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RESEARCH ABSTRACT

Learning for design reuse

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1. DESIGN ASSISTANCE

Over the past decade "design assistance," that is, where the computer is viewed as an *Intelligent Design Assistant* (IDA) (MacCallum et al., 1987), has emerged in knowledge based design support and has formed the basic research strategy for the CAD Centre, University of Strathclyde, since the mid-1980s. Within this philosophy, an IDA would act as a colleague to a designer, providing guidance, learning from past design experiences, carrying out semi- and fully-automated tasks, explaining its reasoning and in essence complementing the designer's own natural skills, and thus leaving the ultimate decision-making, control, and responsibility with the designer (Fig. 1).

The ability to learn and evolve has been recognized as one of the key components of an IDA for it to fully support the designer's activities. Consequently, we have been directing our research effort on two main fronts, formalizing our understanding and developing models of learning and reuse in design, and building appropriate software tools to step toward the concept of IDA.

2. MODELLING LEARNING AND REUSE IN DESIGN

2.1. Learning in design

IDA may be achievable through the development of improved computational models of design. To build appropriate computational models, we first of all need to understand what is learning in design. We first attempted this by asking three basic questions (Persidis & Duffy, 1991): how does learning occur, what knowledge is learned, and when does learning occur?

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2.1.1. *How?*

To understand learning it is useful to examine what constitutes a learning event. We consider that learning occurs in three basic ways:

- Acquisition: the process of receiving new knowledge.
- Modification: the process of altering existing knowledge.
- Transformation/Generation: the process of creating new knowledge from existing knowledge.

2.1.2. *What?*

There are no clear boundaries to the design knowledge we learn, however, there are main areas. For example, we learn of: the **environment** in which the design solution must operate and fulfill its functional requirements; the **design/artefact**, which represents a description of the total solution, including necessary life cycle and life phase systems; the **design activity** and its **management**; and the **domain** in which the design activity/solution belongs.

2.1.3. *When?*

Designers learn when they encounter knowledge that is sufficiently different from their present state of knowledge. Learning is a perpetual process that occurs during and outwith the design activity. It can be actively sought or passively achieved and can occur at any time or any place. The *Design/Learning Loop* (Fig. 2) illustrates how the activities of design and learning are coupled. The lower loop links design and learning activities from the solution to/from experiential knowledge reflecting the interactive nature of design and learning. That is, where the designer, at various stages of the design process, develops a design solution, learns from that solution and activity, feeds such learned knowledge back to some store of experiential knowledge, and reuses this knowledge to aid in the evolution to an acceptable design solution. During design, some of the learned knowledge will transform to longer term experiential knowledge and some only used

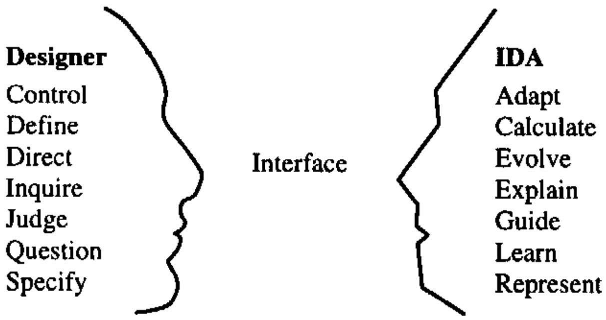

Fig. 1. Designer and IDA roles (Duffy, 1986).

to help the design process progress. Thus, the experiential knowledge reflects that knowledge that will be reused in new design scenarios whereas the *transient knowledge* will only be used to assist in problem-solving and the evolution of the design to a final conclusion.

Some of the more obvious occasions when learning takes place are when evaluating or analyzing the design solution; when recovering from errors or mistakes; when asking for advice or actively participating in problem-solving; when exploring the domain for appropriate solutions, answers, or new knowledge; and at the completion of the design.

2.2. Design reuse

To effectively use learned knowledge we have developed the first *Design Reuse Model* (Duffy et al., 1995) in engineering design, as illustrated in Figure 3. The knowledge components of this diagram are:

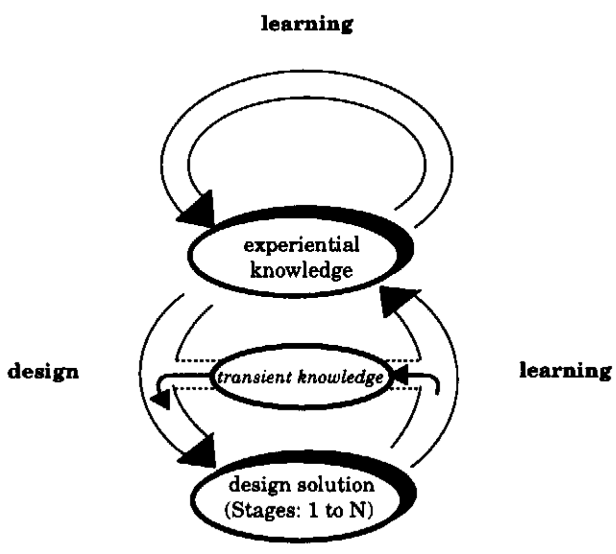

Fig. 2. *Design/Learning* loop (Duffy & Duffy, 1996).

- *Design requirements*: refers to a statement of a design need/desire.
- *Domain knowledge*: knowledge pertaining to a particular design domain.
- *Reuse library*: A storage location holding reusable (compiled) design knowledge, information, and data.
- *Domain model*: represents a designer's conceptualization of a design domain that is applicable to the current design problem.
- *Evolved design model*: a statement of an evolved design.
- *Completed design model*: a statement of a fully defined new design that is believed to satisfy the design requirements.

and the processes are:

- *Design by Reuse*: the process in which knowledge resources are searched so that useful knowledge can be identified, retrieved, and applied to the new design problem.
- *Domain Exploration*: the process of searching, understanding, generalizing, and, in general, "conceptualizing" the domain to gain an understanding of the features of that design domain from which reusable fragments of knowledge can be identified, extracted, and stored for subsequent use in design.
- *Design for Reuse*: a process carried out to record knowledge that is generated during design for subsequent reuse.

3. SOFTWARE TOOLS

3.1. NODES—learns from past designs and supports the creation of new design solutions

NODES (Persidis, 1989) is a Numerical and Object based DESign system developed to support modelling operations during the early stages of design and provides assistance in the building, manipulation, and analysis of a model of the design artefact (Duffy et al., 1996). To fulfill this role, NODES uses its knowledge of a domain, which it obtains by accumulating solutions of problems defined within that domain. Thus, although to begin with, the system allows the representation and analysis of designs, it soon acquires, modifies, and generates enough knowledge to be able to actively assist with the creation of new design solutions.

The system maintains a designer initiated *reuse library* by allowing newly evolved concepts (models) to be stored in the library and for the previously stored concepts to be updated as a result of the new concept. That is, the reuse library consists of a set of classification hierarchies (*concept libraries*) of commonly used domain concepts; for example, in the domain of car design, commonly used

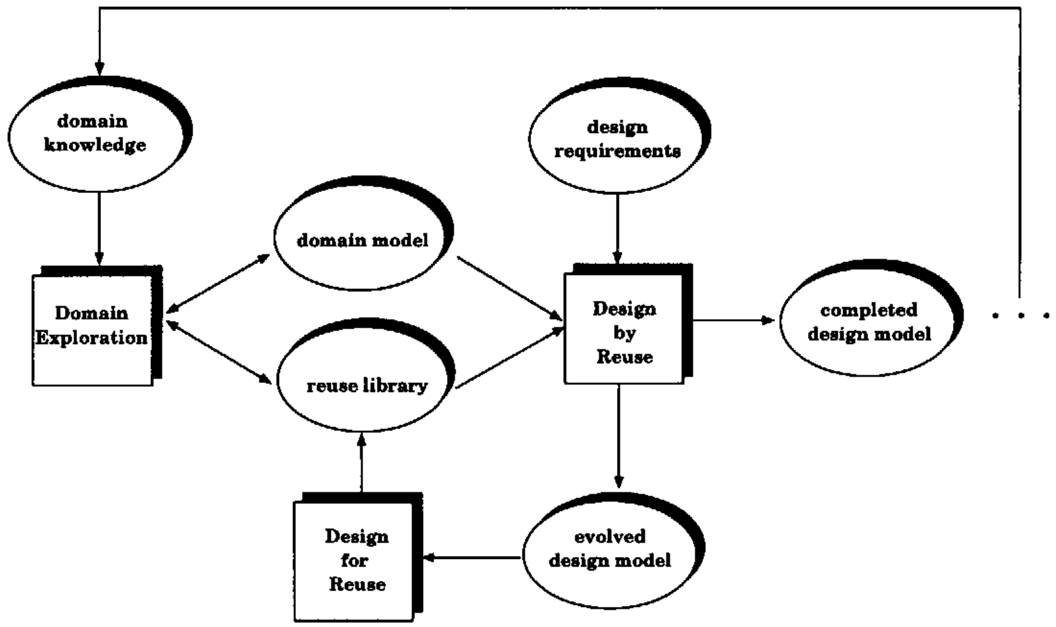

Fig. 3. A design reuse model (Duffy et al., 1995).

concepts might be the chassis, engine, gear-box, etc. However, a key feature of these hierarchies is that the subclasses do not inherit their properties from their superclass, as in other typical class hierarchies, but generalize from their subclass or past design instances/examples "up" the concept hierarchy. Thus, concept libraries represent the knowledge NODES has acquired of some domain and become relevant when:

- they are being created by the designer – the designer defines a taxonomic hierarchy of similar concepts, where the more specific concepts are subclasses of the more abstract ones.
- a completed design is added to them – when a design is completed, each concept, together with its associated knowledge, is automatically added as a member of its corresponding class.
- the knowledge they contain is used to decompose some model – in designing a *car* for example, the knowledge that is associated with the class *sports-xx* in the library *cars*, can be used to decompose or synthesize the model of the new car design.

When a design has been completed, the evolved model in NODES is used to expand its knowledge by acquiring the knowledge concerned with that new design. In the acquisition stage, the system automatically "breaks down" the design into its constituent concepts, along with appropriate constituent and connective relations, and merges each concept with its corresponding library, that is, *Design for Reuse*. Alternatively, the designer can select particular components of the design to add to a respective library.

NODES also generalizes ("abstracts") knowledge from the most comprehensive concepts within a concept library to the less specific. Numerical parameter ranges and compositional knowledge are generalized to all associated superclasses to ensure that there is no contradiction between a particular concept and its specializations. This knowledge can then be used in a process of *Design by Reuse* to not only provide guidance to a designer but also to assemble (synthesize) new concepts.

3.2. PERSPECT – supports Customized Viewpoints and Shared Learning

This system couples learning and design by supporting *Domain Exploration* and *Design by Reuse*. It is based on the belief that a) within the abundant explicit information of individual past designs, there exists a wealth of implicit knowledge that should be made explicitly available to the designer and b) that designers require different viewpoints from past designs and abstractions to facilitate the effective utilization of past design knowledge (Duffy & Kerr, 1993). It highlights the need for a dynamic design tool capable of automating the rationalization of past designs to suit a designer's particular needs (Kerr & Duffy, 1992). Current approaches to viewpoint support enforces the knowledge engineer's perspectives, do not support the automatic generation of customized design viewpoints, and consequently do not adequately meet the needs of designers. This is partly realized by PERSPECT (Kerr, 1993), which applies clustering and statistical approaches to rationalize past design examples into abstract groups and supports the application of the generated knowledge to develop a new design solution. Consequently, PERSPECT supports preliminary numerical design and is aimed at supporting the effective utilization of numerical experiential knowledge in design.

PERSPECT's functionality has been used to explore the possibility of realizing "learning" assistance in IDA by introducing a new concept called *Shared Learning*. *Shared Learning* is proposed to empower CAD tools with more useful learning capabilities than those currently available, and thereby provide a stronger interaction of learning between a designer and a computer. "Controlled" computational learning is proposed as a means whereby the *Shared Learning* concept can be realized. Thus, within the *Shared Learning* concept the designer defines the requirements for knowledge, directs and controls the IDA's learning capabilities, makes enquiries about the knowledge IDA presents, makes judgements about this knowledge and is able to override any knowledge presented by IDA. That is, the designer uses the system to learn about a design domain (i.e., *Domain Exploration*) and the design solution currently under development. In contrast, the IDA system should adapt its knowledge to meet the needs of the designer, carry out learning activities when requested and (in some instance) automatically present generated knowledge, continually maintain (i.e., update and evolve) its knowledge, provide explanations about learned knowledge, and provide suggestions that may help guide the designer when exploring the design domain or solving particular design problems. Given PERSPECT's ability to support *Domain Exploration*, this system has been used to assess the viability of the new *Shared Learning* concept (Duffy & Duffy, 1996).

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