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A DESIGN REUSE MODEL

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ABSTRACT

The problem with design reuse in engineering practice is the apparent lack of any formal guidelines or approach to help encourage its application and thereby allow designers to effectively benefit from previous domain knowledge. In response to this situation, this paper formalises an approach to reuse in engineering design. The resulting Design Reuse Model consists of **processes**: *design by reuse, domain exploration* and *design for reuse*, and six **knowledge-related components**: *design requirements, sources of domain knowledge, reuse library, domain model, evolved design model* and *completed design model.* The reuse processes are then proposed as the essential aspects of computationally supporting reuse, and as such are used to indicate the failure of existing support to recognise the totality of design reuse.

INHALTSANGABE

Das Problem der Konstruktionswiederverwendung in der Ingenieurpraxis ist der sichbare Mangel jeglicher formeller Richtlinien oder Vorgehensweisen, um der Anwendung auf den Weg zu helfen und dadurch den Konstrukteuren zu ermöglichen, aus früherem Fachbereichwissen effektiven Vorteil zu ziehen. In Übereinstimmung mit dieser Situation formalisiert dieser Bericht eine Vorgehensweise für die Wiederverwendung in der Konstruktionstechnik. Das sich ergebende Konstruktionswiederverwendungsmodell besteht aus den Prozessen: *Konstruieren durch Wiederverwendung, Untersuchung von Fachwissen* und *Konstruieren durch Wissensvorbereitung*, und sechs wissenrelatierten Komponenten: *Anvorderungen, Quellen von Fachwissen, Weiderverwendungsbibliothek, Wissensgebietmodell, ausgearbeitetes Konstruktionsmodell* und *komplettiertes Konstruktionsmodell.* Die Wiederverwendungsprozesse werden dann als die essentiellen Aspekte bei der computerunterstützten Wiederverwendung vorgestellt, und werden als solche angewendet, um das Fehlen existierender Unterstützung aufzuzeigen für das Erkennen der Ganzheit in der Konstruktionswiederverwendung.

1. INTRODUCTION

Knowledge of the past provides designers with a great expanse of information which they can employ to help develop solutions to new design problems. Brown discusses in general five main areas where such knowledge can assist in design [1], however more specific reasons why designers may reuse knowledge are, for example, to:

- save designers' time and effort by avoiding the 'reinvention of the wheel';
- prevent unnecessary variety and proliferation of components;
- prevent duplication of design faults;
- overcome defects;
- encourage adoption of design successes;
- improve existing designs/artefacts;
- redesign or design similar products; and
- extend the capabilities of existing designs/artefacts.

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Designers' use of knowledge of the past is termed here 'design reuse'. However before we proceed with the use of this term it is necessary to clearly explain what we mean. Previous definitions of the term 'reuse', most notably in the domain of software engineering, are proposed here to be too restrictive. According to Prieto & Freeman "reuse is the use of previously acquired concepts and objects in a new situation" [2]. Consequently, in the context of general engineering design, this definition refers to the subsequent use of concepts such as ideas, knowledge, decisions, past designs, etc., and objects such as artefacts (realisation of designs), assemblies of components, sub-assemblies of components, components, etc., in new situations. In other words the reuse of explicit knowledge. Prieto & Freeman's process of reuse involves the subsequent use of many resources defined at various levels of abstraction (i.e. from objects existing in reality to chunks of knowledge which describe reality) and degrees of abstraction within these levels. However their definition promotes the *regurgitation* of the past, where previously known concepts/objects are re-applied to solve design problems. In contrast to this definition, this paper advocates *application* of the past. This recognises that the past plays an important role in the development of new designs, however does not solely advocate the direct use of existing concept/objects to solve new design problems. Instead knowledge of the past is also used to identify, extract and use knowledge previously unrecognised in a design domain. In other words, the type of 'design reuse' advocated in this paper is the *application* of the past which involves using knowledge of the past to identify, extract and use both implicit and explicit knowledge of that past.

Unfortunately, the problem with 'design reuse' in engineering practice is the apparent lack of any formal guidelines or approach to help encourage its application and thereby allow designers to benefit from the design domain. Consequently, the current policy for employing 'design reuse' is very much *ad hoc*. The research presented in this paper is a response to the apparent lack of understanding specifically related to 'design reuse'.

This paper discusses some of the issues involved in 'design reuse' by presenting a model which helps to formalise a 'reuse' approach for engineering design. The development of the design reuse model is based on the identification of existing design practices which relate to design reuse, an existing 'reuse process model' from the domain of software engineering [3] and prior research into the use of experience in design [4].

2. A MODEL FOR EFFECTIVE DESIGN REUSE

To develop a design reuse model, existing design practices were identified and classified into three general **processes**: *design by reuse, domain exploration* and *design for reuse*. However to assist in the explanation of these processes it is necessary to identify and present a number of general knowledge categories which are used by such processes, namely: design requirements, domain knowledge, reuse library and models. These knowledge categories help to explain the contents of six **knowledge-related components** used for design reuse.

Figure 1 illustrates the design reuse model to be discussed; its purpose being to depict the relationship between each of the three identified *processes* and their relationship with defined *knowledge-related components.*

2.1 Knowledge Categories

Designers use and generate a wealth of knowledge when designing. There have been numerous attempts to classify this knowledge and illustrate its wealth: e.g. specifying the types of design science knowledge (i.e. design process, technical systems, working means) [5], specifying the breadth, depth and extent of knowledge [6] and specifying the origins (i.e. external or internal to a company structure) of knowledge [7]. However such classifications have not addressed the issue of design reuse. In the context of this paper, knowledge will be broadly categorised into four areas as detailed below and from which the six **knowledge-related components** of the design reuse model will be explained.

Design Requirements

This refers to a statement of design need which designers use as a basis to stimulate design.

Domain Knowledge

Domain knowledge is defined here as knowledge pertaining to a design domain. Designers can access this knowledge through a paper (e.g. manuals, catalogues, notebooks), computer (e.g. electronic libraries)

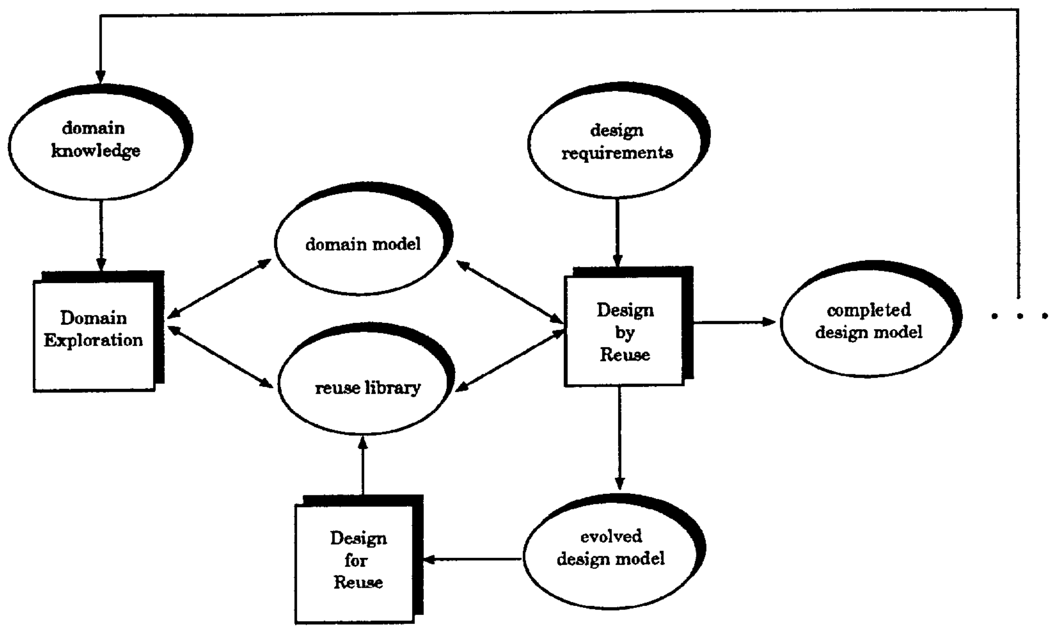

Figure 1: Design Reuse Model

or human-based (i.e. experts) medium which can encompass existing product information, past designs, design alternatives, potential solution alternatives to recognised design problems, etc. This component signifies the diverse and scattered items of knowledge/information that a designer can employ when designing.

Reuse Library
A storage location holding reusable (compiled) design knowledge, information and data. The important aspect of this 'library' is that the reusable knowledge (where hereafter knowledge will encompass information and data) is organised. Indeed such knowledge may be organised into multiple reuse libraries. The important point is that the resulting libraries are not 'bins' (i.e. an unorganised collection of knowledge).

Models
The ability to build models is central to design. Its purpose is to externalise designers' conceptualisations by providing representations which are open to design scrutiny, help to guide the development of a design solution and help designers manage the complexity of design. Models in design can represent abstractions of reality (existing designs) or envisaged reality (proposed designs). Consequently the design reuse model distinguishes between the domain model (i.e. a model of the domain that has been constructed from reality) and the design model (i.e. a model of a proposed design belonging to a particular domain).

* **Domain Model** - A model which represents a designer's conceptualisation of a design domain which is applicable to the current design problem.
* **Evolved Design Model** - A statement of an evolved design. The evolved design may be at any level of abstraction, i.e. it may be a description of an incomplete, proposed design or a final, fully completed design.
* **Completed Design Model** - A statement of a fully defined new design which is proposed to satisfy the design requirements. Through manufacture, transport, use, etc., knowledge of the new design feeds back to the general domain knowledge.

From the discussion of the four categories of knowledge, six **knowledge-related components** for design reuse are identified *design requirements, domain knowledge, reuse library, domain model, evolved design model* and *completed design model.*

2.2 Design Reuse Processes

The design reuse model presented in this paper consists of three **processes**: *design by reuse, domain exploration* and *design for reuse.* These processes are individually explained here and associated existing design practices identified.

Design by Reuse
'Design by Reuse' is the process in which knowledge resources are searched so that useful knowledge can be identified, retrieved and applied to the new design problem. Design reuse involves the subsequent use of various resources defined at various levels of abstraction (i.e. from objects existing in reality to chunks of knowledge which describe reality) and degrees of abstraction within these levels. Various approaches to design can be interpreted as exhibiting 'Design by Reuse', for example:

* *Design Adaptation*
* *Component-based design*
* *Feature-based design*
* *Exemplar design*

These approaches indicate the reuse of resources at various levels of abstraction, e.g. from the reuse of specific past designs, components or design features, to the reuse of a prototypical design. Of course there are other approaches which, rather than reusing existing knowledge of past designs/artefacts, use knowledge of past design processes, e.g. by reusing design plans, episodes, etc.

Before reuse can take place such reusable knowledge must be accumulated. In other words 'Design by Reuse' can only occur if reusable resources are available. 'Domain Exploration' and 'Design for Reuse' are two processes which can be employed to establish, accumulate and evolve such resources.

Domain Exploration
'Domain Exploration' refers to designers' abilities to conceptualise a design domain, i.e. to understand ('picture') the characteristics of a design domain, from which reusable fragments of knowledge can be identified, extracted and stored for subsequent use in design. According to Logan [8] 'conceptualisation' is governed by: the interest and experience of individual designers, the level of abstraction considered appropriate to the design problem, and how a designer prefers to structure and process information. Consequently as the required level of problem abstraction, and designers' interests and preferences change, designers can explore the design domain to identify and extract applicable conceptualisations for subsequent use in design. Two approaches relating to 'Domain Exploration' have been identified. These are:

* *Knowledge Engineering/Conceptualisation*
* *Reverse Engineering*
  - *Redocumentation*
  - *Design Recovery*

Design for Reuse
During design a wealth of proprietary information and knowledge is generated about a design, and if captured presents a rich resource that has significant benefit in assisting designers carry out subsequent duties. In addition to providing a source of knowledge that is of potential use in subsequent design projects (e.g. the refinement of existing designs, substantially adapting such designs or creating new designs), the captured knowledge can be used to:

- educate designers of limited experience;
- educate experienced but new designers of a project's status and background;
- avoid the loss of knowledge when experienced designers leave a project;
- remind designers of decisions made earlier on (particularly important if the design life of the project is long, i.e. in units of years); or
- improve communication between designers, managers and manufacturers.

'Design for Reuse' is a process carried out to record knowledge which is generated during design. It requires designers' conscious effort to identify and extract possible reusable knowledge fragments and enhance their knowledge content, record design alternatives (discarded or adopted) and modifications, and note the associated reasoning process behind the selection of alternatives and modifications, i.e. design history and design rationale. In other words 'Design for Reuse' requires designers' directed effort towards identifying, extracting and recording reusable knowledge of design that is under development. Such activities are carried out during:

* *Documentation*
* *Standardisation*
* *Parameterisation*
* *Modularisation*

2.3 Discussion

Figure 2 illustrates the wide scope of knowledge which designers can purposefully gather and use to tackle subsequent design problems, when adopting the design reuse model. For example, 'Domain Exploration' and 'Design for Reuse' encompass knowledge from *design issues* through to the *side effects* of a design or artefact.

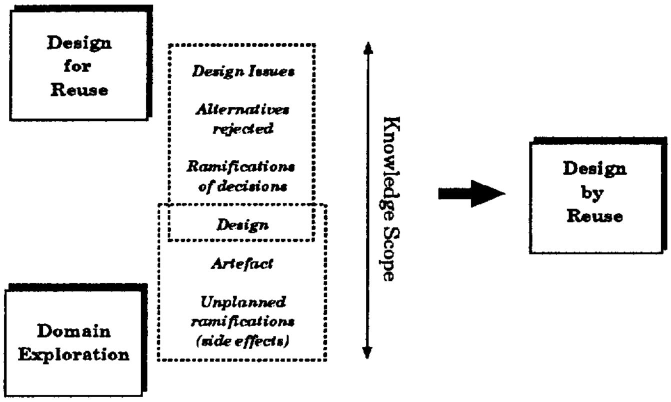

Figure 2: Scope of reuse knowledge, adapted from [9]

This figure illustrates the equal importance of 'Domain Exploration' and 'Design for Reuse'. An advantage of 'Domain Exploration' over 'Design for Reuse' is the capture of *design side effects* and the reuse of knowledge originating from designs and artefacts created by other designers. The knowledge associated with 'side effects' relate to unplanned behaviours/performances of a design once it is realised. This type of knowledge is very important as it incorporates knowledge of, for example: how well a design is accepted into the market place or how well the design performed 'in situ'. This type of knowledge can only be captured after the completion of a design. However 'Design for Reuse' enables the accumulation of knowledge pertaining to a developing design and as such involves the capture of knowledge during design. Therefore for effective 'Design by Reuse' knowledge it is necessary to accumulated knowledge during and after the completion of a design.

3. SUPPORTING DESIGN REUSE

The Design Reuse Model emphasises design as a knowledge-intensive activity. That is, one involving (a) the exploration of a wealth of knowledge, from which a domain model and reuse library is generated, (b) the reuse of knowledge held in such a domain model and reuse library to help evolve a design, and (c) the continual feedback of accumulated knowledge of the design to the reuse library.

Support for design, as a knowledge-intensive activity, has been the concern of many researchers working on the application of artificial intelligence in computer aided design and in particular knowledge-based design. An analysis of resulting systems has identified a number of mechanisms/approaches which have been implemented and which appear to support aspects of the presented Design Reuse Model. Some of these are presented in Table 1.

	Design Reuse Phase	
Design by Reuse	Domain Exploration	Design for Reuse
Component/Product Selection [10] *Case-Based Reasoning* [14] *Concept-Based Reasoning [18]* *Prototype-Based Reasoning* [22] *Design Stories* [23]	*Concept Formation* [11, 12] *Rule Extraction* [15, 16] *Equation Discovery* [19] *Customised Viewpoints* [4]	*Electronic Notebooks* [13] *Knowledge Capture* [17] *Rationale Capture* [20, 21]

Table 1: Supporting mechanisms/approaches for 'design reuse' processes

From the above, it would seem that the topic of design reuse is being extensively researched. However there is no *overall* effort into the effective support for design reuse. That is, until now there has been no recognition of different processes of design reuse and how the totality of design reuse can be supported.

The authors have been investigating and formalising the totality of design reuse, and propose that effective support for design reuse will be achieved by the joint support of the three design reuse processes presented in this paper.

4. SUMMARY

This paper has presented a design reuse model consisting of three *processes* and six *knowledge-related components*. It has been shown that design reuse has received much attention from researchers trying to computationally support design. However failure to identify the totality of design reuse has lead to discrete efforts in research. The design reuse model presented in this paper is an attempt at formalising design reuse and thereby identify the scope of support required by such computational tools.

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