INTERNATIONAL CONFERENCE ON ENGINEERING DESIGN
ICED 99 MUNICH, AUGUST 24-26, 1999

AN ANALYSIS OF DESIGN REUSE BENEFITS

A H B Duffy and A F Ferns

Keywords: Performance Metrics, Process Improvement, Design Reuse Process Model

1 Introduction

Although the concept of design reuse is accepted as a valid approach to design, little attempt has been made to formalise the elements that constitutes design reuse. The few approaches formalising design reuse, e.g. 'Concept Reuse Approach for Engineering Design Problem Solving' [1], tend to be prescriptive, detailing procedures and functions that have to be carried out in order to reuse designs. Such procedural methods fail to identify the underlying processes and knowledge resources of design reuse and tend to relate to an approach or method of tackling reuse rather than reuse itself. It would seem that the only current model encompassing design reuse is 'The Design Reuse Process Model' [2]. The elements of this reuse process model have been used as a basis upon which to identify and analyse the benefits of design reuse when considering key metrics relating to competitive product development, that is time, cost, quality and performance.

2 The Design Reuse Process Model

The design process can be defined as a series of tasks and decisions utilising scientific principles, technical information and creativity in order to produce a solution to meet an actual or perceived need. It requires different information at various stages of its process. The difficulty associated with making decisions during the design process is dependant on the knowledge and choices available to the designer. A feature of design decision making is the reuse of previous design experiences. Such experience holds a wealth of explicit and implicit knowledge and can be interpreted differently depending upon the needs of the designer(s) [3]. Experienced designers will generally find certain decisions easier to make than novice or inexperienced designers as they can draw on knowledge gained from previous experiences [4].

The 'Design Reuse Process Model' [2] was influenced by processes from the domain of software engineering and describes the design reuse process using the interactions between six knowledge resources and three main processes. The knowledge resources (KRs) are: *Domain Knowledge*, sources of knowledge concerning past designs or artefacts; *Domain Model*, a designers conceptualisation of a design domain applicable to the current design problem; *Reuse Library*, an organised storage for holding reusable knowledge; *Design Requirements*, a statement of a design need; *Evolved Design Model*, a description of an incomplete, proposed or final design, at any level of abstraction; and *Completed Design Model*, a statement detailing the complete definition of a new design. The design reuse processes (DRPs) are described as: *Design by Reuse* , the reuse of previously acquired concepts in a new design situation; *Design for Reuse*, the identification and extraction of possible reusable knowledge fragments and the

enhancement of their knowledge content; and *Domain Exploration*, the examination of a design domain from which reusable fragments of knowledge can be identified, rationalised, extracted, stored and subsequently used to develop new designs.

In essence the Design Reuse Process Model is a cyclic process where knowledge is abstracted from a new design and used to build or enhance the domain model, through domain exploration, and add to the knowledge within the reuse library. These two knowledge resources, the domain model and reuse library, are then used during the process of 'design by reuse', consequently resulting in: (i) a completed design model and (ii) knowledge relating to the product, process and rationale, which in turn are fed back into the reuse process to aid future design. Design by reuse can occur with various types of knowledge such as plans, schema's, episodes and general principals. All require an adequate store of knowledge to be effective.

3 Scope of investigation

The Design Reuse Process Model has been used for an initial investigation through working with industry to identify the main and foreseen benefits of design reuse. To achieve this seven areas of engineering design, within a large made to order company, were analysed against the reuse process model; the areas were electrical, structural, heating and ventilation, weight assessment, resistance and propulsion, platform, and 'forward' design (innovation). Within each of the areas the reuse process model was critically discussed with practising designers and current and foreseen practices were mapped within the model.

An initial set of possible benefits and drawbacks of design reuse have been developed with a view of determining if design reuse is considered by practising designers to have an affect on the design development process. The set is not intended to be all encompassing or reflective of all the possible benefits or drawbacks for a particular company but rather they were used as a first attempt in evaluating the current and foreseen impact of reuse and to identify areas for further research. Further, the set was derived through discussions and a questionnaire with the practising designers and reflect their view as to the benefits and drawbacks that can be gained from design reuse. For the purposes of this paper only the benefits are considered under the main metrics of time, cost, quality, and performance. For a detailed description of the breakdown of benefits for each of these metrics the reader is referred to [5].

4 Findings

Due to time constraints imposed upon the project only the forward design area, with four practising designers, was analysed. The analysis took the form of a matrix where the current and foreseen effect of the reuse model's processes and knowledge resources are determined against each of the identified possible benefits. The effects were measured by the designers defining the value of 9 for a high effect, 5 for medium effect, and 1 for a low effect. The values had to be also justified and detailed through discussions. The results of the analysis are shown in Figures 1 to 8 where the benefits relating to time, cost, quality and performance have been normalised in order to more clearly compare the current effect against the foreseen and across these metrics.

4.1 Knowledge Resources

Current Practice: Both time, quality and performance (Figure 1) have comparable benefits from reuse at 11-12%, with cost obtaining almost half with 7%. The greatest current benefits come from domain knowledge (Figure 2) at 14% with the completed design and reuse library contributing 9% and 7% respectively. This may reflect the company's current practice of low reuse of completed designs and over reliance upon designing from first principles and domain knowledge. The least amount of benefits are received from design requirements and the evolved design at 2% each, with the domain model at 5%. The lack of benefits from the former two KRs may possibly be attributed to communication and insufficient knowledge capture approaches but also the design requirements will change between designs and their reuse for new designs are limited.

Foreseen Benefits: The greatest foreseen benefits of the KRs (Figure 1) are considered to be reduced costs at 30%, with quality a major benefactor at 28%. Time is also a significant benefactor at 23% followed by performance with 18%. The KRs (Figure 2) would seem to provide their greatest foreseen benefits from the reuse library and domain model with 22% and 21% respectively. This may not be surprising as these KRs reflect the results of processing other KRs and embody rationalised and structured knowledge directly used in design by reuse. The completed and evolved designs can contribute 18% and 17% respectively, domain knowledge 13% and design requirements 8%.

Potential Improvement: The greatest potential for improvement for the metrics (Figure 3) is seen to be with cost reduction at 328% while quality is slightly less than half of that at 155%. Time may benefit 92% while performance 64%. Domain knowledge (Figure 4) is envisaged to provide -8% improvement which may reflect a future perception that the design process should be based more on reuse of in-house designs rather than from first principles. The greatest scope for improvement is from the evolved design with an improvement of 750% though achieving only a potential benefit of 17% (Figure 2). The benefits from the domain model and design requirements are quadrupled (320% and 300%) with the reuse library trebled (214%) and completed design doubled (100%).

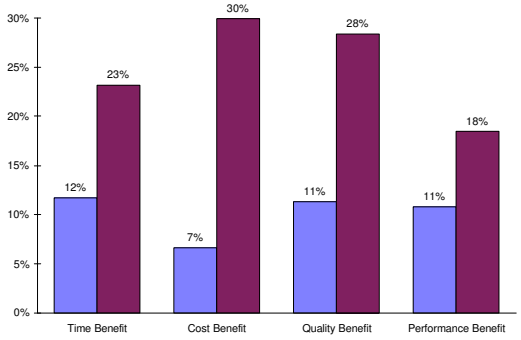

Figure 1: KRs' main benefit areas

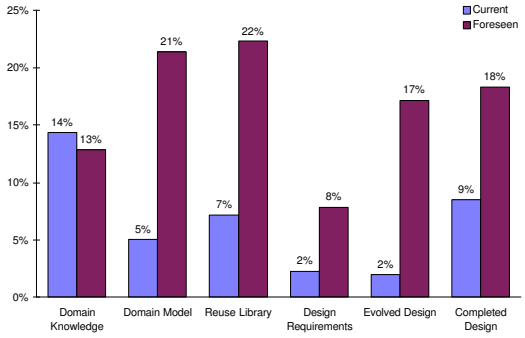

Figure 2: Overall benefits from KRs

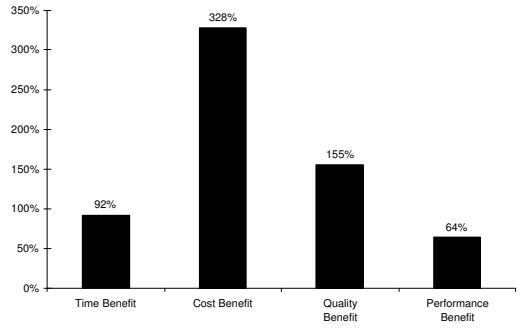

Figure 3: KRs' foreseen benefit area improvements

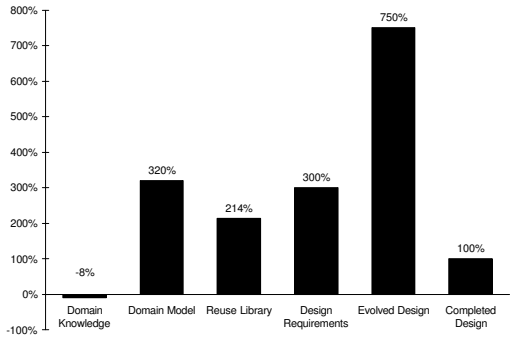

Figure 4: Foreseen benefits from KRs

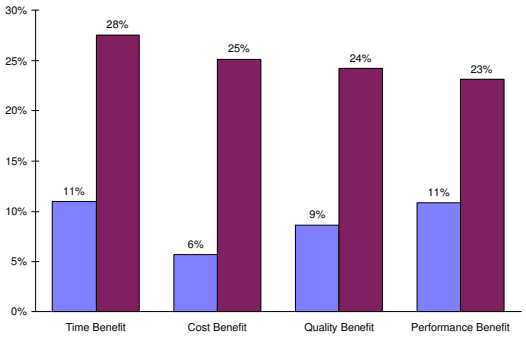

Figure 5: DRPs' main benefit areas

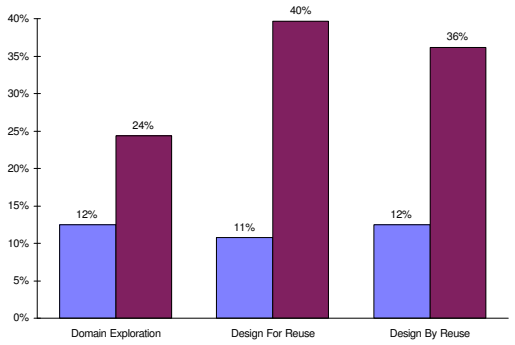

Figure 6: Overall benefits from DRPs

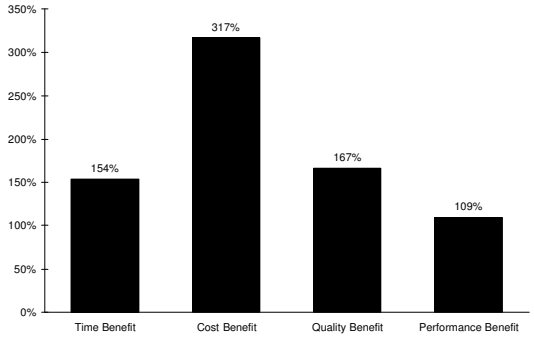

Figure 7: DRPs' foreseen benefit area improvements

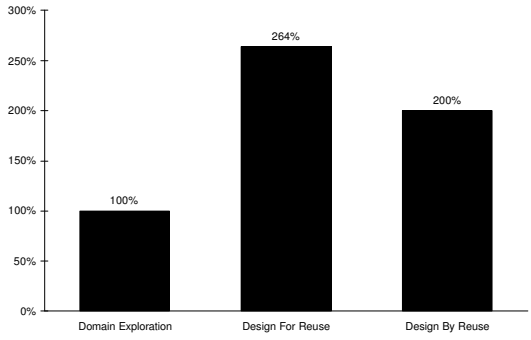

Figure 8: Foreseen benefits from DRPs

4.2 Design Reuse Processes

Both performance and time (Figure 5) benefit the most from the current practices at 11%. Both these metrics are nearly double the current cost benefits at 6%, with performance benefiting at 9%. The greatest potential benefit from DRPs would seem to be to time at 28%, with cost at 25%, followed closely with quality at 24% and performance at 23%. This reflects the belief that all the main metrics will benefit considerably through enhanced processes.

Domain Exploration (DE), Design For Reuse (DFR) and Design By Reuse (DBR) all currently provide similar benefits at 11-12% (Figure 6). This may reflect design reuse being conducted informally and in an ad-hoc manner with traditional computational support through standards and databases. A more pro-active and formalised approach may account for potential benefits associated with DFR at 40% and DBR at 36%, with DE at 24%.

The greatest scope for making improvements in the specified metrics is again with cost at 317% (Figure 7), followed by quality at 167%, time at 154% and performance over doubled with 109%. It is encouraging that practising designers have recognised the importance of DFR and its potential benefits. Historically within the company this has not been an area of design that has received any particular attention, though it is the one providing the greatest improvement at 264% (Figure 8). The benefits from DBR can be trebled (200%) while with DE they can be doubled (100%). This may reflect a future reliance on a more pro-active design reuse approach with relatively little additional effort being dedicated to domain exploration.

4.3 The Benefits of Design Reuse

Considering design reuse as a whole (Figure 9) we can see that time, quality and performance are all currently benefiting from reuse to a similar degree at 10-11%, with cost nearly half as much at 6%. The greatest overall potential benefit is seen to be cost reduction with 28%, followed closely by improved quality with 27% and reduced time at 25%, while performance is at 20%. Thus, cost reduction has by far the greatest scope for improvement of 367% (Figure 10). Improved quality on the other hand has a potential for improvement of 170%, with time at 127% and performance at 82%.

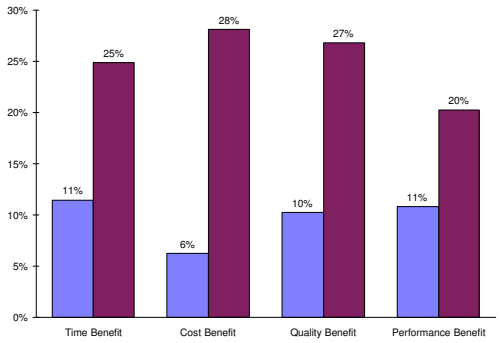

Figure 9: Overall metric benefits

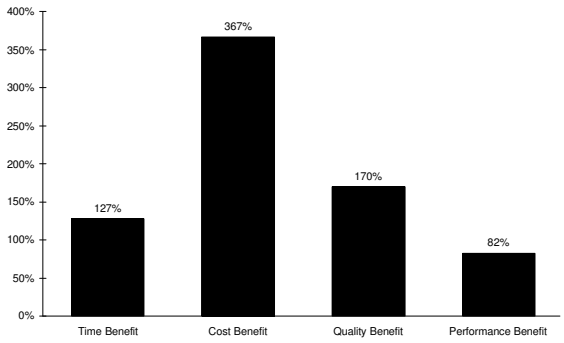

Figure 10: Foreseen metric improvements

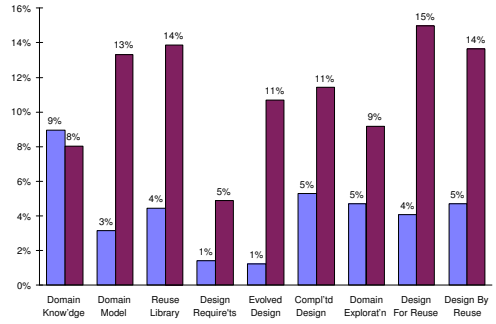

Figure 11: Overall benefits from design reuse

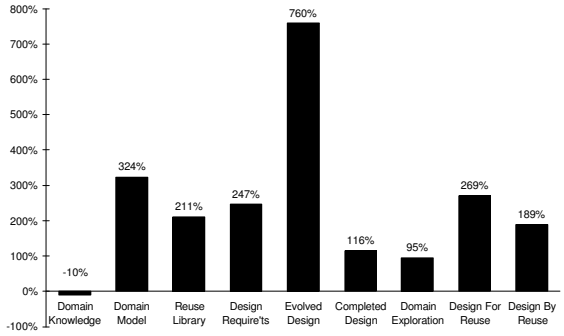

Figure 12: Foreseen improvements for design reuse

The greatest overall potential benefit from design reuse (Figure 11) would seem to be from design for reuse at 15%, followed closely by design by reuse and the reuse library with 14%, and the domain model with 13%. These processes and models are at the core of the design activity and influence in a cyclic nature the evolved and completed designs, each potentially providing a benefit of 11%, with domain exploration and domain knowledge 9% and 8% respectively. Design requirements are seen to only provide a potential benefit of 5% which again may reflect that design requirements can only be reused to a limited degree as new

requirements generate the need for new designs. For the company to get maximum benefit from design reuse the overall trend would be of moving away from utlising domain knowledge and designing from first principles to one of adopting a pro-active and formalised approach to design reuse. The greatest scope for improving the benefits from design reuse (Figure 12) is through the evolved design with 760%. Domain knowledge is seen to be less beneficial in future design scenarios with -10%.

5 Conclusion

This paper has presented an analysis of some of the current and foreseen benefits, as perceived by practising designers, when considering an encompassing design reuse process model. It can be concluded that design for reuse can provide the greatest benefits to the product development process when considering metrics such as time, cost, quality and performance. This is followed closely with design by reuse, the reuse library and the domain model. The analysis indicates a shift, for the company analysed, away from designing from first principles and 'blank sheet' design to a more pro-active and formal design reuse approach in order to gain the greatest benefits from design reuse.

References

[1] A. Taleb-Bendiab, "A Concept Reuse Approach for Engineering Design Problem Solving," in *7th International Conference on the Application of Artificial Intelligence in Engineering*. Waterloo University, Ontario, Canada, 1992.

[2] S. M. Duffy, A. H. B. Duffy, and K. J. MacCallum, "A Design Reuse Model," The Tenth International Conference on Engineering Design (ICED), Prague, 22-24 August, Heurista Zurich pbs, 1995.

[3] S. M. Duffy and A. H. B. Duffy, "Sharing the learning activity using intelligent CAD," *Artificial Intelligence for Engineering Design, Analysis and Manufacturing*, vol. 10, no. 2, 1996, pp. 83-100.

[4] M. Pearce, A. K. Goel, J. L. Kolonder, C. Zimrig, L. Sentisa, and R. Billington, "Case-Based Design Support ~ A Case Study in Architectural Design," *IEEE Expert*, vol. 7, October 1992.

[5] A. Ferns, "Benefits of engineering design reuse," Masters dissertation, CAD Centre, Dept. of Design Manufacture and Engineering Management,. University of Strathclyde, Glasgow, 1998.

Dr A H B Duffy
University of Strathclyde,
CAD Centre, Design Manufacture and Engineering Management,
75 Montrose Street, Glasgow G1 1XJ
Scotland, UK.
Tel +44 141 548 3134
Fax +44 141 552 3148
E-mail: *alex@cad.strath.ac.uk*