New Developments in Engineering Design Theory

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Abstract

In this presentation, the main developments of engineering design methodology over the last thirty years will be discussed. Design methods depend on a range of design theories. By looking at the different theories it is possible to get a better idea of which design methods are best suited for particular engineering projects. A new straightforward way of looking at design and the management of design will be described and recent directions in design thinking will be indicated, especially with regard to social, environmental and ethical issues in engineering design. Sources of information for the most up to date design methods and theory will be provided.

Preamble

This paper is intended to give some exposure to the work being done in the 'backroom' of design research, part of the discipline of engineering which receives little public attention.

First it is necessary to draw a distinction between the two terms 'engineering theory' and'design theory ' which are often used interchangably. For example, 'Engineering Design Theory' or its abbreviated form 'Design Theory' has been used as a catch-all to include anything theoretical which an engineer might use.

In this paper, the following distinction will be made.

> ***Engineering Theory*** - is what engineers use to model situations in attempting to gain more information. It includes the mathematical models and calculations used by engineers.
>
> ***Design Theory*** -is what design researchers use to model the activity of designing.

The difference between the two 'theories' reflects the difference in perspective needed to understand work in this area. Sargent[i] provocatively explains the situation as,

> 'Research into design is actually a scientific not an engineering discipline, and it has to involve engineers because they are the subjects of the study and not the proponents.'[1]

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[1] Sargent describes the distinction between engineering design and design research clearly, however, I feel uncomfortable with his description on two counts. Firstly, many engineering designers and those associated with design **are** interested in the activity of designing in a way which transcends 'doing' designing. Secondly, I feel that it is unfruitful to insist that research into designing is undertaken only

To emphasise this difference in perspective between engineering research and design research, the technological issues which engineers and engineering designers are concerned with can be contrasted with issues of design research. For example, one of the most important aspects of design research is, 'The study of how potential ideas might be influenced before they are conceived.' It is difficult to see how this could be conceived as a purely technological study.

A Brief History of Engineering Design Research

Research and theorymaking about the activity and processes ofdesigning is reckoned to have begun around the late 1950s (see for example; Jones (1966)[ii] and Cross (1993)[iii]). The three main disciplinary focii of what was known as the Design Methods Movement, were Engineering, Architecture and Planning.

Theorists and researchers started first with an underlying conception of the designer as 'magician'. As a consequence of this, the focus was on unravelling the details of a problem so that a designer's 'magic' could be used on it. This theory fitted well with the development of the new methods for handling complex problems which had been developed during and after the Second World War.[2]

Figure 1. The Designer as a 'Magician' (from Jones (1970)[iv])

Almost immediately, the role of the designer in design theory changed twice. Firstly, The new Systems perspective was not only applied to the problem, it was also applied to the designer. From this came the idea of the 'designer as a computer'. 'Inputs' were given to the designer (including some form of 'problem definition'), the designer 'synthesised' a solution and then 'evaluated' it. This process was repeated inside the designer until an acceptable solution was 'output' from the designer for others to see.

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within a *scientific* paradigm. (Others (such as Coyne[13](1991)) would argue that it is impossible to investigate design scientifically.)

[2] E.g., Operations Research, Systems Analysis, Systems Engineering and Linear Programming

Figure 2. Designer as a 'computer' (from Jones (1970)[v])

The second change in design theory was to completly remove the designer from the model of designing. Thus, designing was seen as a 'black box' process consisting only of inputs, outputs and some unknown transformational process between them.

Figure 3 'Black box' view of Design (from Jones (1970)[vi])

Removing the designer from the scene paved the way for the development of a myriad of systematic design methods and a wide variety of speculations on the best way to describe design and design process.

The most common ways of modelling designing and design process in engineering has been to use some sort of flow chart together with a a conception of designing as the transformation of information. Illustrated below is a recent example of this view of design from a text written by Ertas and Jones (1993) for the training of American engineering designers.

Figure 4. The Design Process (from Ertas and Jones (1993)[vii])

This idea of the design process as a flow diagram of information transformation is so commonplace and apparently ubiquitous that the suggestion that it is based on faulty premises[viii] and rarely used by engineers[ix], may come as a surprise to some. The search for a more appropriate basis for design theory must be directed elsewhere.

Taking a broad sweep over the literature relating to research into designing it may be seen that there are almost as many theories as there are theorists. The following statements are precis of different theories about design process:

According to different theories, design is seen as a process of moving:

- From an **ABSTRACT** statement of a problem to a **CONCRETE** solution.
- From **CONCRETE** needs to an **ABSTRACT** specification of a solution.
- From an **ABSTRACT** statement of needs to an **ABSTRACT** specification of a solution.
- From **CONCRETE** needs to **CONCRETE** solutions.

With this level of disagreement, establishing the epistemological status of the entities of design theory becomes difficult, if not impossible.

Another, potentially more fruitful, way of classifying the different design theories is as follows:

- Artefact based theories
- Management based theories
- Process based theories
- Information transformation theories
- Axiomatic theories
- Theories of designing as a human action
- Philosophically based theories

There are two main positions with regards to these theories. Some theorists see the creative activity of designing everywhere, and other see designing as something that something that occurs some times and in some places. The first point of view may be summarised as:

- Design encompasses almost all human activity.
- Engineering design relates to anything that is at least in part technological.

One of the main problems with such a wide definition is that it is so wide as to be almost useless - unless a strong case was to be made that 'designing' is a primary human activity like'thinking' or 'feeling'. No one, as far as I know, has been bold enough to make this their theoretical mainstay. It would require a substantial amount of justification. A further problem is that, in academic terms, this view of designing cuts across almost every other academic's turf. All other disciplines would then be expected to addresss this issue of designing - or arrange for a design theorist to address it for them.

The other way of viewing design is to see it as a particular activity which is associated with other activities or which needs other activities to support it. A parallel may be made between this perspective on designing and the act of painting pictures. A painter, such as Van Gogh, may do a variety of activities such as; eating lunch, sweeping his studio and cleaning his brushes. These activities are necessary, and they support the act of painting. But, **sweeping the floor is not painting**.

There has been considerable confusion over this issue in engineering design research. Engineering designers undertake many activities which are necessary to support the act of designing. These activities may include: looking up data, filing drawings, using mathematical models, or even banking their pay cheque. The creation of an artefact may be supported by these activities, but should they be considered as part of the act of designing? (To assume this is to move towards a position that 'everything is designing'.) The most fundamental confusion is between mathematical analysis and engineering design. Mathematical analysis (or engineering calculation) is necessary. It is the means of adding value to information. If information or data is not available directly, then often the designer may obtain it by calculation or modelling, thus it is a more sophisticated or complex way of 'looking up data'. Regardless of its current academic and professional status, engineering calculation must be seen to lie in other realms (data collection, for example) rather than designing.

How can it be decided whether something is designing or not? The test which seems most obvious (to me at least) is to ask, 'Is this activity exclusive to designing or is it just an example of an activity which is common to many other situations?' To give an example: Design management is often taken to be an essential part of design, and therefore it should be researched under the discipline of design. Using the above test would indicate that design management is an example of the more general activity of managing and therefore would be best researched in the disciplines in which management is studied. Applying this test to each area of design leaves very little left! Even information processing is devolved elsewhere. **What is left is what is essentially design.**

What I wish to propose here, is that consequent on the above, a human centred perspective on designing is the best approach. It is not the only approach, but it does seem to provide better theoretical coherence with a wide range of other bodies of knowledge. It simplifies engineering design research as a discipline, offers a philosophically justifiable basis for its epistemology and ontology, and perhaps most importantly, fits well with the extensive work done by researchers and theorists of design over the last 40 years. A human-centred perspective towards design implies the following assumptions:

- Design is human creative activity.
- Design is not routine activity.
- Only a small part of creating something is designing.
- Other activities such as management, analysis, modelling, information gathering, financial control, and decision making are necessary, but are not designing. (These, however, in their turn,may also contain some designing.)

This may be seen as a new paradigm of engineering design, but the idea that designing is best considered as a human activity has been well established in other design disciplines for some time. From the perspective of industrial design, Jones[x] in 1970 offered an idea of the self organising designer illustrated below. As early as 1964, Alexander[xi] was suggesting that the difference between primitive building and architecture was that architecture was done by human architects who design in a 'self-conscious' manner. (This may be seen as a similar concept to that of Schon's 'reflective action'.) Schon[xii] developed his concept of the 'reflective practitioner' , in the mid 1980s. This concept although not generally taken to be central to the question of what design is, has made frequent appearances in the literature of design research in a variety of creative disciplines. From a hermeneutic perspective, Coyne[xiii] has discussed the necessity for including the valueladenness of the designer in any theory of designing, and technological commentators such as Crane[xiv] have deduced that adequate treatment of ethical issues depends on such an inclusion.

Figure 5. The designer as a self organising system (from Jones (1970)[xv])

Implications of Design being seen as a human activity

By using this perspective of design as a human activity, some issues, which were problems in perspectives of design which are not human centred, are resolved. Other problems are transformed. Dealing with qualitative[3] issues is a major problems for researchers using more mechanistic theories of design. The problem is usually expressed as, 'How can *qualitative* issues be expressed *quantitatively* so that they can be incorporated into mathematical models.'[4] It may be said that there is no epistemologically satisfactory solution. Using a human centred theory of design results in a reversal of the problem. Consider the following.

1. Most engineering information is ***quantitative***.
2. Designers' creative processes including their use of 'design worlds' and their evaluation of partial conceptualisations are fundamentally ***qualitative***.
3. Mathematical models are best seen as 'data collection' rather than as part of designing.

Therefore, the above problem no longer exists for qualitative issues. For quantitative issues, such as the information gleaned from calculations, the issue is resolveable. The question then becomes,

> 'How can ***quantitative*** data be converted to a ***qualitative*** form that is more easily useable by designers?'

Practically, examples of this sort of problem are now being seen in situations where large volumes of data are being dealt with (eg, electricity generator control rooms, satellite data analysis, music recording studio consoles and computerised design aids). Research in these matters is normally undertaken within the provinces of psychology and human factors engineering, or as it used to be called 'ergonomics'.

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[3] 'Qualitative' here is being used in its conventional sense, ie, as used in Social Science research to refer to that which involves human values, rather than the pseudo-sense of a number of events which may be given a qualitative title.

[4] The 'weighting' methods (for example; Multicriteria Programming and MultiVariable Analysis) which attempt to convert qualitative issues into qualitative ones are subject to the same epistemological criticisms as Risk-Cost-Benefit Analysis. (For example, their dependence on a fact-value dichotomy.)

Social, Environmental and Ethical Issues

Social, environmental and ethical issues in design have two sides to them; quantitative and qualitative.

Quantitative - Bounds or criteria defined by government agencies, Professional Codes or Law (eg. maximum amounts of gaseous emission). These may be dealt with like any other quantitative information.

Qualitative - issues which depend on human values. As designers function qualitatively and this provides the means whereby social, environmental and ethical considerations can influence which designs are conceived and how they are evaluated[5].

As indicated above, the problem of including social, environmental and ethical issues into a human centred theory of engineering design is straightforward. (This is not to say that its detail may not be complex or difficult, only that it has a more coherent philosophical foundation.)

Management of Design

Perhaps the most important information needed by managers is 'Who is doing What?' For the manager of design activities there are three aspects of designing which come directly out of the above human centered perspective on designing. These are:

- Others, besides designers, contribute to the design of engineering artefacts and systems.
- Most of what good engineering designers do is not 'designing'.
- Knowing the difference between 'designing' and other activities enables designers and design departments to be more efficient and cost effective.

Hubka and Eder[xvi] provide an analysis of some of the different subjects which may be associated with designing which uses mechanical engineering knowledge. A diagram illustrating their analysis is shown below. Each of the subject areas shown on the diagram lying outside what they call 'general design science'[6] is the source of expertise in a discipline other than design. It is difficult to see why such matters should frequently be seen as matters to be studied as part of design.

[5] 'Evaluation' here is used in the sense of drawing out their 'value'. It is human values which are being discussed here, not mathematical ones.

[6] As is noted before, there are design theorist who argue that the 'science' is an inappropriate conceptual basis for the study of design.

Figure 6.

Connections between Design Science and other areas of knowledge (from Hubka & Eder (1990)[xvii])

The distinction between the activity of designing and other activities which are associated with designing may be seen in a process network or time line analysis. The one below is from Ross. It shows how the majority of the activities in this design process are associative activities. It may also be noted that those activities clearly indicated as 'design' in Ross' diagram do not refer to activities which are exclusively design activities. For example, 'do trial design' may also include non-design activities. Most, if not all, of the other items on Ross' diagram, however, will also include elements of human design activity.

Figure 7 - Design Network (skeleton) (from Ross (1966)[xviii])

Using Models for the Management of Design

Most general process models of engineering design are inaccurate at best and totally unrepresentative at worst. To be useful to a manager, a model must be a close match to the design process which is managed. The situation being modelled depends on the time, the place and the people involved in the process. Those involved in research into the management of complex systems (see for example; Flood[xix], and Flood and Jackson[xx]) have recently evolved methods which deal with human centred activities. Thes methods fit well with a human centred perspective on designing.

The essential basics of the above are:

- Construct a management model of the particular process under scrutiny - identify the different activities in detail and investigate how the activities function together.
- Use the expertise from the disciplines which most closely fit the different activities (together with systems management methods) to improve how the process works.
- Break down the work of the design team into components such as: information gathering, time management, financial management, evaluation, decisionmaking, mathematical modelling, communication, routine administration and creative design.
- Look for shortcomings and redundancies in each category of resources.
- Use this information to guide management strategy, employment strategy, investment strategy and organisational structure.

Summary

The above theoretical emphasis on human action in design results in the decisions about the implementation of technology in human affairs being located (theoretically, at least) in humans. It effectively acknowledges the role of well trained professionals using their skills, rather than reducing the role of designers, engineers and managers to that of machine minders. In this sense, it provides a representation of the activities and processes of design which is closer to reality.

To summarise the main points developed in this paper:

- ***Designing*** is human creative activity
- ***Design process*** includes designing along with other activities
- The expertise in most activities in engineering design processes lies outside design (and often outside engineering).
- Make pertinent local models of design processes (using information from Design Theory as appropriate).
- Use local design process models to guide management strategies, investment and decisionmaking.
- Use appropriate sources of disciplinary knowledge, ie, Design for design, Analysis for analysis, Management for management. . . .

Journals containing information about Engineering Design Research

- *Design Studies* Oxford: Butterworth - Heinmann.
- *Journal of Engineering Design* Abingdon: Carfax Publishing Company.
- *Research into Engineering Design* New York: Springer-Verlag.
- *Artficial Intelligence for Engineering Design, Analysis and Manufacturing (AI - EDAM),* Cambridge University Press, USA

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