The Nature and Role of Theories in AI in Design Research based on a Design Research Methodology

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1.   Introduction

This short position paper will address the following issues in order to encourage a discussion:
*   What could be the aim of AI-in-design research.
*   What is involved in design research.
*   What is the nature of design theories.
*   What is the role of AI in design.
The paper concludes with the nature and role of design theories in AI-in-design research as envisaged by the authors.

The point of view taken is from design research, with a possible bias towards mechanical engineering, as this is the main area of both authors.

In the following sections the main points of each of the issues will be addressed in order to encourage a discussion of the authors' view.

2.   The aim of AI-in-Design research.

Rich and Knight [1] give the following definition of AI:
> the study of how to make computers do things which, at the moment, people do better.

According to Winston [2] the purpose of this is:
> to understand the principles that make intelligence possible, and to make computers more useful.

The overall aim of engineering design research can be stated as:
> To develop knowledge of design which can improve the chances of producing a successful product.

Combining these aims, a possible overall aim for AI-in-design research is:
> to explore AI-techniques that could be used to develop knowledge of design and to improve the chances of producing a successful product.

3.   Design research.

Two types of design studies can be distinguished: descriptive and prescriptive. Descriptive studies provide a description and explanation of what design is. Prescriptive studies provide a description of what improved design (product and process) is, and provide guidelines on how design could be improved.

Both studies are to be linked to fulfil the aims of design research. In order to develop a prescriptive theory and to develop tools, it is necessary to take into account the existing descriptive theories. It may also be clear that in order to determine whether the tools had the

expected effects, another descriptive study is necessary. The results may be improved descriptive theories and may lead to the improvement of prescriptive theories and tools. The link between the two types of theories becomes clear from the research results. 'Descriptive researchers' often suggests ways to improve design based on their results. 'Prescriptive researchers' often base their theories about how design could be improved on experience. The authors propose an overall methodology for design research in which these links have been made explicit* This methodology is visualized in Fig. 1 and elaborated in the next paragraphs.
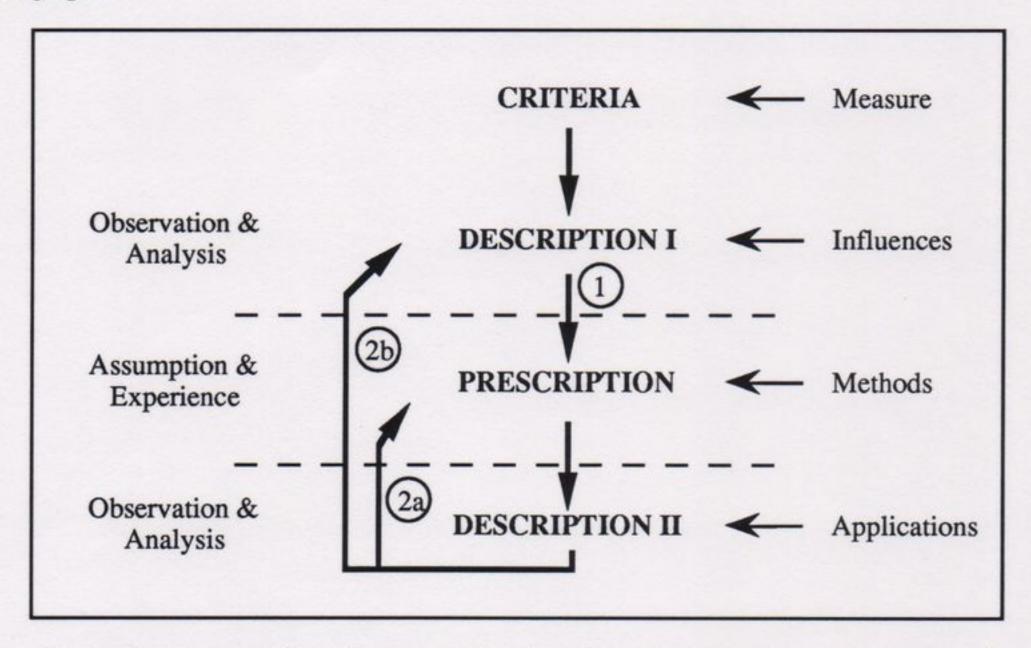

Fig. 1 Design research methodology (numbered are the links that need addressing).

Improving design in practice is considered as the overall aim of design research. This raises several questions: 1. What is meant by a successful product?; 2. How is a successful product produced?; 3. How could the chances of being successful be improved? The first question leads to issues such as what criteria should be used to judge success; the second to issues such as what are the influences on success, how do these influences interact and how can they be measured; the third to issues relating to the development and validation of design methods. A simple example will help clarify the methodology.

Example:
Criteria:	Increase of profit is identified as a criterion for success.
Description I:	A descriptive study is executed, involving observation and analysis, which shows that decreasing cost contributes to increasing profit.
Prescription:	A method (or tool**) is developed to decrease cost.
Description II:	The method is applied and a descriptive study is executed to validate the method. This includes two tests. The first test is whether the costs have been decreased (a comparison with Prescription). The second test is whether the initial criterion has been realized, i.e. whether profit has increased (a comparison with Description I). There might be reasons as to why the second test fails, such as side-effects of the method.

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* The schema has been developed together with Ken Wallace of the Engineering Design Centre in Cambridge. It has been presented during the Workshop on Engineerring Design Research in November 1993 at the Open University, Milton Keynes.

** A tool is defined here as a method implemented in software

Most of the steps in this methodology have been addressed in design research, in various areas, using many different methods (see [3] for an overview). The oldest area is the development of design methods (Prescription in Fig.1). Examples are the methods of Asimov, and of Pahl and Beitz [4, 5]. Descriptive studies of how designers design in the area of mechanical engineering (Description I) are relatively recent. Some of these studies focused on the influences that contribute to the quality or success of a product (e.g. [6, 7, 8, 9]). Some descriptive studies focused on processes in which a specific method has been applied (e.g. [3,10]). They can be considered to belong to the Description II step of the proposed methodology. However, comparisons of processes applying a specific method (or tool) with processes without such a method have seldom been addressed explicitly.

Three key issues remain. The first is the establishment of link '1' in Fig.1 between the results of descriptive studies (Description I) and the development of design methods (Prescription). In the development of methods and tools to improve design, the available body of knowledge about design should be consulted. The other two key issues address the need to validate developed methods. As indicated in the example, this has to be done through the establishment of links between Description II and Prescription (link '2a') and Description I (link '2b'). Section 5 will discuss the role AI can play in establishing these links.

4.   The nature of design theories.

The different design theories that result from design research, whether descriptive or prescriptive, can be of a diverse nature. To say they should be physical or behavioural does not do justice to the large number of different aspects of and influences on design and their interrelationships. Design involves, among others, people, products, and organisations. This results in a spectrum of theories such as cognitive [11], social [12], engineering [13], organisational [9].

A typical characteristic of design research is that it not only aims at understanding the phenomenon of design, but to use this understanding in order to change it. The latter requires more than a theory of what is, but also a theory of what would be desirable and how the existing situation could be modified into the desired.

The overall aim of engineering design research as mentioned in section 1 can therefore be divided into two sub-aims:
    Understanding how designers work.
    Developing methods to improve design.

5.   AI and design.

In correspondence to the aforementioned aims, the results of design research can be divided into descriptive/explanatory and prescriptive, both of which can be computer -based or manual. In descriptive studies, the role of AI could be to provide an implementation possibility for the theories developed and to compare the outcomes of the AI-program with the outcome of human designers, i.e. to test the theory and increase our understanding of design. The role of AI could also be the development of computational theories of design. In prescriptive studies, AI could be used to develop tools for the designers, incorporating these theories, to improve their design.

Similar to the overall aim of engineering design research, the overall aim of AI-in-design research can thus be divided into two sub-aims:
    Using AI-techniques and theories to understand how designers work.
    Using AI-techniques and theories to develop tools to improve design.

At present AI-in-design research seems to concentrate mostly on the generative aspect, i.e. on the development of tools, and in some cases on developing computational theories of design,

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rather than on testing design theories, either prescriptive or descriptive. Several AI-based programs focus on automating the design process, not in order to test the theories, but as a tool for the designer. Furthermore, although AI theories have been frequently used in AI-in-design research, theories resulting from design research have been rarely consulted.

Looking at these research areas, it seems that AI-in-design research has a close parallel in the areas that are lacking sufficient attention to those identified in design research (see missing links in Fig. 1). These are: testing the theories, and using existing theories to develop means to support designers.

6.   Conclusions

The authors see a clear role for AI-in-design research in two different ways, each involving a specific type of theory and research methodology: to improve our understanding of design, and to improve design, i.e. both the product and the design process. In order to achieve this, a closer cooperation between AI and design researchers is necessary.

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