Systems Models and Engineering Design Theory

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Abstract

In this paper some of the philosophical considerations of the use of systems models in engineering design theory are discussed. The paper begins with an exposition of the role of systems models as an historical basis for engineering design theory and design methodologies. The widespread underlying presence of a 'systems' based paradigm in design theory is noted and some of the implications of this are explicated. The paper concludes with suggestions as to the philosophical appropriateness of the future application of systems modelling techniques to different areas of engineering design theory.

Preamble

The study of designing and the processes of design is relatively recent. Although a small handful of texts were published in the 1950s, it is generally acknowledged that design became recognised as a subject of study in the mid 1960s (Cross (1993)). Research into design and the development of new systematic design methods became well established during the 1970s. The main focus of design research was the creation of methods to improve the output of designers. Four other identifiable streams in design research were; the consideration of the philosophical aspects of designing (trying to identify the underlying basis of design), attempts to unravel the details of designers' internal creative processes (usually from a viewpoint of cognitive psychology), the study of the problem-solution relationship, and the modelling or optimising of the management of design activities. Cross (1984) identified four different overlapping themes in design research which he maintains also represent the chronological development of research into design and theories about design to that time. These differences can be attributed to Cross' focus on design research as design methodology. He lists the themes as:

1. Management of the design process
2. The Structure of Design Problems.
3. The nature of Design Activities
4. "Reflection" on the fundamental concepts of design

Although this list of themes represents both the main preoccupations of design researchers and theorists, it must be emphasised that at all times from the 60's to the present there has been a diversity in subject matter within the literature.

The main focus of design research is and has been research into methods and techniques (Cross (1993). Past and present research and theory development in the field of engineering design is aimed at improving the output of designers by the use of systematic methods. In most cases, what is being attempted is the routinisation of

design activity. This has been supported by the increasing availability of computers over this time. This, in its turn, has led to the development of an extensive range of computer based aids for designers. An underlying theme in much of this side of design research is that of attempting to totally automate the design process, so that the 'intelligence' and 'expertise' would become located in machines and processes external to the human designer.

Systems Models as a Basis for Engineering Design Theories and Methodologies

There are two strands in the historical development of design theory which reinforce the dependence of design theory on systems methods. The first strand is the externalisation of design: trying to make designing more visible and less mysterious. The second strand, is that of automating design. This reduction of design to an externalised automatic process has been one goal of design research, theorising and method generation. For theorists and researchers with this perspective, the Taylorisation of designing is straightforward: consider designing as a process, model this process using systems methods, then find means to emulate and automate it.

It can be seen from a cursory examination of the literature that these outlooks have been dominant from the earliest conferences (see for example; Jones and Thornley (1962) and Gregory (1966))on design research to the present. Perhaps the most seminal publication was that of J C Jones on design methods (Jones (1970). In it he collected together and classified the main methods of design available in the late 1960s. This book offered a new vision of design as a rational process that would remove the mystery from the activity of designing and enable design to be managed as easily as managing any other industrial process. Jones' outlook and most of the design methods which he collected together were based on the newly emerging theories and techniques developed for managing complex activities, such as; General Systems Theory, Operational Research and Linear programming. Prior to this, Alexander (1964) had proposed and demonstrated his computer based, decompositional method for designing. This method was based on a systematic analysis of the 'fit' or 'misfit' between different functional aspects of form and context. The method reduced design problems and their solutions to an hierarchical system of misfit relationships. Newall and Simon (1972) and Simon (1984) used systems based models of information management to represent human creative problem solving and designing. More abstract aspects of designing, such as the analysis of interrelationships between functions (Matchett (1962) in Gregory), were developed as design methods based on systems analysis.

Designing came to be seen as a process akin to the industrial manufacturing process. General Systems Theory provided a simple visual and symbolic representation which was applied to design. As systems models became more widely used in the 1950s, they provided a tool not only for designing complex engineering artefacts (by then seen as systems of interrelated functions), but also for managing design activities. From the 1960s onward, systems models of designing became commonplace, to the extent that many writers defined the activity of designing and design process as a 'design system'

unconsciously conferring 'privilege ' on this one conceptualisation of designing and the design process.

The development of system models of design may be seen in the visual representations of design process. Perhaps the simplest early systems model of designing is that of Jones (1970) in his 'glass box' view of a designer,

Fig 1.   The designer as a 'Glass box' - from Jones (1970)

Other writers and theorists, seeing the shortfalls of such a model, increased the complexity of their descriptions. An example of a recent version of this model is that proffered by Ertas and Jones (1993) in a text aimed at engineering design students in America.

Fig 2. Steps in the engineering design process - Ertas and Jones (1993)

Other researchers have concluded that the design process includes much more than what designers do. They propose that design permeates every part of a profit generating process based on making artefacts. Perhaps the most complex system based model of design from this view point is the multi-dimensional model of 'Total Design' proposed by Pugh (1990).

Fig 3. 'Total Design' - Product Design Activity Model - from Pugh (1990)

The systems outlook has become the most prevalent outlook in design theory. Critical analysis of the writings of design theorists and design methodologists indicates that (whether stated explicitly or not) the designing of technologically based artefacts is almost exclusively seen from within a 'paradigm' of General Systems Theory (in the sense of paradigm as used by Kuhn (1970)). My purpose here is to identify some of the problems which arise from this position.

Criticism of Systems Models of Design

There are several elements that are commonly considered to be essential parts of the process of producing an engineering design[1].

These essential elements are:

- Definition of 'needs'
- Creation of solutions
- Evaluation of Solutions
- Decision making
- Feedback

Simple system models of design attempt to portray these in a defined sequential manner. Several writers, however, appear to be uncomfortable with rigid systematic theories of design by noting that the sequence in which the above elements occur is fluid and depends on many factors such as the organisation, the individual designers and the problems in hand. Ullman (1992) reports on research by Hales and Ullman which concludes that it is not possible to follow a design in progress using such models. French (1970) has suggested that block diagrams representing design process may be drawn in many different ways. All design theories, models and methodologies have ontological and epistemological bases. Technological design is almost universally grounded in a positivist, scientistic, value-neutral framework where concepts and facts have fixed meanings which are objectively verifiable (in theory at least!). It appears that these ontological and epistemological assumptions are essential for the sensible modelling of designing as a system.

Coyne (1990) challenge this paradigm of design conceptualisation by arguing, from a hermeneutic perspective, that positivism and scientism and the assumptions on which they are based are an inappropriate foundation for design theory and method. Christians (1989) argues against the assumed neutrality of technology and its associated activities and artefacts. It is obvious that systems theory has some role to play in the development of engineering design theories and methods, but rather than systems theory being a useful tool of design research it appears that the activity of designing and its interpretation has been forced into a 'systems' perspective.

Design theory exists at many levels of conceptual abstraction. To use the terminology of Coyne and Newton (1992) of metaphoric theory of design - 'Systems models of design process' is a conceptual metaphor that has been given an unusual amount of privilege (Coyne, R and Newton, S (1992), Coyne, R, Snodgrass, A and Martin, D (1992)). The metaphoric representation of designing as a system has been widely adopted but in doing so it has shaped what is understood by design. To test whether such privilege is justified it is necessary to look again at the activity of designing and the theorising about it. This must be done so that theorising becomes the object of study. This is what Stegmuller (1976) calls a *second level rational analysis* or *meta-theoretical study*, or what in

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[1] Where 'design' is used as a noun to mean the drawings and specification of an artefact to be manufactured, as distinct from the physical artefact itself.

philosophy is known as meta-analysis[2]. What is being considered here is a further step in abstraction, ie the theorising about design theory and the use of systems theory in it. Looking at design theory as a subject, the main issue of design research might be expressed as,

> *The study of how ideas might be influenced before they are conceived.*

There is general consensus that the creative aspect of design is the activity which differentiates design from other activities involved in the production of artefacts. The identification of designing with creativity leads to a definition of 'design process' along the lines of 'any process which includes the activity of designing'. Thus, a design process may also consist of other activities besides designing. In the research to date, much has been made of these peripheral processes of design as 'design activities' ignoring the fact that the academic and practical study of many of these peripheral activities is well developed in other disciplines. To give examples: the analysis of 'needs' is dealt with by sociologists and philosophers, the choice between potential design options is more appropriately part of the study of decisionmaking (and hence, politics, business economics or ethics) rather than design itself. A simple test for whether an activity must be included in design research is whether the activity is unique to designing or whether it is simply an instance of an activity which occurs in other circumstances and is investigated generically in other disciplines. By deconstructing design in this manner it is clearer where systems methods are more usefully applied.

The challenge then, for design researchers is to derive a systematic representation for the essentially creative part of the design process. If it is not possible to do this and to adequately represent creative activity using systems theory, then it calls into question the assumption of validity of a systematic representation of the whole design process.

There appear to be several difficulties in representing creative designing using systems theory. Some of these are:

- The fundamental inclusion of the variability in an individual designer (or design team) of human values and the meanings ascribed to 'facts'.
- The apparently universal psychological use of 'design worlds' - where a designer creates an internalised representation of potential solutions or part solutions and their environmental contexts.
- The temporal nature of partial conceptualisation, ie the transitional nature of the values, meanings and conceptualisations inherent in the use of design worlds.
- The dependency of partial solution evaluation and choice by 'feeling' mechanisms.
- The 'reflective' development of both the artefact specification and the designer (see Schon(1983, 1992)).

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[2] Perhaps it is appropriate to note again, that design theory is theory about designing **not** the theories which designers use which are pertinent to the domain which they are working in or the artefact being designed is created in.

These are the difficulties that are immediately apparent and there are others which arise from the interpretive, praxical and value-laden nature of designing. All of them lead to two questions:

1. How can systems theory be used to portray a process which includes a need to select and modify creative thoughts before they are known?[3]
2. How can systems theory be used to describe a process where meaning is fundamental to the process and is not necessarily factual, ie it is a qualitative, value-laden element, dependent not only on the participants but also on the geographic, historic, cultural and religious placement of the process?

Conclusions

Design theory and design research has been shaped by its use of a paradigm of systems analysis. There are questions and difficulties which have not been addressed and which must be addressed for the intelligent development and use of systematic models of design activities. Taking a meta-theoretical overview there are three sides to the use of systems models in design theory. Firstly, it seems obvious that systems analysis may be applied to many parts of the overall process of creating products (as described by Pugh for example). Secondly, it appears to be very difficult to model creative human activities using a general systems approach unless ontological and epistemological considerations are ignored. Finally, there must be some question over the validity of modelling the total design process as a system if the creative elements cannot be adequately modelled but are an essential part of the system model. Therefore, I conclude that systems theory can provide useful tools in the realisation of aspects of the design process, but is incomplete as a model or description of the design process as a whole.

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[3] This is the purpose of design method and is one of the fundamental aspects of design which any theory of design must seek to encompass.

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