989, Arora created 'Optimum Design', a mathematically based design method for optimising the design outcomes of engineering systems. For Arora, the formulation of an optimum design problem involves,

> *Transcribing a verbal description of the problem into a well defined mathematical statement.*

This mathematical vehicle for modelling engineering design activity constrained his theoretical picture, or definition, of what design is because all variables or constraints which impinge on the specification of the designed object must be defined in a numeric manner. There are epistemological problems with this perspective because many aspects of situations are not only difficult or impossible to quantify. These are problems that apply to any perspective on design based on positivism. Arora's method also has problems with satisfying its main aim, design optimisation, because multi-attribute and multi-objective optimisation become problematic with more than one optimisation parameter, especially if they are dependent. In Arora's words,

> *In other situations, there may appear to be two or more cost functions. These are called 'multi objective design optimisation problems'. There is no general and reliable method for solving such optimum design problems . . .*

Further epistemological contradictions in Arora's view of design exist between his quantitative method and his conviction that engineering design depends on human designers: 'The designer's experience, intuition and ingenuity are required in the design of systems in most fields of engineering'. Arora's design theory is an engineering theory and by classifying it as such many of the epistemological difficulties disappear.

Corrigan and Morris (1989) had a similar interest in finding optimal solutions to problems, an area of endeavour that, like Arora, they called 'Optimum Design'. Their methods were explicitly directed at providing better information to the designer by using mathematical modelling techniques. Their methodic perspective lay in systems theory and from a systems standpoint they stated that, 'design is an iterative process'. To this point, they are epistemologically consistent in defining design as a process that does not exclude the possibility that humans undertake it and that design methods are aimed at adding value to the information that designers use. This epistemological consistency is disturbed when they apply a value-free systems engineering model to their interpretation of the design process. This 'value-free' assumption was contradicted by the inclusion of human values that is implicit in their view that,

> *Engineers strive to design the best systems and, depending upon the specifications, best can have different connotations for different systems. In general it implies cost effective, efficient, reliable and durable systems.*

Therefore the definition of design that underlies the position of Corrigan and Morris is systematic, human, and informatic but excludes those aspects of human functioning that Rosen (1980) viewed as fundamental to creativity and synthesis.

Langrish (1988) discussed similar epistemological difficulties to those that underlie the proposals of Arora and Corrigan and Morris with respect to design and technology transfer. 'Technology transfer' is used by Langrish to describe the adoption of new or different technology by any society or individual, sometimes also referred to by others as 'innovation' (see, for example, Beitz 1989; Roy 1993). From the perspective of chemical engineering, Langrish defined design as the creative and synthetic aspect of technology development. He argued that design was often mistakenly regarded as being analytical, and that this was due to societal and professional hegemonic pressures promoting analysis in such a manner that it discouraged the development of synthetic or creative approaches. Langrish's definition of 'synthesis' as 'building out of elements' is exact for design in the chemical industry, and this explains his inclusion of creativity alongside synthesis in his definition of design.

The dichotomies of value-free/value-laden, human activity/ahuman process, and creative/routine are part of the difficulties in establishing an epistemologically coherent structure for an independent discipline of design. A seasoned campaigner in the problems of design theory, Cross (1989) avoided defining design directly. He circumnavigated the difficulties of definition by reviewing common properties of design problems which is, however, tantamount to proposing that design problems should be the focus of design theory. He suggested that most design problems are similar because,

- *They have a goal.*
- *Some constraints within which the goal is to be achieved.*
- *Criteria for recognising successful designs.*

Later, Cross (1989) had design as 'working with ill-defined problems' and characterised it in similar manner to Rittel and Webber's (1972, 1973, 1974, 1984) analyses relating design to 'ill-structured problems'. For Cross, the characteristics of ill-defined problems are,

- *No definite problem formulation.*
- *Any problem formulation may embody inconsistencies.*

- *Formulation of the problem is solution dependent.*
- *Proposing solutions is a means of understanding the problem.*
- *There is no definitive solution to the problem.*

Implicit in Cross' analyses is a definition of design as a human intentional activity that uses essentially human attributes along with intellectual and practical tools to solve problems that are not readily determinable in that situation. In this sense, Cross' perspective is a development of that expressed earlier by Thomas and Carroll (1979).

For a variety of reasons, many researchers followed the pattern of the 1960s and 1970s and did not define design or defined it in part. For example, Waldron (1989), using a critical methodology in a similar way to that proposed by Franz (1994), avoided defining design in his experimental investigation into how human designers interpret design specifications. Biggioggero and Rovida (1985) offered to describe a means of dealing with qualitative factors in mechanical design but did not do so, and in part this was due to an inadequate underlying definition of design. Eversheim, Abolins and Buchholz, (1985) changed the scope of their definition of design in mid-stream from meaning 'everything to do with designing' (when they speculated on their CAD system's potential) to 'design is drafting' when they reported what had actually been developed.

The foregoing presents the mainstream of definitions of design in the 1980s. In this period, however, a few researchers presented arguments that suggest that the mainstream was misdirected. In outline, these arguments are that it is inappropriate to define design in terms of objects, problems and processes, and that design can only be defined and researched in terms of its human situation. For example, Dilnot (1982) argued that the subject of research, i.e. designing, is lost to view and epistemologically neglected or excluded from the research investigation when design is defined in terms of information about a designed object, or a problem that is being solved, or a process of designing. For Dilnot, 'design is a social activity' and designing must be seen as a human activity that is essentially socially situated.. The structural conclusion implied by Dilnot's arguments is that the relationship between design and technology must be reversed, and that technology is a subset of design. That is, instead of viewing design as a technological activity, technology practice should be viewed as but one of the activities of designing. The substance of Dilnot's arguments are supported in parts by a variety of sources (see, for example, Abel 1981; Alexander 1980; Daley 1982; Holt, Radcliffe and Schoorl 1985; Jones 1984; Robinson 1986; Thomas and Carroll 1979). Jones (1984) suggested that design can be seen as an activity of designing 'without a product', and pointed to a post-positivist future for design research in which he sketched a definition of designing as a way of being. This definition includes and extends Dilnot's definition of design as a social activity because it is claiming that designing is an essential aspect of being human. The difference between the two positions is similar to that between defining an activity as (say) 'running', and defining an activity as 'movement'. 'Running' is a particular human activity that is happening or no,t and this parallels Dilnot's position. 'Movement', however, is something intrinsic to humans in that humans only stop moving when dead, and this parallels Jones perspective that designing is an undercurrent in all human action. Both point foreshadowed to the 1990s when, for example, Coyne and Snodgrass (1993) argued that Continental philosophy provides a better basis for design research and theory-making.

In summary, the 1980s continued the lack of attention of the 1970s and 1960s to the epistemological and conceptual foundations of design research. The term 'design' was explicitly and implicitly defined in many different ways. When it was defined, it was done opportunistically in the sense that researchers addressed the conceptual confusion by including in their work a definition of design that supported it. The systematic outlook on design remained strong and it is clear that much engineering design research was grounded in definitions of design that were based on engineering rather than human designing. A similar situation existed where design was viewed in terms of its management and its commercial context. The informatic perspective on design evolved in the 1980s to become the dominant view, yet the epistemological justification of this informatic outlook was contradicted in many cases by researchers simultaneously acknowledging that designing depended on humans or was a fundamentally human activity. This epistemological contradiction between definitions of design as a human activity and definitions of design based on other premises exists in most of the literature, and in most cases remained unresolved. The exceptions pointed to design being a fundamental aspect of social and individual human functioning, and consequently implied that research into design that is based on informatic premises or the details of the relationships between problems and solutions is more appropriately viewed as engineering or science research.

1.5 1990–1995: the computer in design, artificial intelligence in design, Total Design, Eco-Design, the philosophy of design

In the half decade between 1991 and 1995, the publishing of papers and books related to engineering design proceeded apace. In the first half of the 1990s much of the design research was developed with computerisation in mind, and this research direction was supported by extensive contributions from the areas of artificial intelligence and architecture (see for example, Adelman, Gualtieri and Riedel 1994; Adie 1994; Akin 1992; Akin and Lin 1995; Beñares-Alcántara 1991; Bullock, Denham, Parmee and Wade 1995; Brown and Hwang 1993; Chakrabarti and Bligh 1994; Chandrasekaran 1990; Coyne 1990b, 1991a; Coyne and Newton 1990; Coyne, Newton and Sudweeks 1993; Coyne, Rosenman, Radford, Balachandrian and Gero 1990; Coyne and Snodgrass 1993; Coyne and Yokozawa 1992; Cross 1991; Cross, Dorst and Roozenburg 1992; Dasgupta 1991, 1992; Dym 1994; Faltings 1991; Fenves and Grossman 1992; French 1990; Gero 1991; Gero and Maher 1993; Hertz 1992; Hillier and Penn 1994; Hills 1995; Hoover, Rinderle and Finger 1991; Hubka and Eder 1990; Konda, Monarch, Sargent and Subrahmanian 1992; Logan, Millington and Smithers 1991; Lowe 1994; Mitchell 1993; Mullins and Rinderle 1991; Oh, Langdon and Sharpe 1994; Otto and Antonsson 1994; Oxman 1990, 1995a; Purcell and Gero 1991; Quadrel, Woodbury, Fenves and Talukdar 1993; Reich 1992, 1995; Reich, Konda, Monarch, Levy and Subrahmanian 1996; Rinderle 1991; Sharpe 1995; Sharrock and Anderson 1994; Steinberg 1994; Suh 1990; Tomiyama 1994; Ullman 1993; Visser 1991, 1995, 1996; Wallace and Burgess 1995; Will 1991; Woodbury 1993; Wong and Shriram 1993; Zeng and Cheng 1991).

Few authors, however, included a description of the model of design or design process that they were using, and fewer still discussed why they chose to use a particular perspective on design or addressed the epistemological issues relating to their choice. The research trends of the 1980s and their underlying definitions of design continued into the 1990s, especially the view of design as problem-solving, although this view was often overlain with other design definitions, for example, by the view of design as searching in a solution space (Chandrasekaran 1990; Fenves and Grossman 1992).

In 1990, Suh published his axiomatic theory of design. In this theory he did not define design directly but much of the detail of his definition can be inferred from his proposals. In particular, he assumed that design was a matter of problem-solving. His definition is human based and reflexive because he claimed that 'design involves a continuous interplay between what we want to achieve and how we want to achieve it'. This human-centred reflexive view of design is, however, contradicted by the way that Suh describes his theory in terms of the information relating to the functional and physical domains of design problem and solution. For example,

> *The objective of design is always stated in the functional domain, whereas the physical solution is always generated in the physical domain . . . .These two domains are inherently independent of each other. What relates these two domains is the design.*

Suh's theory axiomatically relates the functional attributes of the design problem to a definition of the physical characteristics of an optimal design solution. In this sense, Suh's definition of design is informatically focused on the characteristics of the designed object and hence positivist. This points to a contradiction between the human-centred aspects of his definition of design activity and the positivist informatic outlook that underpins his axiomatic theory. Whilst Suh's axiomatic analyses were obviously carefully undertaken, his overall epistemology was marked by a lack of linguistic and conceptual clarity relating to the 'actors' or agents involved in designing. An example of this lack of clarity is his use of 'the design's objectives' to refer to the 'objectives of the designer' in order to attribute purpose to the axiomatic process.

Chandrasekaran's (1990) view of design as problem solving was based on research paradigms of neo-behaviourism and computerisation. From this perspective, Chandrasekaran saw design not as any type of problem solving, but as problem solving by searching in a 'solution space of sub assemblies' in which the design problem lies: formally, a search problem in a large space of objects that satisfy multiple constraints. Chandrasekaran's view of design equated creativity with synthesis which was viewed as 'assembling new artefacts from discrete preformed elements'. He used this definition of synthesis to introduce a new definition of design as 'doing tasks' which in turn provided the theoretical basis for the development of a computerised system design that was intended to automatically 'choose' which methods it would use to assist a designer. In this sense, Chandrasekaran's definition is positivist because it relies on all of the aspects of the design problem and its situation being defined informatically, and takes little account of the role of human values.

Zeng and Cheng (1991) also defined design as a problem-solving process, but with an emphasis on logic, or more specifically 'types of logic', in order to support the development of a computer based system concept of automatic design. They proposed a new type of logic, 'recursive logic', and claimed that this is the logic of design. Their view of 'design as recursive logic' was connected with the more general view of 'design as problem-solving' by arguing that problem-solving processes consist of the logic of the process and the knowledge based on that logic. By this means, they imply a model of creativity in designing that parallels the linguistic concept of a sentence (creative statement) that consists of 'verbs' (the logic of the process) and 'nouns' (the logic based knowledge). A similar outlook is found in linguistic and grammar-based syntactical definitions of design (see, for example, Alexander 1977; Lawson 1993; Mullins and Rinderle 1991; Rinderle 1991; Stiny 1980). Zeng and Cheng's definition of design as logic manipulation is at odds with definitions of design that relate to ill-structured or ill-defined problems, and in which it is assumed that designing involves elements that are unknown or unknowable. What Zeng and Cheng's proposals do, however, is make a short, direct connection between a particular, logically limited synthetic activity, whether seen as design or not, and a means of replicating or automating that activity using electronic logic.

Fenves and Grossman (1992) used an underlying definition of design as problem-solving to describe tertiary engineering courses in the synthesis aspect of design. In line with the preoccupation in the field for computer design assistance or computer automatisation of design, Fenves and Grossman viewed 'design problem-solving' as equivalent to 'searching in a solution space'. This perspective may account for their surprising suggestion that the two main methodologies of synthesis in design are mathematical programming and knowledge based expert systems. This suggestion is unusual in that there exists an extensive and readily available literature of methods pertaining to synthesis in design (see, for example,Andreasen 1985; Clausing and Ragsdell 1985; Jones 1970; Westerberg, Stephanopoulos and Shah 1974). Fenves and Grossman identified that one of the epistemological difficulties associated with defining design synthesis in terms of the above two methodologies is that many aspects of design information or knowledge are qualitative and the above two methods are unsuited to dealing with qualitative information, mainly because qualitative information cannot be adequately represented quantitatively in an information-processing perspective. This description of the situation is over simplified, however, because Fenves and Grossman used the term 'qualitative', in a similar manner to Faltings (1991), to refer to the application of a quantitatively defined label to a qualitative property. This does not accord with the commonly accepted interpretation of 'qualitative' as pertaining to qualities whose meanings depend on social, economic, cultural, ecological, legal, and historical context, and on continuously changing individual human values. Fenves and Grossman's underlying definition of design does not include these qualitative aspects of what it is to synthesise a design.

Ferguson (1992a) regarded 'engineering' as the same as 'engineering design', and focused on those aspects of design that were not adequately epistemologically addressed by Fenves and Grossman's perspective on design synthesis. As an historian, Ferguson (1992a) took a historical view in which engineering design is a culturally-placed problem-solving activity.

Like Bassalla (1988) and Thring and Laithwaite (1977), Ferguson grounded his argument on a long temporal view of design and technology rather than arguing axiomatically from principles and theory. This historical basis for developing engineering design theory has the advantage of helping researchers avoid the possibility of propagating misconceptions due to basing new theory on faulted old theory, and in addition it allows the possibility of identifying historical data that challenge existing theory. From Ferguson's perspective (expanded upon in Ferguson (1992b)), a designer invents by solving ill-defined problems in a contingent manner. Ferguson's definition of design moves the focus away from the analytical activity that features prominently in contemporary engineering courses and courses on engineering design such as that described by Fenves and Grossman (1991) towards a view of design that depends more on human intuition and valuing. The essence of Ferguson's definition of engineering design is human-centred , creative, intuitive, and based on a problem-solving metaphor in which problems are incompletely defined and are not expected to have a deterministic relationship to their solutions.

Visser (1995) also took an historical perspective on design, but focused on each individual designer's history and argued that designing is based on knowledge of prior solutions. This is an epistemologically more specific position than generalised assertions such as 'designing is based on knowledge', or 'designers use information'. The subtlety of Visser's argument is similar to Hamlyn's (1990) analysis of the inadequacies of information-processing theories of mind that attempt to explain the extraction from memory of elements that are 'something like' another element. Visser viewed design as problem-solving in a manner that was grounded in his earlier work on integrating research from behaviourally-based cognitive psychology, and the application of research outcomes and methods from the field of artificial intelligence to engineering design (Visser, 1991). His main proposal in 1995 was that designers re-use problem-solving elements drawn from episodes in their experience: hence, 'episodic' knowledge. Conceptually, this is similar to the research into cognitive re-use by Purcell and Gero (1996) concerning the role of fixation in how experts review prior information. Purcell and Gero's work broadly supports Visser and vice-versa. The definition of design that underlies Visser's analyses of the role of episodic knowledge is human-centred, yet he did not adequately address the role of human valuing, or ethical and aesthetic considerations in design cognition.

In addition to the problem-solving perspective on design, the first half of the 1990s was marked by contributions from the field of artificial intelligence and attempts to automate design through the use of computers. These contributions depended on design being viewed as the transformation of one type of information into another, and this informatic perspective led to designing being viewed as an ahuman process that did not include the qualitative aspects of human designing (see, for example, Quadrel et al 1993).

Many of these informatically-based contributions to design research were found in the usual design research publications, but others were disseminated via specialist channels such as the journal *AIEDAM* which publishes refereed papers relating to the application of artificial intelligence techniques and theories to engineering design and manufacturing. The first international conference on artificial intelligence in engineering design was held in Edinburgh, Scotland in 1991. In his preface to the forty seven papers in the proceedings, the editor, Gero (1991), suggested that a two-way flow of paradigm had occurred in which, on the one hand, the computational, symbolic paradigm had provided a basis for new models and processes which might be used in designing, and, on the other hand, the activity of designing had provided a new challenge for artificial intelligence researchers because of its nature as a complex activity that is essentially based on intelligence.

One example that fits the above genre closely is the work of Dasgupta (1991, 1992, 1994). Dasgupta's (1992) perspective on engineering design was tied to the cognitive science/behaviourist outlook developed in the field of artificial intelligence and design research by theorists such as Simon (1969) and Newall and Simon (1972). For Dasgupta:

- Design is one of the most ubiquitous human activities.
- Design is the means of creating the 'artificial'.

- Design is a cognitive process.
- Design has a significant domain-independent component.

In the above, Dasgupta's use of the term 'cognitive' was based on a central-processing model of computer architecture similar to, for example, its use by Newall (1990) and Simon (1982). This definition of 'cognitive' contrasts with human-centred definitions that include the specifically human aspects of thinking and knowing (see, for example Hamlyn 1990). Dasgupta argued for a new start in developing a science of design, and suggested two 'laws of design' as an initial basis for the development of epistemologically well-justified foundations for such a science (see also Dasgupta 1994). These proposals are grounded in Dasgupta's detailed development of the relationships between design theory and computer science in 1990. The explicit and implicit aspects of Dasgupta's position on design in these texts indicate an underlying positivist definition of design whose purpose is the computer-based automation of designing. This positivist definition of design assumes a behaviourist metaphor of design cognition which is intended to define determinable relationships between quantitative information about design problems and their solutions.

In 1995, Steinberg investigated research methodologies that were appropriate to both design research and artificial intelligence research. He emphasised decomposition and a structural analysis of his position indicates that he viewed research into design as similar to research into physics and mathematics. The main focus of his study was for the development of a complete prescriptive model of design process. For Steinberg, designing was a collection of tasks that can be defined in a scientific manner such that it is possible to choose from a range of well-established methods to complete them.

Yoshikawa (1981) proposed a theory of design which he referred to as 'General Design Theory' (GDT) that was founded on the 'design theory' that is a su-discipline of mathematics and which relates to group theory, graph theory, coding theory, geometry and statistics (Hughes and Piper, 1985). GDT was reviewed in detail by Reich (1995) with respect to epistemological and methodological issues. He suggested that GDT attempted to cast design in the framework of set theory, and argued that it did not live up to Yoshikawa's claims, especially that 'as a model of design it did not clarify the human ability to design'. Reich concluded that GDT provided a useful prescription for the development of CAD systems because it started with assumptions about the nature of objects and used them to prove theorems about the nature of design, but his analysis implied that it is not appropriate to use GDT for anything other than well-defined and well-structured routine problems. It may be of especial assistance in situations where routine problems become massively complex. Reich's review of GDT and his earlier discussion of design research methodologies in 1994 apply to many computational, knowledge, information or artificial intelligence based models of design. Implicit in Reich's analyses is not that these models of design are faulty per se, but that their claims of applicability and validity are too extensive.

Mullins and Rinderle (1991) proposed a grammatical representation of mechanical engineering design based on the work of Stiny (1980) which was supported and extended by Rinderle (1991). Their argument for defining engineering design in grammatical terms was:

- Design can be viewed as a transformation of functional requirements to a physical device. This claim is based on Mostow (1985), and Rinderle (1987) and is also found in Suh (1990).
- Formal grammars are also based on a transformational paradigm.
- Formal grammars are the basis for computer languages and therefore are an efficient means for the computerised representation and manipulation of design information.

Rinderle (1991) argued that the most appropriate set of formal grammars for this purpose are the attribute grammars. In theory, attribute grammars are useful for computerising a topic because they offer a way out of the semantic 'contextuality problems' associated with language because they allow contextual meaning to be attached to symbols in the grammar. It is not obvious, however, how this avoids the epistemological difficulties associated with the role of human values in the interpretation and construction of individuals' realities that is detailed in Chapter 3 of this thesis. The use of attribute grammars offers a means of controlling the computational demands of inferential processes associated with representing aspects of design, but they do this by what Logan, Millington and Smithers (1991) describe as being 'economical with truth'.

The use of attribute-based grammars of design also points to a subtle epistemological problem with respect to engineering design theory in that the contextual information fixed to grammatical symbols is also temporally fixed, whereas the contextuality of meaning in many aspects of design is more temporally fluid. An example of this in everyday language is the contextually-based nature of a phrase like 'Should I put the cat out?'. Obviously, the exact meaning attributed by my partner to this question of mine depends on a 'history' which gives it context and which may be seen as a contextual attribute. The meaning also depends on things which may change, such as what time it is, or how long the cat has been locked in the house, or what we are doing. Hence, it would seem that the attribute grammars are only appropriate to model design elements whose meaning is temporally unchanging with respect to context.

In 1992, Konda and his associates differentiated between 'engineering' and 'design', arguing that if something fails because it violates known engineering principles it is an *engineering* failure, but that it is a *design* failure if it fails for contextual reasons which lie outside engineering analysis, for example, due to economic, social, political, legal, ecological and firm-specific factors. Konda et al (1992) used this contextual perspective on design to propose a new unifying paradigm for engineering design research and theory-making that emphasised the role of the shared memories of different aspects of a design problem, its solution and its context. Konda et al argued that the role of shared memories is central to design theory because these shared memories provide the social and indiviual contexts of information and of designing itself. This shared memory model of engineering design and its associated contextual perspective are supported, superficially at least, by arguments relating to the importance of considering cognitive artefacts 'in context', that is, in interaction with the user, and the role of episodic knowledge in designing (Norman 1992; Visser 1995).

This social constructivist outlook on which Konda and associates have based their concept of shared memory is, however, insufficient to adequately address the epistemological issues relating to individual contexts and interpretations, and the role of context and interpretation in human cognition (Hamlyn 1990). Human memory consists of information that is interpreted and constructed on the basis of an individual's human values and ontological assumptions, and these ethical and aesthetic bases vary temporally depending on prior circumstances. That is, how an individual conceives and values a particular piece of information depends on what experiences and thoughts precede it. This means that adequately encapsulating the nuances of shared memory in theoretical or practical terms is dependent not only on placing designing in a socially constructed context but also on an adequate constructivist theory of how individuals interpret and utilise knowledge. These problems with the epistemology of individual memory and context are the same as those found in respect to Rinderle and Mullins' (1991) proposals for defining design in terms of formal grammars because they are both attempts to find a way of encoding context to enable contextual matters to be manipulated mechanically without addressing qualitative issues.

The definition of design that is implicit in the model of shared memory developed by Konda and associates has several dialectical contradictions; it is obviously human-centred , yet it is essentially informatic, because it is intended to be computerisable; it includes qualitative issues, yet it is intended to do so in a quantitative manner; it is based on social constructivism, a post-positive perspective, yet it includes aspects of individual cognition in a positivist manner.

Chakrabarti and Bligh (1994) focused on conceptual design and abstract functionality: a similar focus to French (1985, 1990) and Suh (1990). They saw conceptual design as,

> *The activity of transforming the functional requirements of a design into a solution concept or concepts for fulfilling requirements.*

From this perspective on conceptual design, it appears that all that is left is to add a few dimensions to the solution concept for it would to be ready for manufacture. Their use of ‘transform’ echoes the writings of researchers working within a computational, information-processing paradigm. This indicates that their underlying definition of design is positivist, informatic and deterministic.

The procedural view of engineering design described by Hubka and Eder (1992) was a natural extension of their theory of technical systems (Hubka and Eder, 1988). Their viewpoint on design is scientific and, as is perhaps inevitable with a procedural model, they focused on ‘process’ and ‘systems’. They emphasised that design is a ‘transformation process’ and formulated their subsequent theory from a perspective of information management.

In theory, it should not be possible to develop a theory of design without consideration of what design is. Bieniawski (1993), however, attempted this by building up a theory of design for excavation in geologic media on the paradigmic bases of the General Theory of Design of Yoshikawa (1981), the Theory of Technical Systems of Hubka (1987), and the Axiomatic Design theory of Suh (1990). His underlying perspective was a process-management view of design, that is, his model and axioms were guides for managing information for use by designers. Bieniawski’s design process was deterministic in direction and this results in his view of ‘synthesis’ being equivalent in his model to ‘the application of state-of-the-art heuristics’. The mathematical mechanistic outlook on design presented by him is, however, in conflict with his assertions about the ill-defined nature of many aspects of designing in geologic media.

In this period, human-centred perspectives on research into design provided some contrast to the widespread informatic perspective that was intended to automate designing. For example, Petroski (1992), as guest editor of *Research in Engineering Design*, defined engineering design in human terms and argued against those proposing theories of design which do not include some provision for a human aspect to designing. He maintained that:

> *Engineering design is an endeavour of, by, and for human beings. In both principle and practice it has incontrovertibly human characteristics . . . . no understanding of engineering design can be expected to be complete without an appreciation of its uniquely human dimensions and attributes . . .*

He further argued that there are many sides to the human aspect of designing engineering artefacts, and claimed that 'the contents of no single issue [of *Research in Engineering Design*] could in any way be expected to present a definitive array of topics covering the breadth and scope of the human context in which design takes place'. In essence, Petroski's view of design is that of a socially-situated activity that results in change. The engineering aspect of Petrofski's definition refers only to the domain in which designed artefacts would be classified or whose technical information is used by the designer.

Similarly, Piela, Katzenberg and McKelvey (1992) argued that, although it was not the norm in engineering design research, it was important to include human behaviour in explanations of design:

> *Engineering design research has historically been evaluated in terms of its computational performance. However, in many cases this research implies hypotheses about human behaviour are ignored.*

Piela, Katzenberg and McKelvey viewed design as a social process involving many participants, and argued that computer based systems that are built with the intention of supporting non-routine design would be improved by considering how people use designed artefacts and what the users could contribute to the design of those artefacts. The definition of design that underpins their approach to design research is essentially human-centred and participatory. It moves away from a view of designing as an activity undertaken only by specialised designers at the behest of sponsors and looks towards a theory of designing that includes users' information, knowledge and creativity.

In contrast to the social constructivism that underpins the definitions of design implicit in the work of Konda et al (1992) and Piela, Katzenberg and McKelvey (1992) , Schön (1992) focused on individual designers' internal cognitive landscapes and, in particular, how these cognitive activities and perceptions change and are changed as a result of experience. Schön's view of designing is as a human activity of learning and self education. That is, Schön explores how designers move from the unknown, the design situation, to the known, the design itself, as a process of individual research and learning. This view of design in educational terms points to the importance of the role of the immediate environment of the designer including the internal environment of the designer's mental content. Schön's analysis of design and his theoretical proposals are a part of a much broader research program on reflective professional action (see, for example, Schön 1974, 1983, 1987; Schön and Wiggins 1992). The definition of design, therefore that underlies Schön's (1992) analyses is of design as a learning activity that results from an individuals reflection on the outcomes of their design proposals. For Schön, the process of designing is via small steps that involve investigating, proposing solutions and reflecting on outcomes and the changes in knowledge about the design situation. Schön implied that phenomenology offered the most appropriate research methodology for investigating design as a reflective human activity. The view of designing as a reflective activity is also found in an earlier work of Cross (1983) that relates to explaining the differences in cognitive styles between expert and novice designers and the implications for the education of designers.

Love (1995a, 1995b), like Petroski and Schön, regarded designing as a contextually placed activity undertaken by humans with individually constructed and interpreted realities That is, design is a human, socially situated experience. He argued that the historical dependence of engineering design theory on systems theory has led to epistemological difficulties because the way that systems theories and the systems perspective has underpinned design theory does not adequately include many of the qualitative, subjective or contextual matters which are essential aspects of successful engineering design. Love drew attention to the fact that researchers in the area of systems are struggling with similar epistemological issues relating to making theory about human creative activities and cognition (see, for example, Flood 1990;

Flood and Jackson 1991). Love's underlying definition of design is human-centred, constructivist and domain-independent.

Design practice is the practical aspect of designing, and defines the overlap between design as an individual pursuit and design as a social phenomenon. Whitney (1990) brought attention to the praxeological nature of design, claiming that general or universal theories about designing will come out of research into design which focuses on practice. Whitney's position on defining design was pragmatic; that the term 'design' needs only to be defined well enough that design research can support designers by theory generation and practical aids. From this pragmatic perspective, he suggested two definitions of design. The first focuses on the individual designer and the second focuses on the social aspects of designing:

- Design is a technical process to be accomplished
- Design is an organisational process to be managed.

Whitney claimed that to develop practice-based unified theories of design it was also necessary to view design in the following ways:

- Design is the technical component of a product-realisation process.
- Design is the process of attaining wide latitude and narrow variance. Where 'latitude' is tolerance to departures from specification or envisaged use, and variance refers to the standard of performance of the product.
- Design is the process of recognising, consensualising and resolving conflict during creation of an entity that meets a set of goals.

Whitney's perspectives and definitions raise many issues and define several areas of research relating to design. The definitions themselves, however, have several internal contradictions. For example, by defining design as the technical component of the product-realisation process Whitney is implying that there are other components that are not design and his human-centred perspective suggests that it is the human aspects that are excluded. Yet, by defining design as a 'process of recognising, concensualising and resolving conflict', Whitney is including human aspects of designing. These epistemological difficulties are eased if Whitney's definitions are viewed as cumulative. That is, if Whitney's intention is to define design as all of the above, then he is free to add to the definition at anytime. In this case, it is necessary for Whitney to bound the scope of this accumulation of definition unless he intends it to be all encompassing, and furthermore it would be helpful to identify the research perspective that each definition is formulated within to avoid inconsistencies between them. In summary, Whitney suggested a variety of pragmatically useful definitions of design but in a manner which implied a lack of epistemological coherence between them.

Will (1991) gave an industrial perspective on product design. He did not define design or design process directly but placed them as phases within Hewlett-Packard's Phase Review Process. This is Hewlett-Packard's term for what is otherwise known as a product realisation process or product development process. How Will saw design must be inferred from the text, and his position appears to have internal contradictions. On one hand he had 'design is an intuitive art' as opposed to a science, but he also argued that the education of design-skilled engineering graduates depends on a science base for design. It appears that Will does not know exactly what design is, but when a Hewlett-Packard Phase Review Process has been implemented it will tell him whether the designing has been done successfully.

The overall position in the design research field as to whether design should be viewed as an activity that is independent of the domains in which it is undertaken is not yet clear. On one hand, design may be viewed as a generic activity which may be applied to any information or knowledge, but, on the other hand, it is clear that the practice of designing is different in each discipline and topic area, and it is in this latter sense that theories of design are domain dependent. The domain-dependent view of design dominates the literature of design research, but the human-centred view of designing points more towards the domain independent perspective. The main argument for the domain-dependent position is that the knowledge content of different domains has led to different theories of design being developed in those domains, and because the answer to the question 'What is Design?' is different in each domain (Lawson 1990, 1993, 1994; Sargent 1994). Lawson (1993) argued against domain independency in design theory because,

> *Design refers to an enormous range of activities from the highly constrained, numerical and well defined problems of say electronic engineering to the under constrained, nebulous and ill-defined problems in say fashion or textiles.*

The differing theories of design and domain-based models of design process are explainable, however, as a consequence of the different paradigms of research that are due to different domain cultures and technical knowledge. The argument for design to be viewed as a domain-dependent activity is also undermined by Dilnot's (1982) conclusion that using information about the design problem and its solution as the basis for design research results in design theory that does not epistemologically include many fundamental aspects of designing. If design information is viewed as the material on which designing acts, a position that accords with both informatic and human-centred perspectives on design, then epistemologically, the role of domain-based information is no longer fundamental to defining design. Together, these imply that, in the interests of epistemological coherency, it may be better for the field to move towards viewing design as domain-independent activity.

In 1991 Pugh published the details of an all-encompassing engineering design paradigm, theory and methodology which he called 'Total Design'. In the short period since its inception, Total Design has become one of the best accepted contemporary methods in product design, by both researchers and practitioners (Hollins, 1994). Pugh proposed Total Design as a process which contains all the factors contributing to the development of a product from conceptual 'cradle' to physical 'grave'. He contrasted 'Total Design' with 'partial design' where 'partial design' was seen as any designing which is undertaken from a specialist or narrow viewpoint. Pugh concludes that this 'partiality' leads to design decisions being made which are not the best when seen from a wider perspective. From this position, he argued against engineering attitudes dominating product development, and suggested that 'misdirected engineering rigour will always give rise to bad total design'.

Pugh's conception is based on a systems outlook and geared to a commercial value base. He defined Total Design as,

> *The systematic activity necessary, from the identification of the market/user need, to the selling of the successful product to satisfy that need - an activity that encompasses product, process, people and organisation.*

One of the most distinctive features of the Total Design model is its 3-D pictorial representation which Pugh uses and which is echoed at different levels of detail and abstraction to fill out the Total Design concept. In conceptual terms, Total Design has a core consisting of its main elements in Pugh's words:

> *Total Design may be construed as having a central core of activities . . . . this core, the design core, consists of market (user need), product design specification, conceptual design, detail design, manufacture and sales.*

Thus, the Total Design core includes the epistemologically different entities of 'needs' (information), product design specification (information), conceptual design (internal activity), detail design (internal activity), manufacture (external activity), sales (internal and external activities).

Total Design is based on the concept of satisfying needs—which may exist independently of the product or be generated by the product because Pugh maintains that, 'All design starts, or should start, with a need that, when satisfied, will fit into an existing market or create a market of its own'. Total design does not take engineering design theory into new country. It has a theoretical base in the systematic design theories of the 1960s and 1970s, and some German theorists might argue that it goes back further. What Pugh and his associates did, however, was to combine into one coherent system different aspects of design theories and methods together with well-established methods from other disciplines. More than that, Pugh demonstrated the worth of the system in practical, non-trivial commercial design situations.

Two other themes in the 1990s have been an increased focus on including environmental issues into design, and a renewed interest in the epistemology of design theory. The focus on environmental aspects of designing is a consequence of public pressure for technology to have less harmful environmental effects. The level of publication relating specifically to the inclusion of environmental issues in design research is low but increased awareness of environmental considerations in designing is evident in many texts (see, for example, Beder 1990; Engineering Council 1993; Goggin 1994; Hillier and Penn 1994; I.E. Aust. 1992; Somers 1992; Woolley 1992). Research into the design aspects of environmentally conscious manufacture is also found in many small European research groups, such as those individual researchers affiliated to the ongoing ECO2-IRN electronic conference organised from the CAE Centre at Cranfield in the UK.

The interest in epistemological aspects of design theory is evident in the increase in publications relating to research methodology and research perspectives in design (see, for example, Coyne 1991b; Coyne and Newton 1992; Coyne and Snodgrass 1992a, 1992b; Dorst and Dijkhuis 1995; Franz 1994; Reich 1992, 1994a, 1994b, 1995). The renewed interest in epistemological issues is also found in the increase in papers concerning structural issues in design theory such as design taxonomies (see, for example, Hubka and Eder 1990; Konda et al 1992; Ullman 1992).

Ullman (1992) argued that design has different meanings to different theorists, and advanced a comprehensive taxonomy for classifying different methods and theories of mechanical engineering design. Although Ullman did not make it explicit, he used an 'artefactual' paradigm of design theory-making to develop his taxonomy. This may be seen, on one hand, by the fact that the most detailed and comprehensive levels of his taxonomy are dedicated to artefact definition, and, on the other hand, by the attention he gives to,

- The environment that the *artefact* is designed in.
- The problem that the *artefact* is a solution for.
- The process which leads to that *artefact.*

This artefactual focus contrasts with, for example, Schön's emphasis on the phenomenon of designing, or Petroski's focus on design as human endeavour, or Zeng and Cheng's logic-based view of design. Since taxonomies of design theory could be developed from each of these perspectives, it would be expected that each of these other taxonomies would have differences in category types and taxonometric structure from that of Ullman.

Together, these interests in the structure and dynamic of design theory, and in methodological issues of design research suggest that a 'Philosophy of Design' is being established.

1.6 Summary

By 1995, the focus of design research had changed from improving 'traditional designing' via systematic design methods to automated designing with computer assistance transforming information about the design problem into a detailed specification of a physical solution. The balance and volume of the literature associated with research into design reflects the magnitude of this change in research direction. The recent focus on computer assistance has led to a change in the privilege and dominance of the different metaphors used in design theory, and in the mid 1990s the predominant theoretical metaphor of engineering design has become the concept of 'design as information processing'.

Some of the main characteristics of the definitions of design that have been used explicitly and implicitly in the texts analysed in this review are listed below:

- That designing is a process.
- That designing involves transforming or processing information.
- That design is a human activity.
- That designing involves creativity and synthesis.
- That designing is similar to problem-solving, managing, learning and planning.
- That designing is a scientific rational process.

There are many other definitions of design in the reviewed literature, relating to, for example, futurism, working with uncertainty, integration and construction. None of the definitions of design is adequately justified in epistemological terms. In most cases, different aspects of theory and definition in the same text are epistemologically contradictory or are not epistemologically justifiable.

In summary, the literature of design research of the period 1962–1995 that was reviewed in this appendix contains a variety of conflicting definitions of design most of which are poorly justified and inappropriately used.

2. References

Abel, C. 1979, 'Rationality and meaning in design', *Design Studies,* vol. 1, no. 2, pp. 69–76.

Abel, C. 1981, 'Function of tacit knowing in learning to design', *Design Studies,* vol. 2, no. 4, pp. 209–214.

Adelman, L., Gualtieri, J. and Riedel, S. L. 1994, 'A multifaceted approach to evaluating expert systems', *Artificial Intelligence for Engineering Design, Analysis and Manufacturing,* vol. 8, pp. 289–306.

Adie, J. F. 1994, 'Optimising the design process', *Professional Engineering,* vol. 7, no. 3, pp. 11,12.

AIDAM, Artificial intelligence in engineering design and manufacturing.

Akin, O. 1979, 'Exploration of the Design Process', *Design Methods and Theories,* vol. 13, nos. 3/4, pp. 115–119.

Akin, O. 1992, 'A Structure and Function Based Theory for Design Reasoning' in *Research in design thinking,* eds. N. Cross, K. Dorst and N. Roosenburg, Delft University Press, The Netherlands, pp. 37—60.

Akin, Ö. and Akin, C. 1996, 'Frames of reference in architectural design: analysing the hyper acclamation (A-h-a!)', *Design Studies,* vol. 17, no. 4, pp. 34–362.

Akin, O. and Lin, C. 1995, 'Design protocol data and novel design decisions', *Design Studies,* vol. 16, no. 2, pp. 211–236.

Alexander et al. 1977, *A Pattern Language,* Oxford University Press, New York.

Alexander, C. 1963, 'The Determination of Components in an Indian Village', in *Conference on design methods,* eds J. C. Jones and D. G. Thornley, Macmillan, New York, pp. 83–114.

Alexander, C. 1964, *Notes on the Synthesis of Form,* Harvard University Press, Mass.

Alexander, C. 1979, *The Timeless Way of Building,* Oxford University Press, New York.

Alexander, C. 1980, 'Value', *Design Studies,* vol. 1, no. 5, pp. 295–298.

Alexander, C. 1984, 'The State of the Art in Design Methods', in *Developments in Design Methodology,* ed N. Cross, John Wiley and Sons, London, pp. 309–316.

Allison, B . 1995, *ARIAD Research Supervisors and Examiners*, ARIAD Associates, Leicester, UK.

Allison, B . 1996a, *Re: ARIAD,* [on-line]Available WWW: http://www.mailbase.ac.uk/lists-a-e/design-research.

Allison, B . 1996b, *Allison Research Index of Art and Design,* 2nd edn, CD-ROM with supporting documentation, ARIAD Associates, Leicester.

Altman, S.M. 1974, 'How long can we go on this way', in *Basic Questions in Design Theory,* ed W. R. Spillers, North-Holland Publishing Company, Amsterdam, pp. 455–460.

Altshuller, G. S. 1984, *Creativity as an Exact Science,* Gordon and Breach Science Publishers, London.

Amabile, T. M. c1983, *The Social Psychology of Creativity* Springer-Verlag, New York.

Andreasen, M. M. 1985, 'The Use of Systematic Design in Practice', in *International Symposium on Design and Synthesis,* ed H. Yoshikawa, Elsevier Science Publishers B. V., Amsterdam, pp. 139–144.

Archer, L. B. 1965, *Systematic Methods for Designers,* Design Council, London.

Archer, L. B. 1968, *Structure of Design Processes,* Royal College of Art, London.

Archer, L. B. 1979, 'Design as a discipline', *Design Studies,* vol. 1, no. 1, pp. 17–20.

Archer, L. B. 1984, 'Whatever Became of Design Methodology' in *Developments in Design Methodology,* ed. N. Cross, John Wiley and Sons, Chichester, UK, pp. 347–350.

Argyris, C. 1980, *Inner Contradictions of Rigorous Research,* Academic Press, New York.

Arora, J. S. 1989, *Introduction to Optimum Design,* McGraw-Hill Inc., USA.

Asimow, M. 1962, *Introduction to Design,* Prentice-Hall, New York.

Baljon, C. J. 1997, 'Design justification as an instance of modal logic, or of rhetoric', *Design Studies,* vol. 18, no. 1, pp. 125–126.

Bañares-Alcántara, R. 1991, Representing the engineering design process: two hypothese' in *Artificial intelligence in design '91,* ed. G. Gero, Butterworth Heinmann, Oxford, pp. 3–22.

Basalla, G. 1988, *The Evolution of Technology,* Cambridge University Press, Cambridge, UK.

Bastick, T. 1982, *Intuition: How we think and act,* John Wiley and Sons, England.

Bazjanac, V. 1974, 'Architectural Design Theory: models of the design process', in *Basic Questions of Design Theory,* ed W. R. Spillers, North-Holland Publishing Company, Amsterdam, pp. 3–20.

Beder, S. 1989a, 'Towards a more representative engineering education', *World Conference on engineering education for advancing technology: Sydney 13-17 February 1989: pre-prints of papers,* Vol. *1,* IEAust, Barton, pp. 43-47.

Beder, S. 1989b, *From pipedreams to tunnel vision: engineers decision-making and Sydney sewerage systems,* Unpublished doctoral dissertation, University of New South Wales, Australia.

Beder, S. 1990, Environmental Impact Statements: The Ethical Dilemma for Engineers, Proceedings of the 1991 National Engineering Conference, Canberra.

Beder, S. 1993a, 'Making Engineering Design Sustainable', *Transactions of the Institution of Engineers, Australia; Multi-Disciplinary Engineering,* vol. GE17, no. 1, paper G92303, June, IEAust, Barton, pp. 31–35.

Beder, S. 1993b, Pipelines and Paradigms, *Transactions of the Institution of Engineers, Australia; Multi-Disciplinary Engineering,* vol. CE35, no. 1, paper G92036, March, IEAust, Barton, pp. 79–85.

Beitz, W. 1989, 'Strategies for planning and developing innovative market orientated products', in *International Conference on Engineering Design (Vol. 1) at Harrogate, UK: proceedings of the I.Mech.E.,* Mechanical Engineering Publications Ltd., Bury St Edmunds, UK, pp. 211–228.

Bellini, J. 1987, *High Tech Holocaust,* Greenhouse Publications, Victoria, Australia.

Benn, T. 1974, 'Technology Assessment and Political Power' in *Man-Made Futures: Readings in Society, Technology and Design*, eds. N. Cross, D. Elliott and R. Roy, Hutchinson and Co. Ltd., London, pp. 157–163.

Berger, P. and Luckmann, T. 1987, *The Social Construction of Reality: A Treatise in the Sociology of Knowledge*, Penguin, Harmondsworth.

Berger, P. L. 1980, *Invitation to Sociology,* Penguin Books, England.

Bieniawski, Z. T. 1993, 'Principles and Methodology of Design for Excavations in Geologic Media', *Research in Engineering Design,* vol. 5, pp. 49–58.

Biggioggero, G. F. and Rovida, E. 1985, 'Proposal for Methodic Design in the Mechanical Field', in *International Symposium on Design and Synthesis,* ed

H. Yoshikawa, Elsevier Science Publishers B. V., Amsterdam, pp. 175–179.

Bjelland, H. 1990, *Writing Better Technical Articles,* Tab Books Blue ridge Summit, PA.

Booker, P. J. 1962, *Principles and precedents in Engineering Design,* Institution of Engineering Designers, London.

Bowers, J. M. 1991, 'The Janus Faces of Design: Some Critical Questions for CSCW' in *Studies in Computer Supported Cooperative Work*, J. M. Bowers and S. D. Benford (eds), Elsevier Science Publishers B.V., North Holland, pp. 333–351.

Brennan, A. 1993, *Personal communication*, Dept of Philosophy, University of Western Australia.

Broadbent, G. 1973, *Design in Architecture,* Wiley, London.

Broadbent, G. 1984, 'Design and Theory Building' in *Developments in Design Methodology*, ed. N Cross, John Wiley, UK, pp. 337–346.

Broadbent, G. H. 1966, 'Creativity', in *The Design Method,* ed S. A. Gregory, Butterworths, London, pp. 111–119.

Broadbent, J. A. 1992, 'Integrated Design and Its Implication for Design Education', *EcoDesign 1 Conference - Sustainability Through Design: Melbourne, conference proceedings,* eds. T. Riley and J. Gertsakis, Centre for Design at RMIT, Melbourne, pp. 66–77.

Brotchie, J. F. and Sharpe, R. 1974, 'Urban Design', in *Basic Questions of Design Theory,* ed W. R. Spillers, North-Holland Publishing Company, Amsterdam, pp. 461–474.

Brown, D. R. and Hwang, K. 1993, 'Solving Fixed Configuration Problems with Genetic Search', *Artificial Intelligence in Engineering Design and Manufacturing,* vol. 5, pp. 80–87.

Bucciarelli, L. L. 1984, 'Reflective practice in engineering design', *Design Studies,* vol. 5, no. 3, pp. 185–190.

Buchanan, R. 1990, 'Myth and maturity: towards a new order in the decade of design', *Design Studies,* vol. 11, no. 4, pp. 195–201.

Budgen, D. 1995, '"Design Models" from software design methods', *Design Studies,* vol. 16, no. 3, pp. 293–328.

Bullock, G. N., Denham, M. J., Parmee, I. C. and Wade, J. G. 1995, 'Developments in the use of the genetic algorithm in engineering design', *Design Research,* vol. 16, no. 4, pp. 507–524

Bunge, M. 1989, 'Development and the Environment' in *Technological Transformation: Contextual and Conceptual Implications*, eds. E. F. Byrne and J. C. Pitt, Kluwer Academic Publishers, Dordrecht, pp. 285–304.

Buzan, T. 1989, *Use your Head,* BBC Books, London.

Byrne, E. F. 1989, 'Globalisation and Community: In Search of Transnational Justice' in *Technological Transformation: Conceptual and Contextual Implications*, eds. E. F. Byrne and J. C. Pitt, Kluwer Academic, Dordrecht, pp. 141–162.

Caldwell, L. K., Hayes, L. B. and Macwhirter, I. M. 1976, *Citizens and the Environment,*Indiana University Press, Bloomington.

Cambridge Dictionary of Philosophy 1995, general ed. R. Audi, Cambridge University Press, Cambridge.

Canter, L. W. 1996, *Environmental Impact Assessment*, 2nd edn., McGraw-Hill, New York.

Carpenter, S. R. 1989, 'What Technologies Transfer: The Contingent Nature of Cultural Response' in *Technological Transformation: contextual and conceptual implications*, eds. E. F. Byrne and J. C. Pitt, Kluwer Academic Publishers, Dordrecht, pp. 163–178.

Chakrabarti, A. and Bligh, T. P. 1994, 'An Approach to Functional Synthesis of Solutions in Mechanical Conceptual Design. Part 1: Introduction and Knowledge Representation', *Research in Engineering Design,* vol. 6, pp. 127-141.

Chandrasekaran, B. 1990, 'Design Problem Solving: A Task Analysis', *AI Magazine,* pp. 59–71.

Chick, A. 1997, 'Insights into the practice of Ecodesign', *EcoDesign,* vol. 1, no. 1, pp, 6, 7.

Christians, C. 1989, A Theory of Normative Technology, E. F. Byrne and J. C. Pitt (eds.), *Technological Transformation,* Kluwer Academic Publishers, Dordrecht, pp. 123–140.

Clausing, D. P. and Ragsdell, K. M. 1985, 'The Efficient Design of Medium and Light Machinery Employing State-of-the-Art Technology', in *Design and Synthesis,* ed H. Yoshikawa, Elsevier Science Publishers B.V., Amsterdam, pp. 203–210.

Colajinni, B., de Grassi, M., di Manzo, M. and Naticchia, B. 1991, 'Can planning be a research paradigm in architectural design?' in *Artificial intelligence in design '91*, ed. J. S. Gero, Butterworth Heinmann, Oxford, pp. 23–48.

Coplin, J. F. 1989, 'Engineering Design - a powerful influence on the business success of manufacturing industry', in *International Conference on Engineering Designat Harrogate, UK: proceedings of the I.Mech.E.,*vol. 1, Mechanical Engineering Publications Ltd., Bury St Edmunds, UK, pp. 1–32.

Corrigan, J. and Morris, J. M. 1989, *Introduction to Optimum Design,* McGraw-Hill, Inc., USA.

Court, A. 1995, *The modelling and classification of information for engineering designers,* PhD thesis, University of Bath, June 1995, [on-line], http://www.bath,ac,uk/~ensawc/home.html.

Court, A., Culley, S. J. and McMahon, C. A. 1993, 'A survey of information access and storage among engineeringdesigners', *Materials and Design,* vol. 14, no. 5, pp. 275–278.

Coyne, R. 1997, 'Creativity as commonplace', *Design Studies*, vol. 18, no. 2, pp. 135–141.

Coyne, R. D. 1990a, 'Design Reasoning without explanations', *AI Magazine,* vol. 11, no. 4, pp. 72–80.

Coyne, R. D. 1990b, 'The impact of Computer use on Design Practice', *Working Paper,* Design Computing Unit, University of Sydney, NSW.

Coyne, R. D. 1990c, 'Learning without explanations: Design Education and Models of Cognition', *Working Paper,* Design Computing Unit, University of Sydney, Australia.

Coyne, R. D. 1991a, 'Modelling the emergence of design descriptions across schemata', *Environment and Planning B: Planning and Design,* vol. 18, pp. 427–458.

Coyne, R. D. 1991b, 'Objectivity in the design process', *Environment and Planning B: Planning and Design,* vol. 18, pp. 361–371.

Coyne, R. D. 1992, 'The role of metaphor in understanding computers in design', *Working Paper,* Design Computing Unit, University of Sydney, Australia.

Coyne, R. D. and Newton, S. 1990, 'Design reasoning by association', *Environment and Planning B: Planning and Design,* vol. 17, pp. 39–56.

Coyne, R. D. and Newton, S. 1992, 'Metaphors, Computers and Architectural Education', *Working Paper,* Dept. of Architectural and Design Science, University of Sydney, NSW.

Coyne, R. D. and Yokozawa, M. 1992, 'Computer assistance in designing from precedent', *Environment and Planning B: Planning and Design*, 1992, vol. 19, pp. 143–171.

Coyne, R. D. and Yokozawa, M. 1992, Computer assistance in designing from precedent', *Environment and Planning B: Planning and Design,* vol. 19, pp. 143–171.

Coyne, R. D., Newton, S. and Sudweeks, F. 1993, 'A connectionist view of creative design reasoning' in *Modelling Creativity and Knowledge Based Design,* eds. J. S. Gero and M. L. Maher, Lawrence Erlbaum Associates Inc., New Jersey, pp. 177–210.

Coyne, R. D., Rosenman, M. A., Radford, Balachandran, M. and Gero, J. 1990, *Knowledge based design systems*, Addison-Wesley Publishing Company, Reading, MA.

Coyne, R., Snodgrass, A. and Martin, D. 1992, 'Metaphors in the Design Studio', *Working Paper,* Faculty of Architecture, University of Sydney, Sydney.

Coyne, R.D. and Snodgrass, A. 1991, 'Is designing mysterious? Challenging the dual knowledge thesis', *Design Studies*, vol. 12, no. 3, pp. 124–131.

Coyne, R.D. and Snodgrass, A. 1992a, 'Problem Setting within Prevalent Metaphors of Design' *Working Paper*, Department of Architecture and Design Science, University of Sydney, NSW.

Coyne, R.D. and Snodgrass, A. 1992b, 'Cooperation and Individualism in Design', *Environment and Planning B: Planning and Design*, vol. 18.

Coyne, R.D. and Snodgrass, A. 1993, 'Rescuing CAD from Rationalism', *Design Studies,* vol. 14, no. 2, pp. 100–123.

Crane, J.A. 1989, 'The problem of valuation in risk-cost-benefit assessment of public policies' in *Technological Transformation: contextual and conceptual implications*, eds. E. F. Byrne and J. C. Pitt, Kluwer Academic Publishers, Dordrecht, pp. 67–79.

Croce, B. 1959, *Æsthetic: as science of expression and general linguistic,* trans. D Ainslie, Vision Press Peter Owen, London.

Cross, A. 1984d, 'Towards an understanding of the intrinsic values of design education', *Design Studies,* vol. 5, no. 1, pp. 31-39.

Cross, N. (ed) 1984, *Developments in Design Methodology,* John Wiley and Sons Ltd., Chichester.

Cross, N. (ed.) 1984d, *Developments in Design Methodology*, John Wiley and Sons Ltd, Chichester, UK.

Cross, N. 1983, 'The Relevance of Cognitive Styles in Design Education',*Design Methods and Theories,* vol. 17, no. 1, pp. 37–50.

Cross, N. 1984a, 'Introduction' in *Developments in Design Methodology*, ed. N. Cross, John Wiley and Sons Ltd, Chichester, pp. vii–x.

Cross, N. 1984b, 'The History of Design Methodology' in *Developments in Design Nethodology,* ed. N. Cross, John Wiley and Sons, London.

Cross, N. 1984c, 'Introduction to Part Four. The Philosophy of Design Method' in *Developments in Design Methodology*, ed N. Cross, John Wiley and Sons Ltd, Chichester, pp. 237–244.

Cross, N. 1989, *Engineering Design Methods,* John Wiley and Sons Ltd., Chichester.

Cross, N. 1990, 'The nature and nurture of design ability', *Design Studies,* vol. 11, no. 3, pp. 127–140.

Cross, N. 1991, 'Research in design thinking' in *Research in Design Thinking,* eds. N. Cross, K. Dorst and N. Roozenburg, Delft University Press, The Netherlands, pp. 3—10.

Cross, N. 1993, 'Science and Design Methodology: A Review', *Research in Engineering Design,* vol. 5, pp. 63–69.

Cross, N. 1995, 'Editorial', *Design Studies,* vol. 16, no. 1, pp. 2–3.

Cross, N. 1996, 'Editorial', *Design Studies,* vol. 17, no. 1, pp. 1–3.

Cross, N. 1997, 'Editorial' *Design Studies,* vol. 18, no. 1, pp. 1–4.

Cross, N. and Cross, A. C. 1995, 'Observations of teamwork and social processes in design', *Design Studies,* vol. 16, no. 2, pp. 143—170.

Cross, N., Cross, A. and Glynn, S. 1986, *Designerly Ways of Knowing: A clarification of some epistemological bases of design knowledge* , Report for ESRC-SERC joint committee, Open University, Milton Keynes.

Cross, N., Dorst, K. and Roozenburg, N. (eds) 1992, *Research in Design Thinking,* Delft University Press, Delft, Netherlands.

Cross, N., Naughton, J. and Walker, D. 1981, 'Design method and scientific method', *Design Studies,* vol. 2, no. 4, pp. 195–201.

Culley, S., McMahon, C. and Court, A. 1995, *Research into the information acess methods and requirements of engineering designers,* University of Bath, England, [on-line] http://www.bath.ac.uk/~ensawc/inforeqts.html

Daley, J. 1982, 'Design Creativity and the understanding of objects', *Design Studies,* vol. 3, no. 3, pp. 133–137.

Dasgupta, S. 1991, *Design Theory and Computer Science,* Cambridge University Press, Cambridge, UK.

Dasgupta, S. 1992, 'Two Laws of Design', *Intelligent Systems Engineering,* winter, pp. 146–156.

Dasgupta, S. 1994, 'Testing the Hypothesis Law of Design', *Research in Engineering Design,* vol. 6, pp. 38–57.

Davies, P. 1995, Effects of concurrent verbalisation on design problem solving, *Design Studies,* vol. 16, no. 1, pp. 102–116.

Davies, R. and Talbot, R. J. 1987, 'Experiencing ideas: identity, insight and the imago', *Design Studies,* vol. 8, no. 1, pp. 17–25.

de Bont, C., Schoormans, J. and Wessel, M. 1991, Consumer personality and the acceptance of product design', *Design Studies,* vol. 13, no. 2, pp. 200—208.

Degree of Doctor of Philosophy Handbook, 1993, University of Western Australia, Perth.

Design Research Newsletter, ed. S. Little, Design Research Society, UK.

Design Studies 1996a, vol. 17, no. 1, Elsevier Science in cooperation with the Design Research Society, Oxford, UK.

Design Studies 1996b, vol. 17, no. 3, Elsevier Science in cooperation with the Design Research Society, Oxford, UK, front inside cover.

DesignWeb Researchers' Database 1997 [on-line], available WWW: http://www.bath.ac.uk/Departments/Eng/design/dweb/offer/resint_form.html.

Dewey, J. 1959, *Art and experience,* Capricorn Books.

Dewey, J. c 1933, *How we think: a restatement of the relation of reflective thinking to the educative process*, D. C. Heath and Company, New York.

Dias, W. P. S. and Blockley, D. I. 1994, 'The integration of product and process models of design', *Design Studies,* vol. 15, no. 4, pp. 417–432.

Dieter, G. E. 1983, *Engineering Design: a materials and processing approach,* McGraw-Hill Inc., USA.

Dilnot, C. 1982, Design as a socially significant activity: an introduction', *Design Studies,* vol. 3, no. 3, pp. 139–146.

Director, S. W. 1974, 'Towards Automated Design of Integrated Circuits' in *Basic Questions of Design Theory,* ed. W. R. Spillers, North-Holland Publishing Company, Amsterdam, pp. 303–324.

Dittmayer, S. and Sata, T. 1985, 'Systematic Product Development', in *International Symposium on Design and Synthesis,* ed H. Yoshikawa, Elsevier Science Publishers B. V., Amsterdam, pp. 197–202.

Dixon, J. R. 1987, 'On research methodology towards a scientific theory of design', *Artificial Intelligence in Engineering Design Analysis and Manufacturing,* vol. 1, no. 3, pp. 145—157.

Dixon, J. R. 1989, 'On a research methodology towards a scientific theory of design' in *Design Theory '88*, eds. S. L. Newsome, W. R. Spillers and S. Finger, Springer-Verlag, Berlin.

Dorst, K. 1995, 'Analysing Design Activity: new directions in protocol analysis' in *Design Studies*, vol. 16, no. 2., pp. 139–142.

Dorst, K. and Dijkhuis, J. 1995, 'Comparing paradigms for describing design activity', *Design Studies*, vol. 16, no. 2, pp. 261–274.

DRS_News, ed. D. Durling, Design Research Society, UK.

Duggan, T. V. 1970, *Applied Engineering Design and Analysis,* Iliffe Books, London.

Durling, D. (ed) 1996a, *DRS_NEWS,* vol. 1, no. 5, [on-line], Available WWW: http://www.mailbase.ac.uk/lists-a-e/design-research

Durling, D. (ed) 1996b, *DRS_News,* vol. 1, no. 1, [on-line], Available WWW: http://www.mailbase.ac.uk/lists-a-e/dsign-research

Dym, C. L. (1994), *Engineering Design: A Synthesis of Views,* Cambridge University Press, Cambridge.

Eastman, C. M. 1981, 'Recent Developments in representation in the science of design', *Design Studies,* pp. 45—52.

Eder, W. E. 1966, 'Definitions and Methodologies', in *The Design Method,* ed S. A. Gregory, Butterworths, London, pp. 19–31.

Eder, W. E. 1981, 'Report on workshop W3', in *Schriftenreihe WDK 7 Results of ICED 81 (Rome),* eds. V. Hubka and W. E. Eder, Heurista, Zurich.

Eder, W. E. 1989, 'Information systems for designers', in *International Conference on Engineering Design, 1989: proceedings of the I.Mech.E., Harrogate, UK,*, vol. 2, Mechanical Engineering Publications Ltd., Bury St Edmunds, UK, pp. 1307–1320.

Eder, W. E. 1995, Viewpoint: Engineering Design - art, science and relationships, *Design Studies,* vol. 16, no. 1, pp. 117–127.

Editorial 1979, *Design Studies,* vol. 1, no. 1.

Ehrlenspiel, K. and Dylla, N. 1989, 'Experimental investigation of the design process', in *International Conference on Engineering Design, 1989: proceedings of the Institution of Mechanical Engineers,* vol. 1, Mechanical Engineering Publications Ltd., Bury St. Edmunds, UK, pp. 77–96.

Ellis, K. 1995, 'The Association of Systems Thinking with the Practice of Management' in *Systems for the Future: Proceedings of the Australian Systems Conference, Perth, Western Australia, 1995*, Edith Cowan University, Perth, pp. 17–22.

Enc, B. and Adams, F. 1992, 'Functions and Goal Directedness', *Philosophy of Science*, vol. 59, pp. 635–654.

Engineering Council 1993, *Engineers and the Environment: Code of Professional Practice,* The Engineering Council, London.

Ennis Jr., C. W. and Gyezly, S. W. 1991, 'Protocol Analysis of the Engineering Systems Design Process', *Research in Engineering Design*, vol. 3, pp. 15-22.

Eno, B. 1996, 'How art frames our world', *Daily Telegraph,* June 22, 1996, p. A5.

Ertas, A. and Jones, J. C. 1993, *The Engineering Design Process,* John Wiley and Sons Inc, New York.

Esherick, J. 1963, 'Problems of the Design of a Design System', in *Conference on design methods,* eds J. C. Jones and D. G. Thornley, Macmillan, New York, pp. 75–81.

Eversheim, W., Abolins, G. and Buchholz, G. 1985, 'DESIGN SYSTEM - Integration of Design Tasks by EDP', in *International Symposium on Design and Synthesis,* ed H. Yoshikawa, Elsevier Science Publishers B. V., Amsterdam.

Faltings, B. 1991, 'Qualitative models in conceptual design: a case study', in *Artificial Intelligence in Design '91,* ed J. S. Gero, Butterworth-Heinmann, Oxford, pp. 645–663.

Fenves, S. J. and Grossman, I. E. 1992, 'An Interdisciplinary Course in Engineering Synthesis', *Research in Engineering Design,* vol. 3, pp. 223–231.

Ferguson, E. S. 1992a, 'Designing the World We Live In', *Research in Engineering Design,* vol. 4, pp. 3–11.

Ferguson, E. S. 1992b, *Engineering and the Mind's Eye,* MIT Press, Cambridge, MA.

Feyerabend, P. 1975, *Against Method,* New Left Books, London.

Finger, S. 1991, 'Editorial', *Research in Engineering Design,* vol. 1, no. 1.

Flood, R. 1995, 'Solving Problem Solving: TSI - A new problem solving system for Management' in *Systems for the Future: Proceedings of the Australian Systems Conference, Perth, Western Australia, 1995*, Edith Cowan University, Perth, pp. 1–16.

Flood, R. L. 1990, *Liberating Systems Theory,* Plenum Press, New York.

Flood, R. L. and Carson, E. R. 1988, *Dealing with Complexity,* Plenum Press, New York.

Flood, R. L. and Jackson, M. C. 1991, *Creative Problem Solving*, Wiley, Chichester.

Fookes, T.W. 1992, 'New Zealand goes for broke' in *The Social Impact Management Bulletin*, jointly published by the CSIRO and the Western Australian Government's Social Impact Unit.

Foqué, R. and Lammineur, M. 1995, 'Designing for patients: a strategy for introducing human scale in hospital design', *Design Studies,* vol. 16, no. 1, pp. 29–49.

Frankel, B. 1987, *The Post Industrial Utopians*, Polity Press, Cambridge.

Franz J. M. 1994, 'A critical framework for methodological research in architecture', *Design Studies,* vol. 15, no. 4, pp. 443–447.

French, M. J. 1985, *Conceptual Design for Engineers,* 2nd edn, Springer, London.

French, M. J. 1988, *Invention and Evolution: Design in Nature and Engineering,* Cambridge University Press, Cambridge.

French, M. J. 1990, 'Function Costing: A Potential Aid to Designers', *Journal of Engineering Design,* vol. 1, no. 1, pp. 47–54.

French, M. J. 1991, *personal communication.*

Furman, T. T. 1981, *Approximate Methods in Engineering Design,* Academic Press Inc. (London) Ltd., London.

Galle, P. and Kovács, L. B. 1996, 'Replication protocol analysis: a method for the study of real world design thinking', *Design Studies,* vol. 17, no. 2, pp. 181–200.

Ganeshan, R., Garrett, J. and Finger, S 1994, 'A framework for representing design intent', *Design Studies,* vol. 15, no. 1, pp. 59–84.

Gasparski, W. 1995, Review of 'Design Methods' (Jones, 1992), *Design Studies,* vol. 16, no. 1, pp. 130–132.

Gasparski, W. W. 1979, 'Praxiological-systemic approach to design studies', *Design Studies,* vol. 1, no. 2, pp. 101–106.

Gault, T. 1997, 'Words of Genius', *Professional Engineering,* vol. 10, no. 6, 26 March 1997.

Gero, J. S. (ed) 1991b, *Artificial Intelligence in Design '91*, Butterworth-Heinmann, Oxford.

Gero, J. S. 1991a, Preface, in *Artificial Intelligence in Design '91,* ed J. S. Gero, Butterworth-Heinmann, Oxford, pp. ix–x.

Gero, J. S. and Maher, M. L. (eds) 1993, *Modeling creativity and knowledge based creative design,* Lawrence Erlbaum Associates, Broadway, NJ.

Giddens, A. 1987, *Social Theory and Modern Sociology,* Polity Press, Cambridge, UK.

Glaser, B. G. and Strauss, A. L. 1973, *The Discovery of Grounded Theory: strategies for qualitative research,* Aldine, Chicago.

Glegg, G. L. 1971, *The Design of Design,* Cambridge University Press, Cambridge, UK.

Goggin, P. A. 1994, 'An appraisal of ecolabelling from a design perspective', Design Studies, vol. 15, no. 4, pp. 459–477.

Goldschmidt, G. 1994, 'On visual thinking: the vis kids of architecture', *Design Studies,* vol. 15, no. 2, pp. 158–174.

Goldschmidt, G. 1995, 'The designer as a team of one', *Design Studies,* vol. 16, no. 2, pp. 189–210.

Gordon, W. J. J. 1961, *Synectics,* Harper and Row Publishers, New York.

Graham, S. L. 1974, 'The design of programming languages', in *Basic Questions of Design Theory,* ed W. R. Spillers, North-Holland Publishing Company, Amsterdam, pp. 371–382.

Grbych, C. (ed) 1996, *Health in Australia,* Prentice Hall, Sydney.

Gregory, S. A. (ed) 1966a, *The Design Method,* Butterworths, London.

Gregory, S. A. 1966b, 'The human perspective, the design situation and its opportunities', in *The Design Method,* ed S. A. Gregory, Butterworths, London, pp. 35–38.

Gregory, S. A. 1966c, 'Design Science', in *The Design Method,* ed S. A. Gregory, Butterworths, London, pp. 323–330.

Gregory, S.A. 1981a, 'Towards a Joystick Model of Possible Actions: A Personal Report on ICED 1981 - Rome' in *Schriftenreihe WDK 7: Results of International Conference on Engineering Design 1981*, eds. V. Hubka and W.E. Eder, Heurista.

Gregory, S.A. 1981b, 'Summary of papers presented in session M2 on the afternoon of Monday March 9' in *Schriftenreihe WDK 7: Results of International Conference on Engineering Design 1981*, eds. V. Hubka and W.E. Eder, Heurista.

Guba, E. C. (ed) 1990a, *The Paradigm Dialog,* Sage Publications, Inc, California.

Guba, E. C. 1990b, 'The Alternative Paradigm Dialog' in *The Paradigm Dialog*, ed. E.C. Guba, Sage Publications, Inc, California, pp. 17–27.

Gunther, J. 1992, 'Experimental Investigation of Individual processes in Engineering Design' in *Research into Design Thinking,* eds N. Cross, K. Dorst and N. Roozenburg, Delft University Press, The Netherlands, pp. 99—110

Hallen, P. 1993, *Environmental Ethics S206: Study Guide and Course Materials Volume 1*, School of Social Sciences, Murdoch University, Perth.

Hamilton, P. 1974, *Knowledge and Social Structure,* Routledge and Kegan Paul, London.

Hamlyn, D. W. 1990, *In and Out of the Black Box: on the philosophy of cognition*, Basil Blackwell Ltd., Oxford.

Hampden-Turner, C. 1981, *Maps of the Mind,* Michell Beazely Publishers Ltd., London.

Harman, R. T. C. 1994, 'The Importance of Graphicacy in an Engineering Education', *Working Paper*, Dept. of Mechanical Engineering, University of Canterbury, New Zealand.

Harre, R. 1981, 'The positivist-empiricist approach and its alternative' in *Human Inquiry,* P. Reason and J. Rowan (eds), John Wiley and Sons, Chichester, England, pp. 3–18.

Harris, A. 1983, 'The intellectual standing of engineering design', *Design Studies,* vol. 4, no.3, pp. 147-150.

Harrison, M. A. 1974, 'Some linguistic issues in design', in *Basic Questions of Design Theory,* ed W. R. Spillers, North-Holland Publishing Company, Amsterdam, pp. 405–416.

Harrison, P. 1987, *The Greening of Africa*, Paladin, London, pp. 46–70.

Haugen, E. B. 1980, *Probabilistic Mechanical Design,* John Wiley and Sons Ltd., USA.

Heath, T. 1993, 'Social Aspects of Creativity and their Impacts on Creative Modelling', in *Modeling creativity and knowledge based creative design,* eds J. S. Gero and M. L. Maher, Lawrence Erlbaum Associates, Broadway, NJ, pp. 9–24.

Heidegger, M. 1962, *Being and Time,* trans. J. Macquarrie and R. Edward, Harper and Row, New York.

Hertz, K. 1992, 'A coherent description of the process of design', *Design Studies,* vol. 13, no. 4, pp. 393–410.

Hillier, B. and Penn, A. 1994, 'Virtuous circles, building sciences and the science of buildings: using computers to integrate product and process in the built environment', *Design Studies,* vol. 15, no. 3, pp. 332–365.

Hills, W. 1995, 'Generic research for design of made-to-order engineering products', *Design Studies,* vol. 16, no. 4, pp. 489—506.

Himmelblau, D. M. 1974, 'Design in Chemical Engineering', in *Basic Questions of Design Theory,* ed W. R. Spillers, North-Holland Publishing Company, Amsterdam.

Hogben, L. 1951, *Mathematics for the Million*, (3rd ed), Allen and Unwin, London.

Hollick, 1993, *An Introduction to Project Evaluation,* Longman Cheshire, Australia.

Hollick, M. 1995, *Environmental Policy 405 Course Notes,* Department of Environmental Engineering, University of Western Australia.

Hollick, M. 1998, *The Science of Oneness,* (in press).

Hollins, B. 1994, 'Conference report: International conference on engineering design (ICED 1993)', *Design Studies,* vol. 15, no. 2, pp. 227–229.

Hollins, W. J. and Pugh, S. 1989, 'Product status and the management of product design—what to do and when', in *International Conference on Engineering Design, 1989: proceedings of the Institution of Mechanical Engineers,* vol. 1, Mechanical Engineering Publications Ltd., Bury St. Edmunds, UK, pp. 229–244.

Holt, J. E. 1997, 'The designer's judgement', *Design Studies,* vol 18. No. 1, pp. 113–124.

Holt, J. E., Radcliffe, D. F. and Schoorl, D. 1985, 'Design or problem solving—a critical choice for the engineering profession', *Design Studies,* vol. 6, no. 2, pp. 107–110.

Hongo, K. 1985, 'On the significance of the Theory of Design', in *International Symposium on Design and Synthesis,* ed H. Yoshikawa, Elsevier Science Publishers B. V., Amsterdam, pp. 169–174.

Hoover, S.P., Rinderle, J. R. and Finger, S. 1991, 'Models and abstractions in design', *Design Studies,* vol. 12, no. 4. pp. 237–245.

Hubka, V. 1985, 'Attempts and possibilities for a rationalisation of engineering design', in *International Symposium on Design and Synthesis,* ed H. Yoshikawa, Elsevier Science Publishers B. V., Amsterdam, pp. 133–138.

Hubka, V. and Eder, W. E. (eds) 1981, *Schriftenreihe WDK 7 Results of ICED 81 (Rome),* Heurista, Zurich.

Hubka, V. and Eder, W. E. 1988, *Theory of Technical Systems,* Springer-Verlag, Berlin.

Hubka, V. and Eder, W.E. 1990, Design Knowledge: Theory in Support of Practice, *Journal of Engineering Design,* vol. 1, no. 1, pp. 97–108.

Hughes, D. R. and Piper, F. C. 1985, *Design Theory,* Cambridge University Press, Cambridge, UK.

Hutchinson, W. E. 1997, *Systems Thinking and Associated Methodologies,* Praxis Education, Perth.

I. E. Aust. 1988, Code of Ethics, I.E. Aust., ACT.

I. E. Aust. 1991, Supplemental Royal Charter and Bye-Laws, I.E. Aust., ACT.

I. E. Aust. 1992, Environmental Principles for Engineers, I.E. Aust., ACT.

I. Mech. E. 1989, I.Mech.E.: Royal Charter, By-laws and Regulations for Voting, I. Mech. E., London.

Illich, I. D. 1974, *Energy and Equity*, Calder and Boyars, London.

Illich, I. D. 1978, *Deschooling Society,* Penguin Books, UK.

Illich, I. D. 1988, *Limits to Medicine*, Penguin Books, London.

Indurkhya, B. 1992, *Metaphor and Cognition,* Kluwer Academic Publishers, Dordrecht.

Johannes, R. 1992, 'Architectural design: a systematic approach', *Design Studies,* vol. 13, no. 2, pp. 157–199.

Jonas, H. 1982, 'Technology and Responsibility: Reflections on the new tasks of ethics' in Engineering and Humanities, eds. J. H. Schaub and S. K. Dickison, James Wiley and Sons, USA.

Jones, J. C. 1963, 'A Method of Systematic Design', in *Conference on design methods,* eds J. C. Jones and D. G. Thornley, The Macmillan Company, New York, pp. 53–74.

Jones, J. C. 1966, 'Design Methods Reviewed', in *The Design Method,* ed S. A. Gregory, Butterworths, London, pp. 295–310.

Jones, J. C. 1970, *Design Methods: seeds of human futures,* Wiley-Interscience, London.

Jones, J. C. 1979, 'Designing designing', *Design Studies,* vol. 1, p. 31.

Jones, J. C. 1984a, *Essays in Design,* John Wiley and Sons, Chichester, UK.

Jones, J. C. 1984b, 'How my thoughts about design methods have changed during the years', in *Developments in Design Methodology,* ed N. Cross, John Wiley and Sons, Chichester, UK, pp. 329–336.

Jones, J. C. 1992, *Design Methods,* 2nd edn, Van Nostrand Reinhold, New York.

Jones, J. C. and Thornley, D. G. (eds) 1964a, *Conference on design methods,* The Macmillan Company, New York.

Jones, J. C. and Thornley, D. G. 1964b, 'Information about the Conference and Contributors' in *Conference on Design Methods*, eds. J. C. Jones and D. G. Thornley, Pergamon Press, Oxford.

Jones, J.C. 1970, *Design Methods,* Wiley-Interscience, London.

Joseph, S. 1996, 'Design systems and paradigms', *Design Studies,* vol. 17, no. 3, pp. 227–239.

Kast, F. E. and Rosenzweig, J. E. 1974, *Organisation and Management: a Systems Approach*, (2nd ed), McGraw-Hill Kogakusha Ltd., Tokyo.

Kenny, A. 1994, 'Descartes to Kant', *The Oxford Illustrated History of Western Philosophy,* Oxford University Press, Oxford, pp. 107–192.

Kipnis, D. 1990, *Technology and Power*, Springer-Verlag, New York.

Kitchener, K. S. and Brenner, H. G. 1990, 'Wisdom and Reflective Judgement: knowing in the face of uncertainty' in *Wisdom: its Nature, Origins and Development,* ed. J. R. Sternberg, Cambridge University Press, Cambridge, pp. 212–229.

Klagge, J. 1989, 'The Good Old Days: Age-Specific Perceptions of Progress', in *Technological Transformation: contextual and conceptual implications*, eds. E. F. Byrne and J. C. Pitt, Kluwer Academic Publishers, Dordrecht, pp. 93–104.

Kolodner, J. L. and Wills, L. M. 1996, 'Powers of observation in creative design', *Design Studies,* vol 17. No. 4, pp. 385–416.

Konda, S., Monarch, I., Sargent, P. and Subrahmanian, E. 1992, 'Shared Memory in Design: A Unifying Theme for Research and Practice', *Research in Engineering Design,* vol. 4, pp. 23–42.

Kostelanetz, R. (ed) 1973, *The Edge of Adaptation,*Prentice-Hall, Inc, New Jersey.

Krouwel, P. 1992, 'Design Thinking in Practice' in *Research into Design Thinking,* eds N. Cross, K. Dorst and N. Roozenburg, Delft University Press, The Netherlands, pp. 11—20

Kuhn, T. S. 1962, *The Structure of Scientific Revolutions,* Chicago University Press, Chicago.

Kuno, S., Kawagoe, K. and Managaki, M. 1985, 'ATHENA, A Knowledge Based CAD System', in *International Symposium on Design and Synthesis,* ed H. Yoshikawa, Elsevier Science Publishers B. V., Amsterdam.

Lai, T. 1989, 'Cryptanalysis: uncovering objective knowledge in hidden realities' in *Technological Transformation: contextual and conceptual implications*, eds. E. F. Byrne and J. C. Pitt, Kluwer Academic Publishers, Dordrecht.

Langrish, J. 1988, 'The Importance of Design in Technology Transfer', *Research Paper 44.,* The Institute of Advanced Studies, Manchester Polytechnic, UK.

Langrish, J. 1993, *Case Studies as a Biological Research Process,* Institute of Advanced Studies, The Manchester Metropolitan University, UK.

Lawson, B. 1990, *How Designers Think,* 2nd edn, Butterworth Architecture, London.

Lawson, B. 1993, 'Parallel Lines of Thought', *Languages of design,* vol. 1, pp. 321–331.

Lawson, B. 1994, *Design in Mind,* Butterworth-Heinmann Ltd., Oxford, UK.

Layton, E.T. 1971, The Revolt of the Engineers, Press of Case Western University, London.

Lazear, D. 1990, *Seven ways of knowing,* Hawker Brownlow Education, Australia.

Lera, S. 1981a, 'Architectural designers' values and the evaluation of their designs', *Design Studies,* vol. 2, no. 3, pp. 131-137.

Lera, S. 1981b, 'Empirical and theoretical studies of design judgement: a review', *Design Studies,* vol. 2, no. 1, pp. 19-25.

Lera, S. 1983, 'Synopses of some recent published studies of the design process and designer behaviour', *Design Studies,* vol. 4, no. 2, pp. 133—140.

Lera, S., Cooper, I. and Powell, J.A. 1984, 'Information and designers', *Design Studies,* vol. 5, no. 2, pp. 113-120.

Levin, M. 1993, 'Reliabilism and Induction', Synthese, vol. 97, no. 3, pp. 297–334.

Lewis, B. N. 1963, 'Communication in Problem Solving Groups', in *Conference on design methods,* eds J. C. Jones and D. G. Thornley, Macmillan, New York, pp. 169–184.

Lewis, W. P. and Samuel, A. E. 1989, *Fundamentals of Engineering Design: ideas, methods and applications,* Prentice Hall of Australia Pty Ltd., Australia.

Liddament, T. 1996, The metamorphosis of the design vocabulary', *Design Studies,* vol. 17, no. 3, pp. 303–318.

Lincoln, Y. 1990, 'The Making of a Constructivist' in *The Paradigm Dialog,* ed E. Guba, Sage Publications Inc., California.

Lindsay, D. 1995, *A guide to scientific writing,* Longman, Australia.

Liu, Yu-Tung 1995, 'Some phenomena of seeing shapes in design', *Design Studies,* vol 16, no. 3, pp. 367–386.

Liu, Yu-Tung 1996, 'Two functions of analogical reasoning in design: a cognitive-psychology approach', *Design Studies,* vol 17, no. 4, pp. 435–450.

Lloyd, P. and Scott, P. 1994, 'Discovering the design problem', *Design Studies,* vol. 15, no. 2, pp. 125–140.

Lloyd, P., Lawson, B. and Scott, P. 1995, 'Can concurrent verbalisation reveal design cognition?', *Design Studies,* vol. 16, no. 2, pp. 237–260.

Logan, B 1996, *Meeting Announcement: Design Dialogues: Two,* [on-line], Available WWW: http;//www.mailbase.ac.uk/lists-a-e/design-research. Email archives April 1996.

Logan, B. and McDonnell, J. 1996, 'Design Dialogues: One', *DRS_NEWS,* vol. 1, no. 1, [on-line] Available WWW: http;//www.mailbase.ac.uk/lists-a-e/design-research

Logan, B., Millington, K. and Smithers, T. 1991, 'Being economical with the truth: assumption-based context management in the Edinburgh Designer System', in *Artificial Intelligence in Design '91,* ed J. S. Gero, Butterworth-Heinmann, Oxford, pp. 423–446.

Love, T. 1995a, 'Systems models and engineering design theory', *Systems for the Future: proceedings of the Australian Systems Conference, Perth, Western Australia, 1995,* eds W. Hutchinson, S. Metcalf, C. Standing and M. Williams, Edith Cowan University, Perth, Western Australia, pp. 238–246.

Love, T. 1996, 'The Philosophy of Design: a meta-level abstraction analysis' *Design Studies,* (under review).

Love, T. 1996a, 'New Developments in Engineering Design Theory: Part 1', *News Bulletin,* Institution of Mechanical Engineers (Australian Branch), NSW.

Love, T. 1996b, 'New Developments in Engineering Design Theory', *News Bulletin,* Institution of Mechanical Engineers (Australian Branch), NSW, (in press).

Lowe, H. 1994, 'Proof planning: A methodology for developing AI systems incorporating design issues', *Artificial Intelligence for Engineering Design, Analysis and Manufacturing,* vol. 8, pp. 307—317.

Lumsdaine, E. and Lumsdaine, M. 1995, *Creative Problem Solving,*McGraw-Hill Inc., New York.

Lyle, J. T. 1985, *Design for Human Ecosystems,* Van Nostrand Reinhold, New York.

Magee, B. 1973, *Popper,* Wm Collins Sons and Co Ltd., London.

Magee, K. 1987, 'The elicitation of knowledge from designers', *Design Studies,* vol. 8, no. 2, pp. 62–69.

Mak, S. 1995, 'Exploring possibilities for change in rainfed lowland rice farming systems' in *Systems for the Future: proceedings of the Australian Systems Conference 1995*, Edith Cowan University, Perth, pp. 201–207.

Mamat, S. 1991, 'Technology for the poor' in *Technology overcoming poverty: The University Contribution, proceedings of the Association of Southeast Asian Institutes of Higher Learning Seminar 1991*, Curtin University, Perth, pp. 146–155.

Mann, R. W. 1963, 'Engineering Specification for a man-computer system for design', *AFIPS Conference Proceedings 23,* (Spring Joint Computer Conference), Cleaver-Hume, London.

Margolin, V. 1992 'Design History or Design Studies: subject matter and methods', *Design Studies,* vol. 13, no. 2, pp. 104–116.

Margolis, J. 1989, 'The Technological Self' in *Technological Transformation: contextual and conceptual implications*, eds. E. F. Byrne and J. C. Pitt, Kluwer Academic Publishers, Dordrecht, pp. 1–16.

Martin, M. W. and Schinzinger, R. 1983, *Ethics in Engineering*, McGraw-Hill Book Company, USA.

Matchett, E. 1963, 'The controlled evolution of an engineering design', *Conference on Systematic Design Methods,* Engineering Employers' West of England Association.

Matousek, R. 1963, *Engineering Design: A Systematic Approach,* trans. A. H. Burton, ed A. H. Johnson, Blackie, London.

McCrory, R. J. 1966, 'The Design Method in Practice', in *The Design Method,* ed S. A. Gregory, Butterworths, London, pp. 11–18.

McDermott, J. 1982, 'Domain knowledge and the design process', *Design Studies,* vol. 3, no. 1, pp. 31–36.

Meadows, D. H., Meadows, D. L., Randers, J., Behrens III, W. W. 1974, *The Limits to Growth,* 2nd edn., Pan Books, London.

Middendorf, W. H. 1969, *Engineering Design,* Allyn and Bacon, Inc., Boston, USA.

Miller, J. J. 1996, *Design Education - was Summary: Design as Communication (long)*, [on-line], Available WWW: http://www.mailbase.ac.uk/lists-a-e/design-research

Mitchell, W. J. 1993, 'A computational view of design creativity' in *Modelling Creativity and Knowledge Based Design,* eds. J. S. Gero and M. L. Maher, Lawrence Erlbaum Associates Inc., New Jersey, pp. 25–42.

Mohr, L. B. 1988, *Impact Analysis for Program Evaluation,*The Dorsey Press, Chicago.

Moore, G. T. 1970, 'Preface', in *Emerging Methods in Environmental Design and Planning,* ed G.T. Moore, MIT Press, Cambridge, MA.

Mostow, J. 1985, (cited in Mullins and Rinderle, 1991), 'Towards Better Models of The Design Process', *The AI Magazine,* Spring 1985.

Motard, R. L. 1974, 'Design Theory: a chemical engineering view', in *Basic Questions of Design Theory,* ed W. R. Spillers, North-Holland Publishing Company, Amsterdam, pp. 143–146.

Mullins, S. and Rinderle, J. R. 1991, 'Grammatical Approaches to Engineering Design, Part I: An Introduction and Commentary', *Research in Engineering Design*, vol. 2, pp. 121–135.

Murray, E. L. 1986, *Imaginative Thinking and Human Existence,* Duquesne University Press, Pittsburgh.

Nadler, G. 1989, 'Design processes and their results', *Design Studies,* vol. 10, no. 2, pp. 124–127.

Nagy, R. L., Ullman, D. G. and Deiterrich, T. G. 1992, 'A Data Representation for Collaborative Mechanical Design', *Research in Engineering Design,* vol. 3, pp. 233–242.

Nakata, K. 1996, '2nd CFP: Special Track on Design' [on-line]. Available WWW; design-research@mailbase.ac.uk.

Neugebauer, O. 1975, *A History of Ancient Mathematical Astronomy,* Springer-Verlag, Berlin.

Nevill Jr., G. E. and Crowe, R. A. 1974, 'Computer augmented conceptual design', in *Basic Questions of Design Theory,* ed W. R. Spillers, North-Holland Publishing Company, Amsterdam.

Newbury, D. 1996, ‘Viewpoint: Knowledge and research in art and design’, *Design Studies,* vol. 17, no. 2, pp. 215—219.

Newell, A. 1982, ‘The Knowledge Level’, *Artificial Intelligence*, vol. 18, pp. 87–127.

Newell, A. 1990, *Unified Theories of Cognition,* Harvard University Press, Cambridge, Mass.

Newell, A. and Simon, H. A. 1972, *Human Problem Solving,* Prentice-Hall, Inc., Englewood Cliffs, New Jersey.

Newton, S. and Coyne, R. D. 1992, ‘Impact of connectionist systems on design’, *Knowledge Based Systems,* vol. 5, no. 2, pp. 66–81.

Nicholls, K. 1990, ‘Getting Engineering Changes under Control’, *Journal of Engineering Design*, vol. 1, no. 1, pp. 5–15.

Nideau, R. L. 1991, *Mind, Machines and Human Consciousness*, Contemporary Books, Chicago.

Nielsen, S. H. and Valbak, E. 1989, ‘A dynamic approach model: an alternative paradigm for co-ordinating design related classical and dynamic systematic/methods’, in *International Conference on Engineering Design, 1989: proceedings of the Institution of Mechanical Engineers,* vol. 1, Mechanical Engineering Publications Ltd., Bury St. Edmunds, UK, pp. 365–374.

Norman, D. A. 1992, ‘Design Principles for Cognitive Artifacts’, *Research in Engineering Design*, vol. 4, pp. 43–50.

Ó Cathain, C. S. 1982, ‘Why is design logically impossible?’, *Design Studies,* vol. 3, no. 3, pp. 123–125.

O’Doherty, E. F. 1963, ‘Psychological Aspects of the Creative Act’, in *Conference on design methods,* eds J. C. Jones and D. G. Thornley, Macmillan, New York, pp. 197–204.

Oh, V., Langdon, P. and Sharpe, J. E. E. 1994, ‘Schemebuilder: An Integrated Environment for Product Design’, in *Computer Aided and Conceptual Design,* eds J. Sharpe and V. Oh, Engineering Design Centre, Lancaster University, UK.

Ong, W. J. 1982, *Orality and Literacy,* Methuen and Co, London.

Ostrofski, B. 1977, *Design, planning and development methodology,* Prentice-Hall, New Jersey.

Otto, K. N. and Antonsson, E. K. 1994, 'Design Parameter Selection in the Presence of Noise', *Research in Engineering Design,* vol. 6, pp. 234–246.

Oxman, R. 1990, 'Prior knowledge in design: a dynamic knowledge-based model of design and creativity', *Design Studies,* vol. 11, no. 1, pp. 17–28.

Oxman, R. 1995a, 'Cognition and Design - Editorial', *Design Studies,* vol. 17. No. 4, pp. 337–340.

Oxman, R. 1995b, 'Viewpoint: Observing the observers: research issues in analysing design activity', *Design Studies,* vol. 16, no. 2, pp. 275–284.

Ozbekhan, H. 1974, 'The triumph of technology - "can" implies "ought"', *Man-Made Futures,* eds N. Cross, D. Elliott, R. Roy, Hutcinson Educational, London, pp. 118–128.

Pacey, A. 1983, *The Culture of Technology,* Basil Blackwell Ltd., Oxford.

Page, J. K. 1963, 'A review of the papers presented at the conference', in *Conference on Design Methods, London 1962,* ed J. C. Jones and D. G. Thornley, The Macmillan Company, New York, pp. 205–216.

Pahl, G. and Beitz, W. 1984, *Engineering Design,* ed K. Wallace, jointly published by the Design Council, London and Springer-Verlag, Berlin.

Papanek, V. 1984, *Design for the Real World: Human Ecology and Social Change*, 2nd edn, Thames and Hudson, London.

Parnas, D. L. and Clements, P. C. 1986, 'A Rational Design Process: How and Why to Fake It', *IEEE Transactions on Software Engineering,* vol. 12, no. 2, pp. 251–257.

Passini, R. 1996, 'Wayfinding design: logic and some thoughts on universality', *Design Studies,* vol. 17, no. 3, pp. 319–332.

Peng, C. 1994, 'Exploring communication in collaborative design: co-operative architechtural modelling', *Design Studies,* vol. 15, no. 1, pp. 19—44.

Perry, C. 1996, *How to write a doctoral thesis - PhD/DPhil* [on-line]. Available WWW: http://www.imc.org.uk/imc/news/occpaper/cpindex.htm.

Petroski, H. 1991, 'Galileo and the marble column: A paradigm of human error in design', *Structural Safety,* vol. 11, pp. 1—11.

Petroski, H. 1992, Preface, *Research in Engineering Design,* vol. 4, p. 1.

Phillips, D. C. 1990, 'PostPositivist Science: Myths and Realities' in *The Paradigm Dialog,* ed E. Guba, Sage Publications Inc., California.

Phillips, D.C. 1987, *Philosophy, Science and Social Inquiry*, Pergamon Press, Oxford.

Phillips, E. M. and Pugh, D. S. 1987, *How to get a Ph.D.,* Open University Press, Buckingham, UK.

Piela, P., Katzenberg, B. and McKelvey, R. 1992, 'Integrating the User into Research on Engineering Design Systems', *Research in Engineering Design,* vol.3, pp. 211–221.

Pitts, G. 1981, 'Information for designers - Workshop', *Schriftenreihe WDK 7 Results of ICED 81 (Rome),* eds. V. Hubka and W. E. Eder, Heurista, Zurich.

Plato 1955, *The Republic,* trans. H. D. F. Lee, Penguin, Harmondsworth.

Platt, D. G. and Blockley, D. I. 1994, 'Process modelling in civil engineering design'. *Design Studies,* vol. 15, no. 3, pp. 317–331.

Popper, K. 1959, *Logic of Scientific Discovery,* Hutchinson, London.

Popper, K. R. 1976, *Unended Quest: an intellectual autobiography,* Open Court, La Salle, Ill.

Porter, W. L. 1988, 'Notes on the inner logic of designing', *Design Studies,* vol. 9, no. 3, pp. 169–180.

Powers, G. J. and Rudd, D. F. 1974, 'A theory for chemical engineering design', in *Basic Questions of Design Theory,* ed W. R. Spillers, North-Holland Publishing Company, Amsterdam.

Protzen, J. 1980, 'The poverty of pattern language', *Design Studies,* vol. 1, no. 5, pp. 291–294.

Pugh, S. 1982, 'Design—the integrative-enveloping culture—not a third culture', *Design Studies,* vol. 3, no. 2, pp. 93–96.

Pugh, S. 1985, 'Further development of the hypothesis of static/dynamic concepts in product design', in *International Symposium on Design and Synthesis,* ed H. Yoshikawa, Elsevier Science Publishers B. V., Amsterdam, pp. 181–188.

Pugh, S. 1990, 'Engineering Design - unscrambling the research issues', *Journal of Engineering Design,* vol. 1, no. 1., pp. 65–72.

Pugh, S. 1991, *Total Design,* Addison-Wesley Publishing Company, Wokingham, England.

Pugh, S. and Morley, I. E. 1989, 'Organising for design in relation to dynamic/static product concepts', in *International Conference on*

Engineering Design, 1989: proceedings of the Institution of Mechanical Engineers, vol. 1, Mechanical Engineering Publications Ltd., Bury St. Edmunds, UK, pp. 313–334.

Purcell, A. T. and Gero, J. S. 1991, 'The effects of examples on the results of design activity', in *Artificial Intelligence in Design '91,* ed J. S. Gero, Butterworth-Heinmann, Oxford, pp. 525–542.

Purcell, P. 1984, 'Editorial', *Design Studies,* vol. 5, no. 3, p. 130.

Purcell, P. A., Mallen, G. L. and Goumain, P. G. R. 1974, 'A Strategy for Design Research', in *Basic Questions of Design Theory,* ed W. R. Spillers, North-Holland Publishing Company, Amsterdam, pp. 75–94.

Purcell. A. T. and Gero, G. S. 1996, 'Design and other types of fixation', *Design Studies,* vol 17. No. 4, pp. 363–384.

Pye, D. 1964, *The Nature of Design*, Studio Vista Ltd., London.

Quadrel, R. W., Woodbury, R. F., Fenves, S. J. and Talukdar, S. N. 1993, 'Controlling Asynchronous Team Design Environments by Simulated Annealing', *Research in Engineering Design,* vol. 5, pp. 88–104.

Ramscar, M., Lee, J. and Pain, H. 1996, 'A cognitively based approach to computer integration for design systems', *Design Studies,* vol 17. No. 4, pp. 465–488.

Ramsden, M. J. 1974, *An introduction to index language construction,* Clive Bingley Ltd., London.

Rapoport, A. 1969, *House form and culture,* Prentice-Hall, Inc., Englewood Cliffs, N.J.

Rapp, F. 1989, 'Cultural Alienation through Technology Transfer' in Technological Transformation: contextual and conceptual implications, eds. E. F. Byrne and J. C. Pitt, Kluwer Academic Publishers, Dordrecht, pp. 249–258.

Reason, P. and Rowan, J. (eds) 1981a, *Human Inquiry,* John Wiley and Sons, Chichester, England.

Reason, P. and Rowan, J. 1981b, 'Issues of validity in new paradigm research' in *Human Inquiry,* P. Reason and J. Rowan (eds), John Wiley and Sons, Chichester, England, pp. 239–250.

Reich, Y. 1992, *Transcending the Theory-Practice Problem of Technology*, EDRC 12-51-92, Engineering Design Research Center, Carnegie Mellon University, Pittsburgh.

Reich, Y. 1994a, 'Layered models of research methodologies', *Artificial Intelligence in Engineering Design and Manufacturing,* vol. 8, pp. 263–274.

Reich, Y. 1994b, 'Annotated bibliography on Research Methodology', *Artificial Intelligence in Engineering Design and Manufacturing,* vol. 8, pp. 355–366.

Reich, Y. 1995, 'A Critical Review of General Design Theory', *Research in Engineering Design,* vol. 7, pp. 1–18.

Reich, Y., Konda, S. L., Monarch, I. A., Levy, S. N. and Subrahmanian, E. 1996, 'Varieties and issues of participation and design', *Design Studies,* vol. 17, no. 2, pp. 165—180.

Reitmann, W. 1965, (Cited by Thomas and Carroll, 1979), *Cognition and Thought,* Wiley, New York.

Reswick, J. B. 1965, *Prospectus for the Engineering Design Center,* Case Institute of Technology, Cleveland, Ohio.

Rhodes, R. G. and Smith, D. G. 1989, 'Market information processing—the first step towards successful product design', in *International Conference on Engineering Design, 1989: proceedings of the Institution of Mechanical Engineers,* vol. 2, Mechanical Engineering Publications Ltd., Bury St. Edmunds, UK, pp. 1257–1272.

Rinderle, J. R. 1987, (cited by Mullins and Rinderle, 1991), 'Function and Form Relationships: A Basis for Preliminary Design', *Proceedings from the NSF Workshop on the Design Process,* ed M. B. Waldron, Ohio State University, Oakland, CA., pp. 295–312.

Rinderle, J. R. 1991, 'Grammatical Approaches to Engineering Design, Part II: Melding Configuration and Parametric Design Using Attribute Grammars', *Research in Engineering Design,* vol. 2, pp. 137–146.

Rittel, H. W. J. 1967a, 'Some principles for the design of an educational system for design', *Design Methods Group Newsletter,* vol. 4, no. 4.

Rittel, H. W. J. 1967b, 'Some principles for the design of an educational system for design', *Design Methods Group Newsletter,* vol. 5, no. 1.

Rittel, H. W. J. 1972a, 'On the Planning Crisis: Systems Analysis of the First and Second Generations', *Bedriftsokonomen,* no. 8.

Rittel, H. W. J. 1972b, 'Son of 'RittelThink'', *The DMG 5th Anniversary Report: DMG Occassional Paper No. 1,* The Design Methods Group, n. p., pp. 5–10.

Rittel, H. W. J. 1984, 'Second-generation Design Methods', in *Developments in Design Methodology,* ed N. Cross, John Wiley and Sons Ltd., London, pp. 317–328.

Rittel, H. W. J. and Webber, M. M. 1972, 'Dilemmas in a general theory of planning', *Working paper - No. 194,* Institute of Urban development, University of California, Berkeley, USA.

Rittel, H. W. J. and Webber, M. M. 1973, 'Dilemmas in a general theory of planning', *Policy Sciences,* vol. 4, pp,155–169.

Rittel, H. W. J. and Webber, M. M. 1974, 'Wicked Problems', in *Man-made Futures,* eds N. Cross, D. Elliot and R. Roy, Hutchinson and Co. (Publishers) Ltd., London, pp. 272–280.

Rittel, H. W. J. and Webber, M. M. 1984, 'Planning Problems are Wicked Problems', in *Developments in Design Methodology,* ed N. Cross, John Wiley and Sons Ltd., London, pp. 135–144.

Roberts, P. 1982, 'Learning to mean', *Design Studies,* vol. 3, no. 4, pp. 205-210.

Robinson, J. W. 1986, 'Design as exploration', *Design Studies,* vol. 7, no. 2, pp. 67–79.

Roe, P. H., Soulis, G. N. and Handa, V. K. 1966, *The Discipline of Design:Experimental Edition,* CanadaPub: University of Waterloo, Waterloo, Canada. pp. 58, 59.

Roozenburg, N. 1992, 'On the logic of innovative design' in *Research into Design Thinking,* eds N. Cross, K. Dorst and N. Roozenburg, Delft University Press, The Netherlands, pp. 127—138.

Rosen, S. 1980, *The Limits of Analysis,* Yale University Press, New Haven.

Roszak, T, 1974, ' The Technocracy' in Man-Made Futures: Readings in Society, Technology and Design, eds. N. Cross, D. Elliott and R. Roy, Hutchinson and Co. Ltd., London, pp. 71–79.

Rowan, J. and Reason, P. 1981a, 'Foreword' in *Human Inquiry,* P. Reason and J. Rowan (eds), John Wiley and Sons, Chichester, England, pp. xi–xxiv.

Rowan, J. and Reason, P. 1981b, 'On making sense' in *Human Inquiry,* P. Reason and J. Rowan (eds), John Wiley and Sons, Chichester, England, pp. 113–137.

Roy, R. 1993, 'Case studies of creativity in innovative product development', *Design Studies,* vol. 14, no. 4, pp. 423—443.

Ryle, G. 1949, *The concept of mind,* Hutchinson, London.

Ryle, G. 1979, *On thinking,*ed. K. Kolenda, Blackwell, Oxford.

Rzevski, G., Woolman, D. and Trafford, D. B. 1980, 'Validation of a design methodology', *Design Studies*, vol. 1, pp. 325-328.

Salminen, V. and Verho, A. J. 1989, 'Multi-disciplinary design problem in mechatronics and some suggestions as to its methodical solution in conceptual design phase', in *International Conference on Engineering Design, 1989: proceedings of the Institution of Mechanical Engineers,* vol. 1, Mechanical Engineering Publications Ltd., Bury St. Edmunds, UK, pp. 533–554.

Sancar, F. H. 1996, 'Behavioural knowledge integration in the design studio: an experimental evaluation of three strategies, *Design Studies,* vol 17, no. 2, pp. 131–164.

Sargent, P. M. 1990, 'Give us the tools and we'll give you doorknobs' in *The Times Higher Education Supplement*, 30th March 1990, p. 15.

Sargent, P. M. 1994, Design Science or nonscience, *Design Studies,* vol. 15, no. 4, pp. 389–402.

Sayyed Hossein Nasr 1980, *Living Sufism,* Unwin, London.

Schon, D. A. 1974, 'Design in the light of the year 2000', in *Man-made Futures,* eds N. Cross, D. Elliott and R. Roy, Hutchinson Educational, London, pp. 255–263.

Schon, D. A. 1983, *The Reflective Practitioner,* Basic Books Inc., New York.

Schon, D. A. 1984, 'Design: a process of enquiry, experimentation and research', *Design Studies,* vol. 5, no. 3, pp. 130–131.

Schon, D. A. 1987, *Educating the Reflective Practitioner*, Jossey-Bass Publications, San Francisco.

Schon, D. A. 1992, 'Designing as Reflective Conversation with the Materials of a Design Situation', *Research in Engineering Design,* vol. 3, pp. 131–147.

Schon, D. A. and Wiggins, G. 1992, 'Kinds of Seeing and their functions in designing', *Design Studies,* vol. 13, no. 2, pp. 135–156.

Schwandt, T. R. 1990, 'Paths to Inquiry in the Social Disciplines: Scientific, Constructivist and Critical Theory Methodologies' in *The Paradigm Dialog*, ed. E.C. Guba, Sage, London, pp. 259–276.

Scruton, R. 1994, 'Continental philosophy from Fichte to Sartre', *The Oxford Illustrated History of Western Philosophy,* Oxford University Press, Oxford, pp. 193–238.

Shah, I. 1979, *The Way of the Sufi,* Penguin Books Ltd, England.

Sharpe, J. E. E. 1993, *The Lancaster Engineering Design Centre*, Engineering Design Centre, Lancaster University, Lancaster, UK.

Sharpe, J. E. E. 1995, 'Computer Tools for Integrated Conceptual Design', *Design Studies,* vol. 16, no. 4, pp. 471–488.

Sharrock, W. and Anderson, B. 1994, 'The user as a scenic feature of the design space', *Design Studies,* vol. 15, no. 1, pp. 5—18.

Shipman, M. D. 1981, *Limitations of Social Research*, 2nd. edn., Longman Group, UK

Simon, H. A. 1981, *The Sciences of the Artificial,* 2nd edn, MIT Press, Cambridge, Mass.

Simon, H. A. 1982, *Models of bounded rationality,* vol. 2, MIT Press, Cambridge, Mass.

Singer, A. E. 1995, 'Ethics and Human Systems' in *Systems for the Future: Proceedings of the Australian Systems Conference, Perth, Western Australia, 1995*, Edith Cowan University, Perth, pp. 260–268.

Sivaloganathan, S., Evbuomwan, N. F. O., Jebb, A. and Winn, H. P. 1995, 'Design funtion deployment: a design system of the future', *Design Studies,* vol. 16, no. 4, pp. 447–470.

Slann, P. A. 1963, 'Foreword', in *Conference on design methods, London, 1962,* eds J. C. Jones and D. G. Thornley, The Macmillan Company, New York, pp. xi,xii.

Slusher, E. A., Ebert, R. J. and Ragsdell, K. M. 1989, 'Contingency management of engineering design', in *International Conference on Engineering Design, 1989: proceedings of the Institution of Mechanical Engineers,* vol. 1, Mechanical Engineering Publications Ltd., Bury St. Edmunds, UK, pp. 65–76.

Smets, G. and Overbeeke, K. 1994, 'Industrial design engineering and the theory of direct perception', Design Studies, vol. 15, no. 2, pp. 175–184.

Smets, G. J. F. and Overbeeke, C. J. 1995, 'Expressing tastes in packages', Design Studies, vol. 16, no. 3, pp. 349–366.

Smith, J. K. 1990, Alternative Research Paradigms and the Problem of Criteria, E. G. Guba (ed), *The Paradigm Dialog,* Sage Publications, Newbury Park, CA, pp. 167–187.

Snow, C. P. 1964, *The two cultures and a second look*, Cambridge University Press, Cambridge, UK.

Social Impact: The Social Impact Management Bulletin, vol. 1, no. 2, jointly published by the CSIRO and the Western Australian Government's Social Impact Unit, Perth.

Somers, M. J. 'The Potential of Project Management For Environmentally Sustainable Projects' in *Eco-Design*, ed. T. Riley and J. Gertsakis, Centre for Design at RMIT, Melbourne, pp. 194–205.

Sonnenwald, D. H. 1996, 'Communication roles that support collaboration during the design process', *Design Studies,* vol. 17, no. 3, pp. 277—302.

Soufi, B. and Edmonds, E. 1996, 'The cognitive basis of emergence: implications for design support', *Design Studies,* vol. 17, no. 4, pp. 451–464.

Special issue: 'Analysing Design Activity' 1995, in *Design Studies*, vol. 16, no. 2.

Spencer, L. C. 1991, 'Barriers to Technology overcoming Poverty' in Technology overcoming poverty: The University Contribution, proceedings of the Association of Southeast Asian Institutes of Higher Learning Seminar 1991, Curtin University, Perth, pp. 383–400.

Spillers, W. R. (ed) 1974, *Basic Questions of Design Theory,* North-Holland Publishing Company, Amsterdam.

Springer, S. P. and Deutsch, G. 1993, *Left Brain, Right Brain* (4th edn), W. H. Freeman and Company, New York.

Spur, G., Krause, F. L. and Dassler, R. 1985, 'Use of Geometry Modelling Capabilities for Design Tasks', in *International Symposium on Design and Synthesis,* ed H. Yoshikawa, Elsevier Science Publishers B. V., Amsterdam.

Starkey, C. V. 1988, *Basic Engineering Design,* Edward Arnold, Great Britain.

Stauffer, L. A. 1989, 'The commonality of design in diverse domains', in *International Conference on Engineering Design, 1989: proceedings of the Institution of Mechanical Engineers,* vol. 1, Mechanical Engineering Publications Ltd., Bury St. Edmunds, UK, pp. 447–466.

Stegmüller, W. 1976, *The Structure and Dynamics of Theories,* Springer-Verlag, New York.

Steinberg, L. 1994, 'Research methodology for AI and design', *Research in Engineering Design,* vol. 8, pp. 283–287.

Sternberg, J. R. (ed) 1990, *Wisdom: its Nature, Origins and Development*, Cambridge University Press, Cambridge.

Stewart, M. G. 1992, 'Simulation of human error in reinforced concrete design', *Research in Engineering Design,* vol. 4, pp. 51—60.

Stiny, G. 1980, (cited in Rinderle, 1981), 'Introduction to Shape and Shape Grammars', *Environment and Planning B*, vol. 7, pp. 343–351.

Stolterman, E. 1994, 'Guidelines or Aesthetics', *Design Studies,* vol. 15, no. 4, pp. 448–458.

Stomph-Blessing, L. T. M. 1989, 'Analysing and Engineering Design Process in Industry', *International Conference on Engineering Design, 1989: proceedings of the Institution of Mechanical Engineers,* vol. 1, Mechanical Engineering Publications Ltd., Bury St. Edmunds, UK, pp. 57–64.

Stupniker, Y. 1994, 'A theory of inventive problem solving', *presentation*, Institution of Engineers Australia, Western Australia Division, 17th August 1994.

Style Manual (5th edn), Australian Government Publishing Service, Canberra.

Suh, N. P. 1990, *The Principles of Design,* Oxford University Press, Oxford, UK.

Sumpter, K. 1997, 'George Stephenson - father of the modern railways', *News Bulletin,* I. Mech. E Australian Branch.

Takala, T. 1993, 'A neuropsychologically-based approach to creativity' in *Modelling Creativity and Knowledge Based Design,* eds. J. S. Gero and M. L. Maher, Lawrence Erlbaum Associates Inc., New Jersey, pp. 91–108.

Talbot, R. 1981, 'Design: Science: Method', *Design Studies,* vol. 2, no. 2, pp. 118–121.

Talukdar, S., Rehg, J. and Elfes, A. 1988, 'Descriptive models for design projects' in *Artificial Intelligence in Engineering Design,* ed J. S. Gero, Computational Mechanics Publications Ltd., Avon, UK.

Tang, J. C. and Leifer, L. J. 1991, 'An observational Methodology for studying Group Design activity', *Research in Engineering Design*, vol. 2, pp. 209-219.

Tempczyk, H. 1986, 'A survey of research and studies on design' in *Design Studies,* vol. 7, no. 4, pp. 199–215.

Thines, G. 1977, *Phenomenology and the Science of Behaviour,* Allen and Unwin, London.

Thomas, J. C. and Carroll, J. M. 1979, 'The Psychological Study of Design', *Design Studies,* vol. 1, no. 1., pp. 5–11.

Thring, M. W. and Laithwaite, E. R. 1977, *How to Invent,* The Macmillan Press Ltd., London.

Tizani, W. M. K. and Davies, G. 1994, 'A construction-led process for tubular trusses', *Design Studies,* vol. 15, no. 3, pp. 248–259.

Toffler, A. 1973, *Future Shock*, Pan Books Ltd., London.

Toffler, A. 1990, *Power Shift,* Bantam Books, New York.

Tofler, A. 1981, *The Third Wave,* Bantam Books, New York.

Tomiyama, T. 1994, 'From general design theory to knowledge-intensive engineering', *Artificial Intelligence in Engineering Design,* vol. 8, pp. 319–333.

Tomiyama, T. and Yoshikawa, H. 1985, 'Knowledge engineering and CAD', in *International Symposium on Design and Synthesis,* ed H. Yoshikawa, Elsevier Science Publishers B. V., Amsterdam, pp. 6–8.

Tovey, M. 1992a, 'Automotive stylists' design thinking: Visual creativity and CAD' in *Research in design thinking,* eds. N. Cross, K. Dorst and N. Roozenburg, Delft University Press, The Netherlands, pp. 87—98.

Tovey, M. 1992b, 'Intuitive and objective processes in automotive design', *Design Studies,* vol. 13, no. 1, pp. 23–41.

Tovey, M. 1995, 'Research in Engineering Design Centres', *Design Studies,* vol. 16, no. 4, pp. 395, 396.

Tovey, M. 1997, 'Styling and Design: intuition and analysis in industrial design', *Design Studies,* vol. 18, no. 1, pp. 5–32.

Traub, P. 1996, 'Optimising human factors integration in system design', *Engineering Management Journal,* vol. 6, no.2, April, pp. 93–98.

Ullman, D. G. 1992, 'A taxonomy for Mechanical Design', *Research in Engineering Design,* vol. 3, pp. 179–189.

Ullman, D. G. 1993, 'A new view on function modelling', in *Proceedings of ICED 93 WDK 93,* ed N. F. M. Roozenburg, Heurista, Switzerland.

VDI 2221, 1985, *Systematic approach to the design of technical systems and products,* VDI-Verlag, Dusseldorf.

Visser, W. 1991, 'The cognitive psychology viewpoint on design: examples from empirical studies', in *Artificial Intelligence in Design '91,* ed J. S. Gero, Butterworth-Heinmann, Oxford, pp. 505–524.

Visser, W. 1995, 'Use of episodic knowledge and information in design problem solving', *Design Studies,* vol. 16, no. 2, pp. 171–187.

Visser, W. 1996, 'Two functions of analogical reasoning in design: a cognitive-psychological approach', *Design Studies,* vol. 17, no. 4, pp. 417–434.

Vivante, L. 1980, *Essays on Art and Ontology,* University of Utah Press, Salt Lake City.

Waldron, B. 1989, 'Observations on management of initial design specifications in mechanical design', in *International Conference on Engineering Design, 1989: proceedings of the Institution of Mechanical Engineers,* vol. 1, Mechanical Engineering Publications Ltd., Bury St. Edmunds, UK, pp. 189–200.

Waldron, M. B. and Waldron, K. J. 1988, 'A time sequence study of a complex mechanical system design', *Design Studies,* vol. 9, no. 2, pp. 95–106.

Wallace, K. 1992, 'Some Observations on Design Thinking' in *Research in Design Thinking*, eds N. Cross, K. Dorst and N. Roozenburg, Delft University Press, The Netherlands, pp. 75–86.

Wallace, K. and Burgess, S. 1995, 'Methods and tools for decisionmaking in engineering design', *Design Studies*, vol. 16, no. 4, pp. 429–446.

Wallace, K. and Burgess, S. 1995, 'Methods and tools for decisionmaking in engineering design', *Design Studies,* vol. 16, no. 4, pp. 429–446.

Wallace, K. M. (ed) 1987, *VDI 2221, 1987, Systematic approach to the design of technical systems and products,* Beuth Verlag, Berlin.

Wallace, K. M. and Hales, C. 1989, 'Engineering design research areas', in *International Conference on Engineering Design, 1989: proceedings of the Institution of Mechanical Engineers,* vol. 1, Mechanical Engineering Publications Ltd., Bury St. Edmunds, UK, pp. 555–562.

Walton, D. 1996, 'The Closure problem in practical reasoning', in *Contemporary Action Theory,* eds G. Holstrom-Hintikka and R. Tuomela, *Synthese Library Series,* Kluwer, Dordrecht (In press).

Ward, A. 1984, 'Design cosmologies and brain research', *Design Studies,* vol. 5, no. 4, pp. 229-238.

Watts, R. D. 1966, 'The elements of Design', in *The Design Method,* ed S. A. Gregory, Butterworths, London, pp. 85–95.

Webster Comprehensive Dictionary 1986, J. G. Ferguson Publishing Company, Chicago.

Weiskrantz, L. (ed) 1988, *Thought without Language,* Oxford University Press, Oxford.

Westerberg, A. W., Stephanopoulos, G. and Shah, J. 1974, 'The synthesis problem with some thoughts on evolutionary synthesis in the design of engineering systems', in *Basic Questions of Design Theory,* ed W. R. Spillers, North-Holland Publishing Company, Amsterdam, p. 170)

Westrum, R. 1991, Technologies and Society: The Shaping of People and Things,Wadsworth Publishing Co., Belmont, USA.

Whitney, D. E. 1990, 'Designing the Design Process', *Research in Engineering Design,* vol. 2, pp. 3–13.

Whittaker, T. J. T., Thornhill, D., Lu, S. and Mitchell, D. 1995, 'Integration of design systems for energy related applications', *Design Studies,* vol. 16, no. 4, pp. 415–428.

Whitworth, D. [on-line] 1996, available WWW: http://www.staffs.ac.uk/engs/des/design.htm

Wilde, G. L. 1983, 'The skills and practices of engineering designers now and in the future', *Design Studies,* vol. 4, no. 1, pp. 21-34.

Will, P. M. 1991, 'Simulation and Modelling in Early Concept Design', *Research in Engineering Design,* vol. 3, pp. 1–13.

Willoughby, K. W. 1990, *Technology Choice: A Critique of the Appropriate Technology Movement*, Intermediate Technology Publications, London.

Wong, A. and Shriram, D. 1993, 'SHARED: An Information Model for Cooperative Product Development', *Research in Engineering Design,* vol. 5, pp. 21–39.

Wong, A. K. C. 1974, 'Bioengineering design', in *Basic Questions of Design Theory,* ed W. R. Spillers, North-Holland Publishing Company, Amsterdam.

Woodbury, R. F. 1993, 'A Genetic Approach to Creative Design' in *Modeling creativity and knowledge based creative-design,* eds J. S. Gero and M. L. Maher, Lawrence Erlbaum Associates, New Jersey, pp. 211–232.

Woolley, L. 1992, 'Developing an (Environmentally Sustainable) Urban Image - a Case Study' in Conference Proceedings of EcoDesign 1 Conference: Sustainability Through Design, eds. T. Riley and J. Gertsakis, Centre for Design at RMIT, Melbourne, pp. 212–217.

Wray, G. 1992, Attaining competence in engineering design at undergraduate level: educational differences between engineering and engineering science, *Outline of Public Lecture* , Dept of Mechanical and Materials Engineering, University of Western Australia, (June 1992).

Wray, G. R. 1992, 'Attaining Competence in Engineering Design at Undergraduate Level; educational differences between engineering and engineering science', *Public lecture,* University of Western Australia, Western Australia, July 1992.

Yoshikawa, H. (ed) 1985c,*International Symposium on Design and Synthesis*, Elsevier Science Publishers B.V., Amsterdam.

Yoshikawa, H. 1981, 'General Theory of Design', in *Man-Machine Communication in CAD/CAM,* eds T. Sata and E. Warman, North-Holland, Amsterdam, pp. 35–53.

Yoshikawa, H. 1985a, 'Introduction' in *International Symposium on Design and Synthesis*, ed. H. Yoshikawa, Elsevier Science Publishers B.V., Amsterdam.

Yoshikawa, H. 1985b, 'Preface', in *International Symposium on Design and Synthesis,* ed H. Yoshikawa, Elsevier Science Publishers B. V., Amsterdam, p. v.

Zeleny, M. 1994, 'Six Concepts of Optimality', paper, TIMS/ORSA Joint National Meeting, Boston, 24–27April.

Zeng, Y and Cheng, G. D. 1991, 'On the logic of design', *Design Studies,* vol. 12, no. 3, pp. 137–141.