KNOWLEDGE SUPPORT SYSTEMS FOR CONCEPTUAL DESIGN: THE AMPLIFICATION OF CREATIVITY

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Abstract. The paper is concerned with computer-based support for conceptual design and, in particular, with the support of creative design. The nature of conceptual design is briefly reviewed and the lack of effective computer support noted. Recent developments in computer-based Knowledge Support Systems, that offer interesting possibilities, are reviewed. The study of the early design of a clearly innovative product, the Lotus bicycle, is used to inform a discussion of the requirements for Knowledge Support Systems that can support conceptual design.

Introduction

As Faltings (1991) puts it,

> "Most research in intelligent CAD systems has focused on *detail* design, the adaptation of an initial concept to precise specifications. Little is known about the process of *conceptual* design, the transition between functional specification and concept of an artifact that achieves it.".

It is suggested that creative thought often occurs at the conceptual stage and hence any support that could enhance the designer's performance at that point could be extremely valuable. A secondary, but significant, issue is that the transition from conceptual to detail design often involves the manual entry of information into a CAD system, because the conceptual data had not been captured electronically. These are the issues that the paper will address.

Background

Perhaps the most important point to note about the nature of conceptual design is that made by Visser (1992), as a result of empirical studies of designers:

> ".. a problem solver is not 'given' problems, but 'constructs' them."

Or, as Hori et al (1993) put it:

> "In ... creative design, humans build new concepts out of *nebulous* mental worlds. They have some *seeds of a new concept*, incubate them and create a new concept..." (my emphasis).

Thus, the process is as much one of problem definition or selection as problem solution: it is essentially creative. The designer generates a set of scenarios or possible prototypical solutions at this stage. A potential problem, in relation to innovation, is that they tend to eliminate options early on in the process (Lawson, 1980). One important role that computer support could play is in keeping ideas open longer by providing "external" memory and concept management facilities.

Figure 1 gives an impression of the role that computers play, at the moment, in innovation. The boundaries between these activities are of prime concern. The question is, simply, "Can the CAE support begin sooner and can it, as a consequence, amplify creative design activities.". The problem is that the earliest stages are characterised by uncertainty, tentative decisions and informal representations of design ideas.

The concept of Knowledge Support Systems, in which the end user manipulates machine representations of knowledge directly (Shaw & Gaines, 1988), has recently been developed in LUTCHI and applied to scientific exploration (Candy et al, 1993a; Edmonds et al, 1993, O'Brien et al, 1992a, 1992b). This work has clearly demonstrated a potential for supporting creative work (Candy et al, 1993b). At the same time, other workers have began to study the approach in the specific context of design (Fischer & Nakakoji, 1992; Hori et al, 1993).

Research into the design process has suggested that many of the requirements for support tools are similar to those observed in the LUTCHI study of scientific exploration above (Visser, 1992; Fischer, 1990). For example, Visser proposes that tools to assist in the management of memory load would positively support design. Her results relate closely to those of Candy et al (1993a) in the use of Knowledge Support Systems in the science domain.

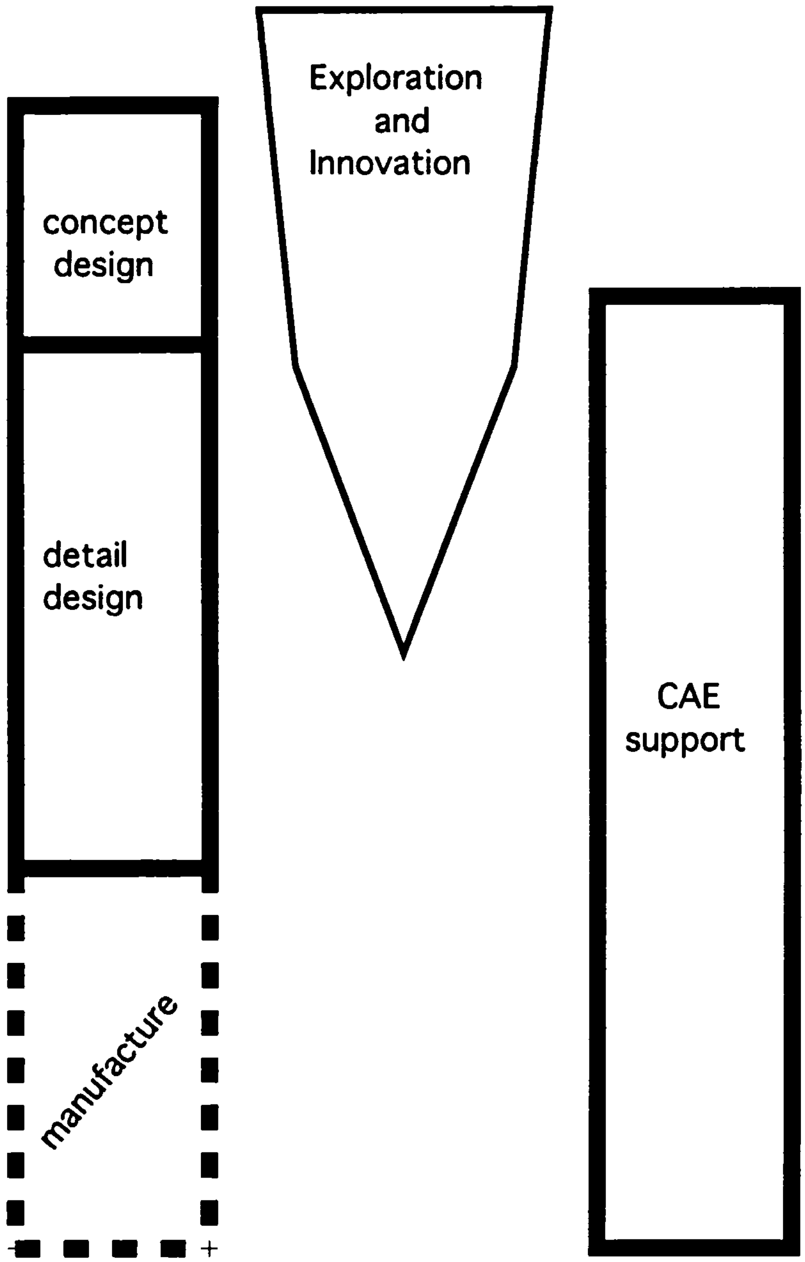

Figure 1: The design process, the designer's exploratory and innovative work and the support from computers:- an impressionistic view

The central problem

The main concern of the paper is to consider the feasibility of applying the recent research developments in computing described above to the provision of computer support for conceptual design.

A pragmatic approach was used for the investigation in which the development of a successful innovative product was investigated. The results of the investigation are related to the practical use of advanced CAD systems in a closely related context.

In the 1992 Olympics, Chris Boardman won the first UK gold medal, in the 4000m cycling pursuit event. He was riding a revolutionary bicycle built by Lotus Engineering based upon the design concept developed by Mike Burrows (figure 2). The design of this bicycle is the subject of the study reported. Computers were not used at all in the development of the original concept whilst, in contrast, Lotus operate a sophisticated CAD infrastructure. The research reported is investigating the feasibility of bridging this gap.

Support for creativity in practice

Lotus Engineering are firmly committed to the exploitation of knowledge-based technology to support design. They have used the ICAD system, from ICAD Engineering Automation Ltd, for several years in order to develop flexible and efficient support for the earlier design stages. They have been able to demonstrate that a number of clear benefits accrue, including reduced timescales, the effective handling of complexity and the possibility of building generic design modules that are readily available for re-use (Gregory, 1992). However, so far this work has not involved the creative concept designer in direct computer use. The Lotus ICAD users are specifically trained and frequently tackle particular problems that are more well defined than the ones that one finds at the very initial conception of a product. Nevertheless, that work includes investigations into support for early explorations and is at the leading edge commercially, clearly pointing towards the increased use of knowledge-based CAD in conceptual design. Our concern is, primarily, the use of systems like ICAD to act as a bridge between support for early conceptual design and the standard CAD system.

The results of the LUTCHI work have identified key design requirements for Knowledge Support Systems. The resulting underlying user interface architecture is designed to be generally applicable and easily tailored for specific domain applications. The work is extending our understanding of how knowledge-based systems can support science and the intention is to now investigate the same approach in design. The cognitive findings are concerned with the nature and accessibility of knowledge to the domain expert. The important distinguishing characteristic of this work is that it is concerned with complex domains in which the expert does not have complete knowledge but, rather, where the approach enables them to extend and refine their own understanding. This issue is central to the creative professional work that is the subject of our concern.

It is, therefore, postulated, with Fischer and Nakakoji (1992), that the knowledge support systems approach could provide helpful support for conceptual design. The authors are exploring this hypothesis in order to draw out the consequential requirements for such a support system in a specific case of recent innovative design.

The Lotus bicycle concept

Mike Burrows is collaborating with the authors so that a cognitive history of the development of the original concept of the new bicycle can be re-constructed. It is pertinent to place this history in the context of other empirical research into early design and, in particular, Knowledge Support Systems. For example, amongst the conclusions of the LUTCHI work referenced above were that the user required:-

- to be able to take an holistic view of the data at any time
- the ability to suspend judgement on any matter at any time
- to be able to readily make unplanned deviations.

The last point was elaborated, in the context of design, by Visser. These results provide a framework for the analysis of the early design history of the bicycle. As a result, therefore, preliminary requirements for computer support are postulated. The development of the bicycle concept from Burrows' early explorations (c1979) to the time of Lotus undertaking the production of the bicycle for the Olympic Games in 1992 has formed the basis of the study.

The design process seems to have been characterized by a number of salient factors or events identified by Mike Burrows as being significant.

1. Time duration:

A lengthy gestation period existed between the formation of the initial thoughts and the final realization of the revolutionary concept. This was a normal experience for Burrows in his design work.

2. Personal and professional goals intertwined:

Burrows is a serious amateur cyclist and monocoque recumbent racer. Personal ambitions provided the stimulus to achieve advantage. Indeed, he expresses his main goal as having been "to go faster": i.e. to satisfy a personal requirements for his racing in cycling events. However, he is also a professional engineer by trade. As well as motivation, skill and knowledge, he had access to machinery for making, for example, hand made bicycle frames. Making was, most probably, an important factor in the design process.

3. Knowledge of the field:

Apart from general design and engineering knowledge, Burrows has a keen interest in the history and development of the bicycle itself. He is very aware of aspects of the process, such as the fixed ideas held about bicycles, and the required series of conceptual leaps and experiments with prototypes that can eventually lead to breakthroughs.

4. Convention and creativity

There are, amongst cyclists, deeply held views of the bicycle concept. Very small changes in the angles used in a frame are very significant to the perception of "experts". It is not clear that this expert opinion is well founded but it is certainly strongly held. Thus, amongst experts, the search space of possible designs is thought to be well understood. Thus a critical factor in creative bicycle design is the ability to move outside the existing search space; i.e. to break with the conventional expectations and images.

Moving outside of the search space is closely connected to the ability to respond and exploit the unexpected: for example, the combined ideas of a lady-frame shape with the BMX small size frame, triggered by hearing of a BMX used for racing. The chance availability of carbon fibre material (1982) caused the realisation that a small, but conventional, frame could be improved by filling it in. A change in the British RTC regulations, allowing the use of rear disk wheels in time- trials, generated new design possibilities.

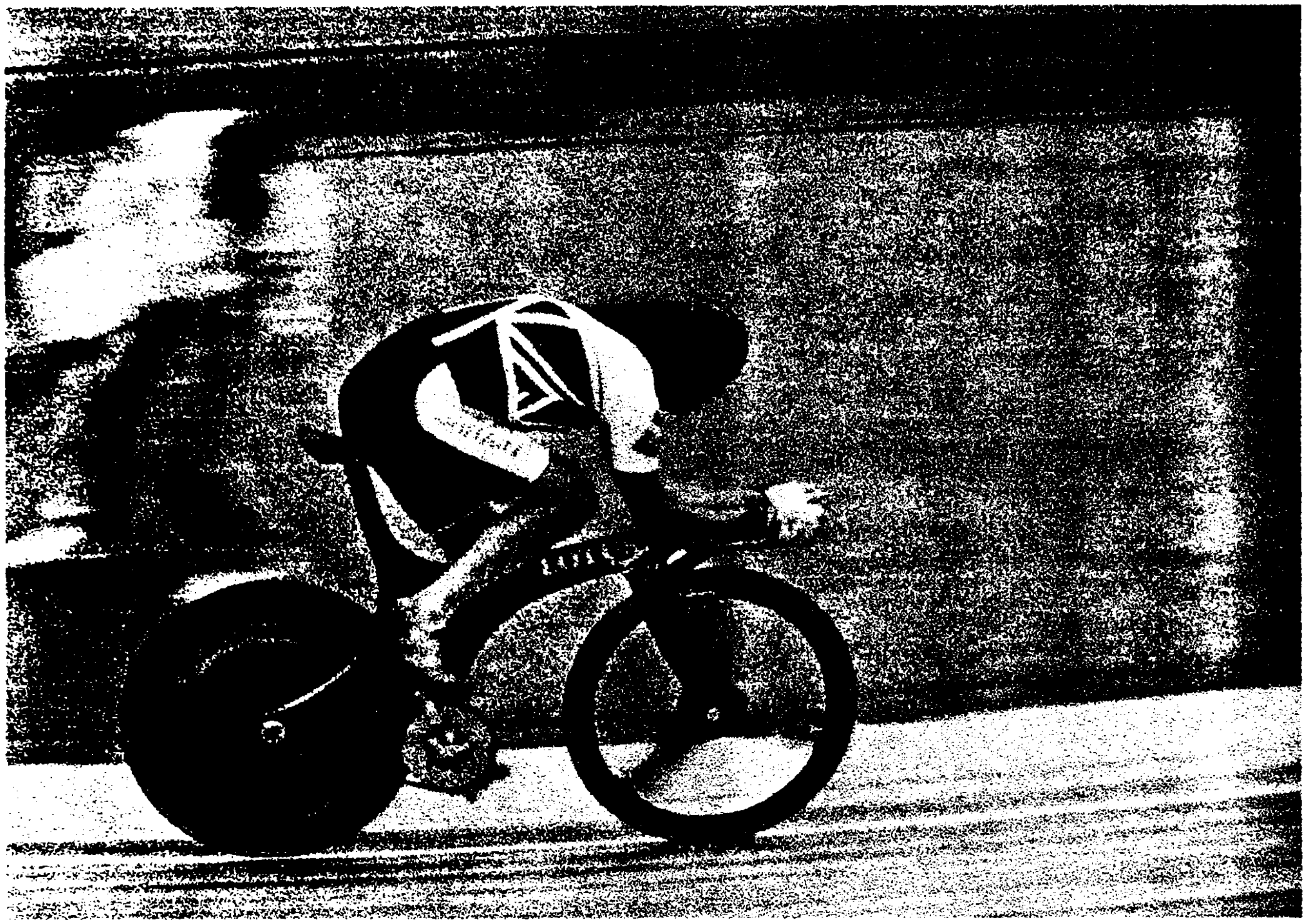

Figure 2: Chris Boardman breaking the world 5000m record on the Lotus bicycle.

These events led progressively, over years, to the realization that increased speed could result from the use of a small filled in frame, set back from the usual position, using a very light weight mouldable material and designed without the need to shield the rear wheel for wind resistance. The resulting bicycle concept was developed in practice to the extent that a working machine existed. The next step was to move that initial concept into the processes of the Lotus design system.

The use of CAD in the earlier stages of design within Lotus is advanced and interesting. Nevertheless, it did not influence the initial bicycle concept. Particular attention is paid to the exploitation of the ICAD software, which has successfully enabled Lotus to support design in a significantly more iterative manner. The parameters within which the postulated additional computer support might take place may be placed in that context. Outstanding questions include, what are the constraints on the form of data that could usefully be transferred into the current CAD systems? To what extent could the existing systems have offered support to the bicycle's conceptual design? What are the future requirements of CAD for early design?

Implications for intelligent support to conceptual design

The requirements for the user to be able to take an holistic view, to be able to suspend judgement and to make unplanned deviations, that were mentioned above, have been strongly supported by the bicycle study. Additional points have also emerged, however.

The need to keep a multitude of design processes alive over long periods of time must be supported. The goals of each of these processes might be at a very high level, such as "go faster", and so may not, in themselves, define a search space. Domain specific knowledge is clearly important but the creative step may well rely upon an act that "breaks set" with conventional wisdom. In other words, creativity may be associated with a re-definition of the problem space.

It is concluded that support systems for conceptual design must allow the user:-

- to take an holistic view of the data at any time
- to suspend judgement on any matter at any time
- to be able to readily make unplanned deviations.
- to return to old ideas and goals
- to formulate, as well as solve, problems
- to re-formulate the problem space

It is the process of interaction between a Knowledge Support System and the designer that is the key element in enabling the amplification of the designer's creative achievements. This process must be allowed to occur in a way that, as a minimum, conforms to the above design ideals.

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