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

SHARING IN DESIGN – CATEGORIES, IMPORTANCE, AND ISSUES

A Chakrabarti

Keywords: Function sharing, structure sharing, categories, product analysis, design synthesis.

1 Introduction

Function sharing is a word popularised by Ulrich [1] who uses this word to describe the phenomenon of using a single physical structure to achieve several functions. For instance, the electrical cable holding a light bulb from the ceiling both supports and supplies current to the bulb. In this context, the word 'function sharing' is a misnomer in that what is shared here is the structure and not function. Therefore, it should be called, more appropriately, *structure sharing*. This concept has been used in different guises in literature, often as integration [2], or combination of functions [3]. It is also possible to have true function sharing – sharing of a function by several structures. For instance, the four legs of a table share the same functions: they together support and provide stability to the table. Again, the concept is not new, and has been called in several names including modularisation [2] and separation of functions [3].

Both function and structure sharing are important concepts in product design, and have often been used, consciously or unconsciously, in order to promote success-bearing factors in products. While integration has been viewed as promoting resource effectiveness and the resulting efficiency, modularisation is often seen as promoting ease of adjustment, reuse, repair and recycling. However, while the importance of these has been emphasised often in literature, a systematic, in-depth investigation into the possible categories of these broad concepts, their relative importance, and how to use them in design is currently missing. The aims of this paper are to establish the importance of sharing in design and the main issues that need resolving in order to support maximising sharing in designs. The objectives are to identify the main categories of sharing that are possible, the importance of each of these categories, and how to choose between them in a design process.

2 Main Categories of sharing in design

In order to identify the main categories of sharing, a range of products is analysed, from literature and catalogues. Four categories of sharing were identified, as explained below.

2.1 Function sharing

This means simultaneous fulfilment of a function by several structures, see Fig. 1. For instance, a motor, gearbox and an impeller connected in series provide an air flow function (serial sharing), or the legs of a table together support and provide stability (parallel sharing).

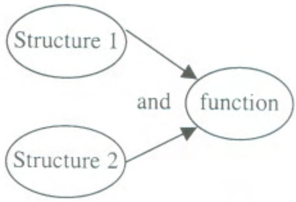

Figure 1. Function Sharing

2.2 Structure redundancy

This means alternative fulfilment of the same function by one structure or another, see Fig. 2. For instance, each engine on a multi-engined aircraft can individually propel the aircraft, or that many items of electrical equipment have the option of being powered by either electrical mains or a battery.

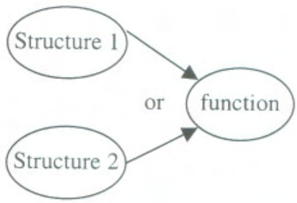

Figure 2. Structure Redundancy

2.3 Structure sharing

Structure sharing means simultaneous use of the same structure by several functions (Fig. 3). For instance, in some mechanical accelerometers, a cantilever beam provides the inertia necessary for developing a force in response to the acceleration as well as the flexibility needed to develop a displacement in response to the force (serial sharing). Another example is that of the multiple-function cable mentioned earlier (parallel sharing).

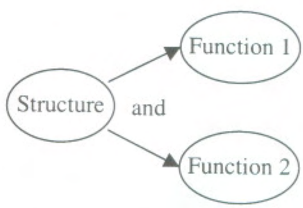

Figure 3. Structure Sharing

2.4 Multi-mode integration

In this category, alternative uses of the same structure for one function or another (Fig. 4) is described. For instance, the same structure can be used as a screwdriver or a spanner, or some mobile library stairs can be used as a static staircase or can be moved around. Yet another example is a sofa-cum-bed, in which the structure can be used both as a sofa and a bed, but not at the same time.

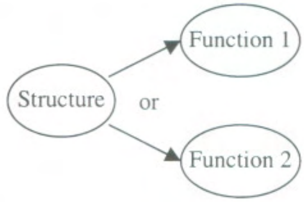

Figure 4. Multi-mode Integration

3 Relative importance of the categories

The importance of these categories is determined both from an analysis of the products as well as from literature that discusses integration and modularity.

3.1 Evaluation criteria

Proponents of integration generally ascribe the benefits of more structure-shared designs as being smaller, lighter, cheaper and more reliable [1]. This, it is claimed, is due to fewer parts, easier assembly and less required adjustment and maintenance. It is also felt that structure sharing is generally a poor design strategy where debugging, adjustment and diagnosis are very important, due to complicated coupling between physical and functional parameters. Modularisation is said to have the benefits of making a product more reliable (due to use of proven modules), cheaper due to reduced resources necessary for development (since a larger proportion of modules designed by others is used), easy to maintain, etc [2, 4, 5].

In order to develop a consistent set of criteria for evaluating the various sharing options, the various reasons mentioned in the literature for products, modular or integrated, were analysed. Two broad categories emerged: changeability and resource effectiveness.

Changeability

Changeability is necessary for products that require in-built ability to adjust settings, e.g., in control devices. It is also necessary for enhancing reuse of parts across product families, or for ensuring minimal disruption to functioning in critical areas of function. Some of the measures for attaining changeability are:

- Increasing adjustability of settings. In general this calls for more parts and interfaces. Modular products generally have greater adjustability than integrated products.
- Enhancing ability to diagnose problem areas in case a product does not function. Products with larger proportion of distinct functional modules are more amenable to diagnosis.
- Minimum disruption to functioning. This can be done by ensuring that a product functions even if parts of it do not, or by making service and repair easier so as to reduce the amount of time during which a product stops functioning. Redundancy, which requires higher modularity, is one way of ensuring continued product functioning when some parts do not. Also, products with greater functional modularity allow quicker and easier repairs.

- Easy reuse of parts from other products. This should lead to more reliability since proven parts are used; parts with greater functional modularity should allow greater reuse of parts.

On the whole, it appears that changeability is more likely to be obtained from less structure-shared, more functionally divided (i.e., more modular) products.

Resource effectiveness

Resource effectiveness is necessary to keep product cost down and reduce time to market; both are essential to keep a product competitive. Some of the measures to attain this are:

- Reducing the chance of failure thereby reducing wastage of resources. An integrated product generally has fewer parts and interfaces, and therefore has less chance of failure and consequently increased reliability. Also the larger the number of parts and interfaces, the harder it is to maintain overall product quality and function (e.g., requiring higher tolerance, and being limited in functionality such as stiffness, sealing etc, see [2], p-322).

- Ease of replacing parts not working, thereby reducing service/repair resources necessary. Products that are more modular are better at achieving this.

- Replacement of a smaller proportion of the product during repair. Products with more parts can allow this better than products that are tightly integrated.

- Ease of (dis-)assembly reducing the amount of assembly resources necessary. In general, designs with fewer parts and interfaces are easier to assemble. Therefore, more integrated products should generally require less resources to (dis-)assemble.

- Reducing the materials requirement of a product, leading to smaller volume, weight and cost. Again, products that are more integrated should require less resources to make.

- Reuse of parts of a product in other products. This is an area where products with many parts may have an advantage.

- Recyclability of a product in terms of reuse of its materials, by increasing the ease of dis-assembly and reuse of a larger proportion of its materials. There are conflicting influences here: while disassembly is easier in integrated products, reuse of a larger proportion of constituent materials is more likely in modular products.

Although some of the above issues are more to do with production oriented modularity than functional modularity (see [2], p-434), the above discussion, on the whole, indicates that products with greater structure sharing are likely to be more resource effective.

3.2 Relative importance

In terms of the criterion of resource effectiveness, it seems that structure sharing is desirable for making a design most resource efficient, smaller and lighter, leading to less parts count and less assembly required. The next best seems to be multi-mode integration. Even though a structure using this may satisfy the same number of functions using the same overall structure, the structure would generally require a larger number of components and interfaces than that in structure sharing in order to enable the change in configuration necessary to exclusively perform each distinct function. The next choice appears to be function sharing where each function requires several structures for its satisfaction, which is worse than the others above. Using structure redundancy would be the worse choice in terms of this criterion.

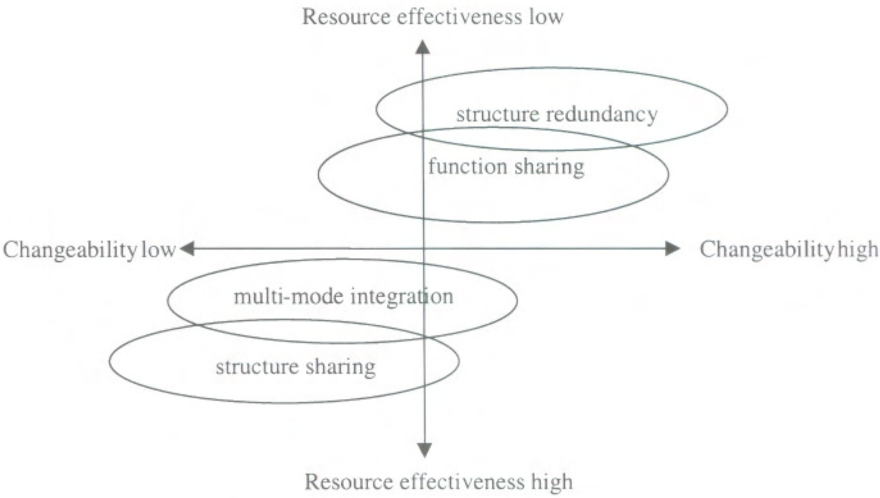

Figure 5. Relative Importance of the sharing options

In terms of changeability, however, the scenario is quite different. In general, structure sharing, which attempts at maximum integration at the structural level, is likely to make a product least desirable in terms of changeability, while structure redundancy, which allows multiple structural alternatives for the same function is most desirable. Function sharing seems closest to structure redundancy in terms of changeability, since each functional module is divided into a large number of individual structures, although not as large as it would have been if the product also had structure redundancy. Multi-mode integration is closer to but not as bad as structure sharing from this perspective (see Fig. 5 for an overview).

3.3 Determination of relative importance of product concepts

In order to evaluate the overall relative importance of a product concept over another (each with none or several categories of sharing present) using the above two criteria, we need a measure for assessing a concept using each criterion. A preliminary attempt at developing these led to the measures discussed below.

The qualitative measure for *resource effectiveness* is taken as the ratio of the number of structures in a product concept to the number of functions that these structures fulfil. This is to give an idea, at the conceptual stage where little quantitative information is available about a product, about the relative amount of resources necessary for fulfilling each of the functions.

Changeability is generally greatest when each structure can be replaced without affecting any (other) function. In other words, changeability is more in a product where there is less coupling between its functions and structures. The qualitative measure for *coupling* is defined as the ratio of the number of relationships between the (high level) functions and structures to the potential maximum number of relationships between these functions and structures.

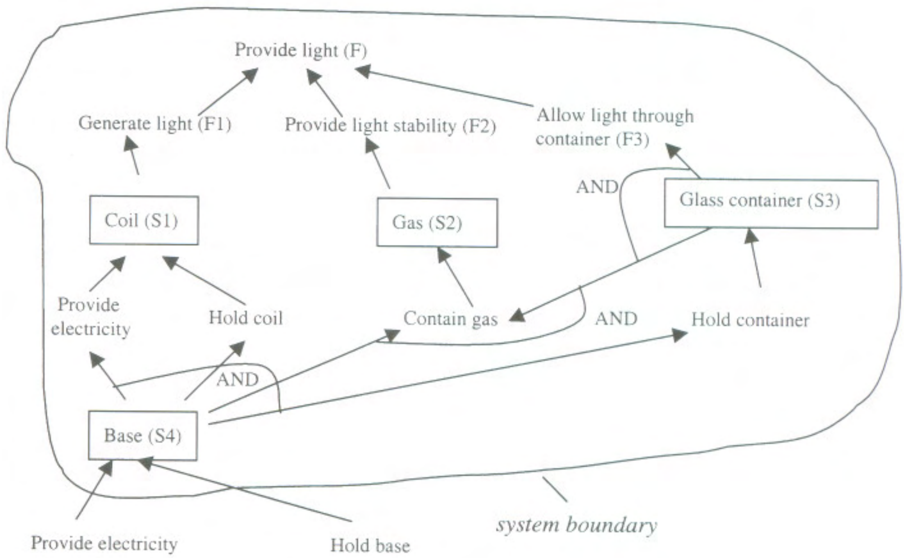

Figure 6. Function-means tree of a miniature lamp with base

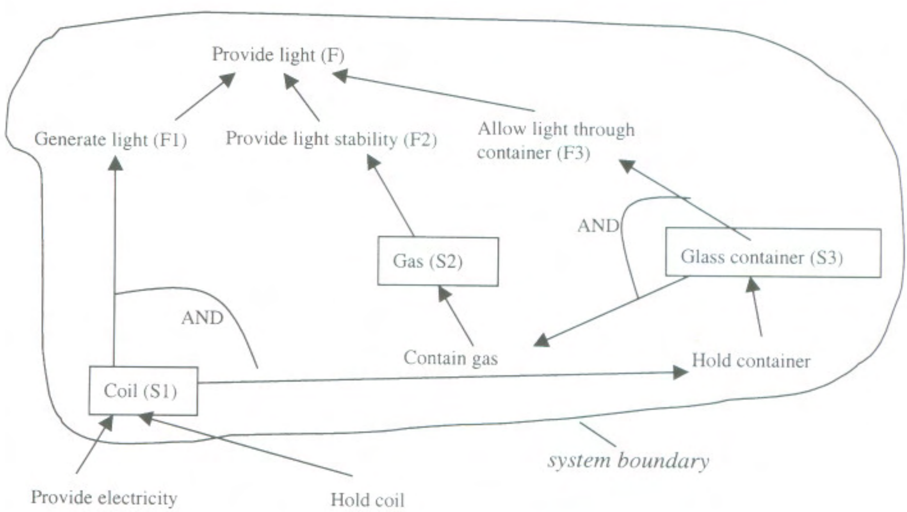

Figure 7. Function-means tree of a miniature lamp without base

The following example, of two alternative designs of miniature electric lamps, is used to illustrate the measures. The first has a separate (metallic) base which holds the rest of the lamp (structure sharing) and shares containment of the gas with the glass container (function sharing, see Fig. 6). The second is where the glass container alone contains the gas, while the coil structure holds the rest of the lamp and generates light (structure sharing, see Fig. 7).

The structure to function ratio, which indicates resource effectiveness, for the structure with base is 4/3 (four structures to fulfil three overall functions), while that for the structure without base is 3/3 (three structures to fulfil three functions). The coupling, which indicates changeability, for the structure with base is 7/12 (among the twelve possible relationships between the three high level functions and the four structures, seven exist either as a direct or an indirect relationship, e.g., the base helps generate light by transmitting electricity to the coil). The coupling for the structure without base is 6/9; among the nine possible relationships between the three structures and three high level functions, six exist either directly or indirectly, e.g., the glass container contains gas and indirectly helps provide stability of the light) Comparison between these numbers indicates that the lamp without base is likely to be more resource effective than the lamp with base, while being slightly more coupled. This should be the case for designs that are more integrated as the lamp without a base seems to be.

3.4 Implications for product design

The examples and the preliminary analysis in Section 3.4 illustrate two points. The first is that in an existing design, there is often a blend of instances of the various sharing categories. This means that function and structure are not hierarchically decomposable when structure sharing or multi-mode integration is present. The conclusion broadly agrees with [6], who found that function and form are often not hierarchically decomposable in mechanical designs. Some of the sharing in a product are designed to keep the cost down, while others are purely incidental. However, each type of sharing can have distinctive uses. Overall, it appears that structure redundancy is useful when it is essential to have alternative arrangements for a product function. For all other functions, the choice should depend on a balance between what is possible and what is desirable. If changeability is essential for a product function, then function sharing should be the first choice, and if not, multi-mode integration should be tried, and so on, and reverse if changeability is not important. However, the issues are not always systematically considered in designs, which points back to the lack of literature and support for designers in making an informed choice between these sharing alternatives.

The second point is that in order to enable systematic consideration of the sharing alternatives, which could be used both to analyse and evaluate a product concept against other competing ones and modify it so as to improve some of the above aspects, it is necessary to have measures to evaluate the aspects. It is envisaged that one possible way of supporting designers would be to enable them to explicitly describe the product functionality necessary, specify the importance of these functions, and identify areas where sharing of various kinds are possible. It would then be possible to consider alternative structures for the fulfilment of these functions with various mix of the sharing options with a clear understanding of their relative merit. This should lead to the identification of potential conflicts in combining the sharing options, thereby enabling modification to better-shared designs. The final outcome, it is hoped then, would be products that would provide an optimum balance between changeability and resource effectiveness. However, this is part of future work.

4 Conclusions and further work

The main conclusions are:

- Sharing is viewed as an important area of design research, but little in-depth investigation has taken place to identify the kinds of sharing possible, their relative importance, and how to choose between these options in a design process.

- Product analysis revealed the existence of four basic types of sharing; these can provide varying degrees of trade-off between resource required and changeability achieved.

- Designer support for exploring design possibilities using these sharing options with an evaluation of the trade-offs they impose is unavailable at present, but is necessary if better shared products are to be consistently developed in future.

The single major future challenge is to develop the preliminary measures presented in Section 3.3 into reliable measures for evaluation of changeability and resource effectiveness. Several issues remain:

- At what level should functions be addressed in the measures? If only the highest level overall function is addressed, much of the details of how function sharing occurs are lost. On the other hand, if the lowest level functions are addressed only, then function sharing at higher levels is lost. How can we account for both? At what level should a structure be considered individual, since this changes the sharing scenario of a product?

- The above issues are partly connected with the dichotomy of function and production modules in product modularity, both of which affect the evaluation in related but distinct ways. The present work supports functional modularity while only indirectly addressing the issue of production modularity. How can we support them both in the future?

- While a support for sharing may be have its benefits as a detailed or redesign tool, the main benefit lies in its use at the early design stages where ideas are qualitative in nature and information is often imprecise or even unavailable. How can we develop measures that take into account only qualitative aspects of a product concept and still enable a designer to draw valuable conclusions about the sharing involved?

References

[1] Ulrich, K.T., Computation and Pre-Parametric Design, PhD Thesis, AI Laboratory, Massachusetts Institute of Technology, Cambridge, 1988.

[2] Pahl, G., and Beitz, W. Engineering Design: A Systematic Approach, Springer, London, 1996.

[3] French, M. Form, Function and Mechanism, McMillan, London, 1992.

[4] http://www.cage.curtin.edu.au/mechanical/staff/rogers/mdesgres.htm

[5] http://dora.eeup.cwru.edu/gcc/Gripper_Guideline_Paper_Html/

[6] Rinderle, J.R. Function and Form Relationships: A Basis for Preliminary Design, Carnegie Mellon University EDRC Report-24-05-87, Pittsbirgh, 1987.

Corresponding author's name: Dr Amaresh Chakrabarti

Engineering Design Centre, Cambridge University Engineering Department, Trumpington Street, Cambridge CB2 1PZ, UK, Tel: +44 1223 766961, Fax: +44 1223 332662, E-mail: ac123@eng.cam.ac.uk, URL: http://www-edc.eng.cam.ac.uk/people/ac123.html