Strathprints Institutional Repository

Smith, J.S. and Duffy, A.H.B. (2001) *Re-using knowledge - why, what and where.* In: 13th International Conference on Engineering Design (ICED 01), 2001-08-21 - 2001-08-23, Glasgow.

INTERNATIONAL CONFERENCE ON ENGINEERING DESIGN
ICED 01 GLASGOW, AUGUST 21-23, 2001

RE – USING KNOWLEDGE: WHY, WHAT AND WHERE

Joanne S Smith and Alex H B Duffy

Keywords: Design Re-use, Knowledge Management, Knowledge Maintenance

1 Introduction

Characteristically designers do not ‘re-invent the wheel’ every time a new design instance calls for one, their natural response is to glean from past experience and ‘re-use’ previously acquired knowledge. Gao, Zeid, Bardasz [red7] estimate that ‘90% of industrial design activity is based on variant design’ and in such a redesign case ‘70% of the information is re-used from previous solutions’ [red8]. We see the concept of ‘re-using’ as inherent within the natural process of design. The origins of formal design re-use are found in the realms of software engineering where re-use became a realistic solution to problems caused by ‘increasing complexity and time-to-market pressures’ [red9]. Similarly, such pressure’s on engineering companies has resulted in an increased focus on support for ‘formalised re-use’.

Previously the ‘re-use’ focus has centred on specific and/or standard parts[red 3], more recently however, ‘[standard components] are being developed…to enable both the re-use of the part and the experience associated with that part’[red4]. This notion is further extended by Finger [red5] who states that ‘designers may re-use a prior design in it’s entirety,…may re-use an existing shape for a different function, or may re-use a feature from another design’. Reinforcing this notion we currently consider re-use to reflect the utilisation of any knowledge gained from a design activity and not just past designs of artefacts.

Our research concerns the improvement of formal ‘re-use’ support and as such we have identified a need to gain a better understanding of how design knowledge can be utilised to support ‘re-use’. Thus, we discuss the requirements of successful ‘re-use’ and attempt to ascertain within this skeleton: what knowledge can be re-used; how to maximise its’ applicability; and where and when it can be utilised in new design?

2 Why Formalise Design Re-use

To stimulate both research and investment towards increased support for the ‘formal re-use’ concept it is essential to gain some appreciation of the potential advantages. The following provides evidence to verify the potential of improved ‘re-use’ mechanisms.

2.1 The Benefits

It is interesting, initially, to consider the current re-use benefits achieved in the field of software design, where formalised ‘re-use’ originated, as a relatively more mature ‘re-use’ research area. For instance, a recent cost model developed for the software industry for Synopsis Inc. (figure 1) highlights the increasing costs of chip design and the widening gap between design costs utilising 'formal' re-use and current practice. The chart shows that chip designers who fail to take advantage of 'formal design re-use' practices face 'unsustainable cost increases, of up to 64 times higher' [redacted].

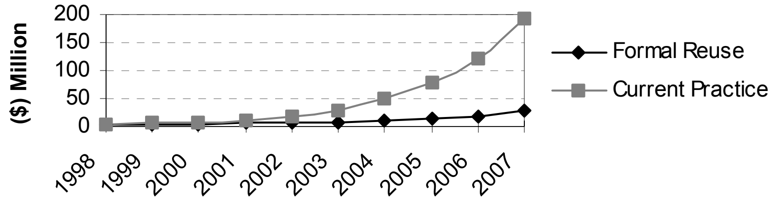

Figure 1 Who Can Afford a $193 Million Chip? [red11]

Time, cost, quality and performance were amongst the main benefits analysed in a study in the engineering design sector [red12]. The study concluded that the potential benefits to an industrial company, of applying an overall re-use approach, far exceeded the benefits they currently received from relying on designers' natural inclination to re-use. Figure 2 summarises a significant benefits analysis finding.

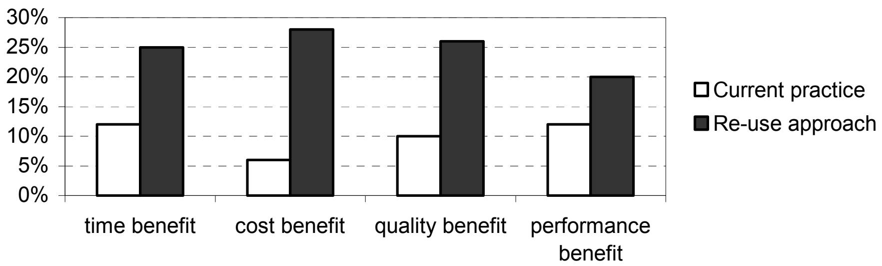

Figure 2 Current and Foreseen Overall Metric Benefits [red12]

We can see the first column in each category (time, cost, quality and performance), shows the benefits received from current 'ad-hoc' re-use practices, these provide greatest benefit to time and performance whilst the costs benefits are almost half at only 6%. The second column in each category indicates the foreseen benefits of a formal approach to 'design re-use' which can be expected to provide overall benefits to time, cost, quality and performance in the region of 20% to 28%. For instance, this can be translated into an improvement in terms of cost benefits, over current practice, of up to 367%.

Thus, it can be argued that there is significant value in re-using knowledge and experience related to existing designs to support future design. The study substantiates the need for formalised approaches, methodologies and systems, in order to achieve the considerable potential benefits shown to be available from a formalised approach to re-use.

2.2 A Formal Model

Like others, Altmeyer and Schurmann [red27] query as to whether 'generic reuse techniques' are possible' and additionally how we can 'identify [re-use] mechanisms which are typical for design but independent of a specific design system?'. Similarly, in addressing this issue, there seems to be only one such generalised 're-use' model, namely, the 'design re-use process model' [red 1]. Other reviewed models were, as suspected by [red27], either highly dependant on the individual system/approach or alternatively were paradigms of Case Based Reasoning (CBR). CBR [Maher] is a research interest in the field of 'design re-use', however, the assumption of the existence of a large base of past design cases; the applicability of cases in their entirety, and its limited focus on mainly representation and recall issues, negate this as comprehensive models of 're-use'.

2.3 Knowledge Issues in Providing 'Formal Support'

Weighted against the potential benefits is the principle that a stored design '99% right for a given task, often takes much more than 1% of the effort needed to create the design in the first place to patch it to fit, cancelling so much of the advantage of reusing it that it may be easier to design from scratch' [red13]. Thus, we identify fundamental issues in providing support for a 're-use' approach: (i) modelling and managing, even for relatively simple artefact, the complex and rich design related knowledge, and (ii) providing solutions to the problems of partially re-using previous design solutions and their associated knowledge to effectively satisfy new design requirements. Accordingly, to obtain the maximum benefits of formal 're-use' requires that we optimise support for this rich and complex knowledge resource, appreciate the source, nature, and growth of design knowledge, and successfully manage knowledge acquisition, maintenance and utilisation for 're-use'. Thus, supporting re-use requires that we can ascertain: what knowledge can be re-used; how it can be maintained to maximise its applicability; and where and when it can be utilised in new design.

3 What can we Re-use?

Previously design knowledge has been referred to as complex [red7] but what do we understand by the term complex, and what are the implications of this for re-use of design knowledge? Firstly, we must consider the factors contributing to design knowledge complexity and secondly how this effects it's ability to be re-used. The notion of complexity is one topic that has received great attention, from mathematicians, scientists, and engineers alike, due to a lack of common definition and concrete theories. Duffy defines the factors influencing complexity, and their associated issues, through the 'design complexity map'[s m duffy fugsloe,1995].

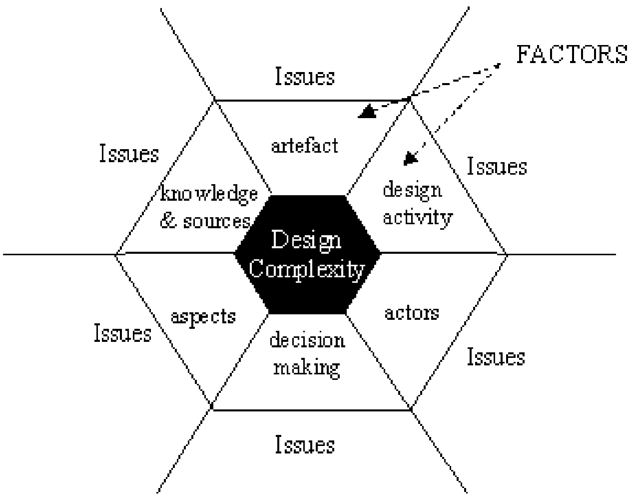

Figure 3 - Design Complexity Map [s m duffy fugsloe,1995]

Thus we can view complexity in design such diverse factors as the artefact being designed, the design activity itself, the actors involved, the decision making process, the aspects impinging on the design, and knowledge and sources used and generated. Moreover, the issues affecting each of these factors further compound complexity. We can now appreciate that even the simplest artefact is associated with a complex array of factors, that shape the activity of design and consequently the final artefact definition, and result in a vast accumulation of related design knowledge. The final artefact definition is dependent on: amongst others, the company organisation; the type of design; the chosen design process, designers, and tools; and external factors out-with the designers control [s m duffy fugsloe,1995]. Thus, this presents a complex problem in terms of modelling knowledge for 're-use'. A problem further amplified by the differences in terms of *characteristics, types, sources, forms* and *origins* of design related knowledge. If we now consider that formal support for 'design for re-use' relies on an ability to identify, extract and explicitly represent reusable fragments of knowledge during design itself we gain a perception of the difficulties of supporting such complex design knowledge for 'exploration', and subsequent utilisation in 'design by re-use'. To further complicate matters, design related knowledge can be considered from many viewpoints such as; functional, structural, and behavioural [ref]. While Brice and Johns [red15], Duffy [red2], Finger [red5], and Mostow [red13], also emphasise the importance of knowledge related to the 'why' and 'when' of decision making, known as the *Rationale* and *History*. Brice and Johns [red15] conclude that 'constructive use of design rationale will become an integral part of design process'. '

Design by re-use' relies on the availability of appropriate knowledge sources thus, to achieve this we require a suitable knowledge modelling mechanism to support 'design for re-use' which would require to capture knowledge from differing *'sources'* and '*viewpoints*' and represent their evolution through the design activity. Thus, formal knowledge modelling mechanisms which adequately support 'design for re-use' must be capable of defining 'knowledge elements' while capturing the '*relationships*' between these both within and across different '*sources*' and '*viewpoints,*' and the *'behaviour'* of these relations as the artefact definition evolves. This would facilitate a deep '*understanding*' as to how and why design knowledge had developed into the final artefact definition and provide the designer with a greater knowledge resource to utilise in 'domain exploration' and support further 'design by re-use'.

Despite our increasing understanding of the utility of consistent capture of 'design knowledge' throughout the design activity, 'typically the only formal documentation is the final set of drawings'[red5]. Additionally, current design tools have the effect, on the practice of engineering design, of emphasising 'those parts of the process that were well understood and/or easily systematised (e.g detailed design, analysis, machine path planning), while minimising those parts that were less well understood (e.g, problem definition, synthesis and conceptual design)'[red5]. Thus, without a shift in working practice/culture it remains difficult to facilitate consistent knowledge capture as the earlier design phases, where more general, abstract knowledge is generated, are not adequately supported. The importance of supporting earlier phases is illustrated when we consider that at the end of the conceptual phase 85% of the lifecycle costs are already committed [red16]. Thus non-capture would negate many of the cost benefits of re-use. Furthermore, documentation generated in current practice are generally based on a low level of abstraction e.g. geometry, tolerance, surface finish, manufacturing requirements. Such formal documentation leaves little or no scope for representing knowledge related to the r*ationale, history,* or *product* knowledge relating to concept principles and dynamic *process* knowledge learnt through experience. This contributes to the difficulty of managing the complexity of product knowledge in that a vast proportion of the *quantity* of generated knowledge related to other complexity factors are not captured explicitly and thus cannot be re-used. Hence, there is a limited range of available knowledge related to *relationships*, and their *behaviours* at a more abstract level of design and therefore our *understanding* of how knowledge elements relating to function, behaviour and solution concepts, decision making, the design activity, actors and aspects and design alternatives have contributed to the overall design is restricted. The result of this in a ‘re-use’ scenario is to force designers to think in terms of design specifics, with limited applicability to the earlier synthesis stages of design, and restricts ‘re-use’ principally to support detailed design (standardised parts/ manufacturing methods etc.). In addition it presents problems when attempting to partially re-use a design solution, or its associated knowledge. The designer has no *‘understanding*’ of the ‘evolution’ of the designed artefact, no knowledge of the function, solution, mechanism concepts realised by the artefacts components and/or possible alternatives to these, on which to base a decision as to potential value of ‘re-using’ individual concepts/parts/subsystems/ in new scenarios. Thus, the potential benefits of re-use (see Figure 1 and 2) cannot be fully realised due to the incomplete knowledge content of the available sources, which in turn, restricts its ‘re-use’ capabilities.

It can be argued, therefore, that knowledge from the earlier, more abstract, stages of design (function, behaviour, solution concepts) and the ‘how’ and ‘why’ (rationale) of a designed artefact are essential to the ‘re-use’ approach. Capturing such high level knowledge can facilitate a ‘re-use’ approach applicable far earlier in the design process.

3.1 Utilising Knowledge in Design Re-use

Having established a case for the ‘re-use of design knowledge and identified the need to support and manage re-usable knowledge sources from the inception of a design activity we must now consider its applicability to new situations.

Mostow, et al [red13] debate whether re-using a previous design can be justified in terms of the additional effort required to make it ‘fit’. Unlike the direct re-use of code, adders, modules and microprocessors in the field of software engineering, as engineering design deals ‘with more abstract concepts’[red14]. However, Mostow, et al [red13] further maintain that despite the difficulties of partial re-use, human designers do ‘modify the structure of a design to fit a new application’ but concede that ‘this process tends to require considerable expertise’. Evidently, it is not always possible to re-use a previous design in it’s entirety and modifying a design to fit can involve expertise beyond the scope of explicitly available design knowledge. However, as the utilisation of previously acquired design knowledge in new design is central to the success of a re-use approach there is a need to overcome such problems by supporting and maintaining knowledge acquired through design experience (explicit and implicit) to support its application to, as opposed to its regurgitation in design.

As the designer is seen to adapt previous solutions to solve a new problem by learning from experience, an effective ‘re-use’ approach must encompass elements of this ‘learning’ process to extend the approaches ability to utilise design knowledge and support re-use of partial solutions [red13]. Here, (as shown in Figure 5) we consider learning to be a process of acquiring new knowledge, the modification of existing knowledge and the generation of new knowledge.

Duffy [red18] states that ‘learning helps to maintain experiential knowledge’, which represents one of the most powerful resources a designer possesses. Such maintenance of experiential design knowledge, through abstraction from the specific to general, supports the dynamic nature of knowledge and prevents knowledge related to design experiences from becoming static and obsolete. Such activities as ‘abstraction and generalisation’ extend the utilisation capabilities of knowledge in a ‘design by re-use’ process as they ‘promote the flexibility of experiences by removing highly specific details and generating more generally applicable knowledge'. Thus, the process of learning: the acquisition, generation and modification of knowledge, alleviates some of the difficulties associated with the application of knowledge from 'a design that is not 100% 'right' to a new situation'.

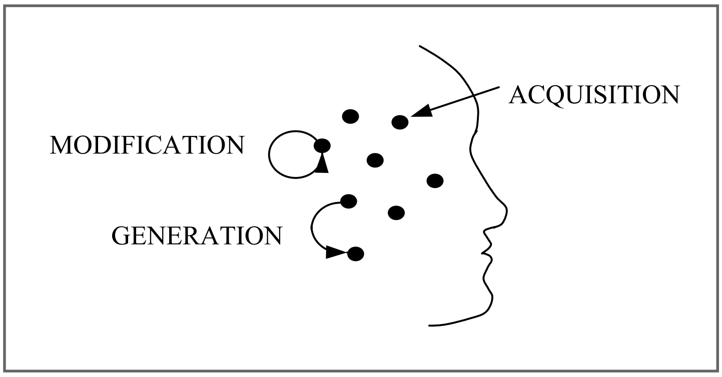

Figure 4 -The Learning Activities [red17]

4 Where – the Applicability of Knowledge Re-use

Having established 'Design Re-use' as an approach concerned with the provision of support for the capture, management and subsequent utilisation of design knowledge, gained from previous experience, to further new design. Now we consider the applicability of such an approach within the field of design itself.

4.1 In the Design Process

Many re-use models or paradigms [red20,80,7,34,35] consider 're-use' as an approach solely concerned aiding new design by re-using past design solutions. However, the concept can be further extended to include not only this phenomena of 'designing by re-use' but also that of 'designing for re-use', whereby the design process and potential solutions are specifically managed and created to promote their future re-use. Indeed an industry based brainstorming program, [red21] highlighted the need for capturing design information into the design re-use system whilst a design is being carried out. Addressing this 'design re-use process model' considers re-use as a total process which, with the support of well developed tools and methods, can encompass all phases of the design life cycle. Thus, a comprehensive approach to 'design re-use' should emphasise support, management and utilisation of design knowledge prior, during and after the completion of a design activity.

4.2 For Different Design Types

Research into why designers re-use experiential knowledge has highlighted the main issues as: an avoidance of previous design faults and unnecessary reinvention; duplication of design success; and the use of known and proven characteristics[red1]. This may suggest that re-use is relevant only to variant (repeat order) or adaptive (evolutionary) design as these issues are readily equated to the repetition, improvement and enhancement of an already existing design.

At first glance, the application of re-use to variant and evolutionary design is far more apparent than to that of original (innovative) design. However, as 'competitive advantage is now obtained by innovation and creation of knowledge rather than access to financial or material capital' [red24] it is important to determine the capabilities of the 're-use' in the 'original' design environment in a bid to optimise the impact of 're-use' benefits in design.

Innovation is deemed to have occurred when either tacit (the collection of data, rule, which lie beyond the realms of explicit knowledge) or explicit knowledge (that which is readily accessible, written down, in computers etc.) is converted to gain additional explicit knowledge, not previously available[red24]. Thus, innovation in the design process can be considered as instances where ‘new variables are introduced into the design process’ and ‘the state space is expanded’[red25]. Thus, the conflict between re-use and innovation arises from the perception of re-use as merely an approach to support and maintain already existing knowledge where innovation requires that new knowledge be created and/or added to the design process. For example, the perception of re-use as a facilitator of negative design fixation (a phenomena whereby designers re-use features to which they are regularly exposed) i.e. complacency, re-use of ‘bad’ design solutions, lack of technology transfer.

The applicability of re-use to original (innovative) design is better appreciated when, as here, re-use is considered as a process capable of supporting existing knowledge while permitting abstraction and generalisation of this knowledge to generate or modify knowledge. Thus, the processes synonymous with knowledge maintenance can not only prevent its stagnation or obsolescence, increase it’s applicability to new design, but also support the ‘utilisation’ of re-usable knowledge in original design environments.

5 Conclusion

We have shown that there is significant value in capturing and re-using the knowledge and experience of current and past designs but that to achieve effective ‘formal’ support we require a greater understanding of the role of knowledge in re-use. We establish, within the spectrum of a comprehensive re-use model, that this could be achieved through better support for the consistent capture, modelling and structuring of all knowledge generated throughout the evolution of a design. However, it has also been shown that for effective ‘exploration’ and ‘re-use’ such knowledge must be maintained to prevent its stagnation and improve its applicability. Design knowledge ‘formally’ supported by such means better supports ‘re-use’ both earlier in the design process and in design environments with more original content than re-design cases to which current ‘re-use’ practice is predominantly limited.

References

[1] [red1]Duffy, S.M., Duffy A.H.B., and MacCallum, K.J., “A Design Reuse Model”, in Proceedings of the International Conference On Engineering Design, Praha, 1995.

[2] [red5]Finger, S., “Design Reuse and Design Research”, Keynote Paper, in Proceedings of Design Reuse – Engineering Design Conference, Brunel University, London, 1998.

[3] [red7]Gao, Y., Zeid, I. and Bardasz T., “Characteristics of an Effective Design Plan to Support Re-use in Case-based Mechanical Design”, Knowledge Based Systems, Vol.10, 1998, p337-350.

[4] [red8]Khadilkar, D.V. and Stauffer, L.A., “An Experimental Evaluation of Design Information Reuse During Conceptual Design”, Journal of Engineering Design, Vol.7, No.4, 1996, p. 331-339.

[5] [red9]Jones, M.E., Reusing Integrated Circuit Designs, Computer Design, July, 1995

[6] [red3]Sivaloganathan, S., “Foreword”, in Proceedings of Design Reuse - Engineering Design Conference, Brunel University, UK, 1998

[7] [red4]Culley, S.J., "Design Re-use of Standard Parts", Keynote Paper, in Proceedings of Design Reuse - Engineering Design Conference, Brunel University, UK, 1998

[8] [red11]Synopsys Inc., "Who can Afford a $193 Million Chip?", Synopsys Design Reuse Cost Model" 1999.

[9] [red12]Duffy, A.H.B., and Ferns, A.F., "An Analysis of Design Reuse Benefits," in Proceedings of the International Conference on Engineering Design, Munich, 1999.

[10] [red13]Mostow, J., Barley, M., and Weinrich, T., "Automated Reuse of Design Plans", in Artificial Intelligence in Engineering Design, p. 2-15, 1993.

[11] [red27]Altmeyer, J., and Schurmann, B., "On Design Formalisation and Retrieval of Reuse Candidates", Artificial Intelligence in Design, Kluwer Academic Publishers, 1996.

[12] Duffy, S.M., "The Design Coordination Framework and the Design Complexity Map", Integrated Production Systems Research Seminar, Fugsløcentret, Fugslø, 3-5th April, 1995.

[13] [red14]MacCallum, K.J., Duffy, A.H.B., Donaldson, I.A., Duffy, S.M., and O'Donnell F.J., "Design Reuse - Design Concepts in New Engineering Concepts", CAD centre, Strathclyde University, UK, 1995.

[14] [red15]Brice, A., and Johns, B., "Improving Process Design by Improving the Design Process, A DRAMA white paper, QuantiSci, 1998.

[15] [red16]Nicholls, K., "Getting Engineering Changes Under Control", Journal of Engineering Design, Vol.1, No.1, p. 5-15, 1990.

[16] [red18]Duffy, A.H.B., "The "What" and "How" of Learning in Design", IEEE Expert, May/June, p. 71-76, 1997.

[17] [red20]Deneux, D., and Wang, X.H., "A Knowledge Model for Functional Re-design", Engineering Applications of Artificial Intelligence, Vol. 13, p. 85-98, 2000.

[18] [red34]Henninger, S., "Accelerating the Successful Reuse of Problem Solving Knowledge Through the Domain Lifecycle", in 4th International Conference on Software Reuse, IEEE, 1996:

[19] [red35]Fothergill, P., Lacunza, J.A., and Arana, I., "DEKLARE: A Methodological Approach to RE-DESIGN", Aberdeen University, Copreci S. Coop. Ltd: Dept of Computing Science, Aberdeen University1994.

[20] [red80]Altmeyer, J., and Noll B., "RODEO - Reuse of Design Objects", p. 1-2, 1998.

[21] [red21]Shanin, T.M.M., Andrews, P.T.J., and Sivaloganathan S., "A Design Reuse System, in Proceedings of Design Reuse - Engineering Design Conference, Brunel University, UK, 1998

[22] [red24]Preiss, K., "Modelling of Knowledge Flows and their Impact" Journal of Knowledge Management, Vol.3, No.1, p. 36-46. 1999.

[23] [red25]Gero, J.S., and Maher M.L., "Theoretical Requirements for Creative Design by Analogy, report number Colorado State University Fort Collins, 1990.

[24] Maher, M.L., Garza, A.G., "Case-Based Reasoning in Design", IEEE Expert, March/April, Vol.12, No.2, p34-41, 1997.

Joanne S Smith
CAD Centre, DMEM Department, Strathclyde University, M209, James Weir Building, 75 Montrose Street, Glasgow, G1 1XJ Scotland, UK Tel: +44 (0)141 548 3020 , Fax: ???, E-mail:jo@cad.strath.ac.uk , URL – www.cad.strath.ac.uk