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PERSPECTIVES ON SIMILARITY IN DESIGN

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1. Introduction

Most new designs are based on existing designs. Some are small adaptations of products created in the same company, while others draw on solution principles of entirely different products. The relationship between two design projects can be viewed in many different ways: the knowledge that is used to generate the design, the process with which it is generated, the project itself, the manufacturing process and the components used. In setting up and planning a new design project it is vital to know how much can be used from past projects and how aspects from different designs fit together. This depends on how similar the design projects are. However, similarity is not an unproblematic concept in design. This paper considers different perspectives used in describing designs and design processes. The meaning of similarity in each case is examined.

2. The Relevance of Similarity

Similarity is at the heart of several types of design activity. Many designs *originate* from an existing design, which is modified to meet new requirements. Parts of existing designs and solution principles are often drawn together from different designs. Designers *plan* the design process for a new product based on past experiences with similar processes. Significant savings can be made, if a project reuses parts of existing designs or processes. In *communicating,* either internally within their project team or company or externally to clients, designers often describe new ideas with reference to existing designs [Eckert and Stacey, 2000]. *Knowledge management* assumes that knowledge, experiences and insights applied to and gained from previous projects can be applied successfully to new projects.

2.1 Features

What is meant by similarity in different design activities is often left unspecified. Two designs can be similar in many different ways. Some similarities are superficial - although a strawberry and a fire engine are both red, we would not usually call them similar. Similarities can be functional - a bottle and a milk carton perform the same function but do not share components. Similarity can often be observed on certain levels of detail, but disappears when the same objects are compared in greater detail. For example all cars have engines and gearboxes, but individual designs may be quite different. Other similarities may only be recognised by those with a deep understanding of the product who can compare solution principles or configurations. Processes used in design and their associated description can also be compared.
Similarity descriptions are typically subjective. Designers use similarities in individual and personal ways, making those aspects of products or processes which are referred to in comparisons, inaccessible to a wider audience. Even if the referent is described explicitly then the context and interpretation of specific aspects will still influence the way that a product is described by a designer.
Similarity is used widely and implicitly in design. In order to reason about modification of products, design planning and communication with greater objectivity, we will consider it more

explicitly.Literature on similarity in other fields, such as the psychology of perception (Tversky 1977) or computation in information retrieval and case based reasoning (Leake 1996) suggests comparing objects through features. Similarity at one level of abstraction can be analysed as identity of a selection of detailed features on a lower level. However, in using or discussing similarity not all features are treated in the same way. Similarity of objects can refer to a set of *typical features* that the object typically possesses. For example a car has 4 wheels, transports 2 to 7 people, etc. These definitions carry implicitly a range of *negative features* that the object does not have; for example a car is not buoyant. The *defining characteristics* of a design are typically determined by differentiating it from other designs, that share many, but not all of the characteristics. For example the primary purpose of a car is to transport people, while a lorry transports loads. When looking at the similarities between designs often only the *interesting features* are considered rather than all possible features.

2.2 The Structure of Similarity

In considering designs that are similar, it is possible to identify several distinct patterns in which designs are put into similarity relationships with each other (see Earl and Eckert [2002], for a detailed discussion). Figure 1 shows some of these patterns. The grey spots show the features shared by pairs of designs. Similarity relationships are described mainly by these features. The black spots indicate common features among all designs in a population. These features have limited relevance when investigating similarity. They are background features which do not serve distinguish designs in the class although they be used to distinguish the class from others. Typical patterns of similarity based on shared features are:

- *Tolerance classes* are a mathematical and philosophical concept. Carnap (1967) used similarity as a fundamental relational structure in creating a constructional system of descriptions. Formal developments (Schreider 1975, Zadeh 1971) define a group of elements as similar if each pair of elements in the group shares at least one common feature.
- *Chains* are groups where each pair of elements is connected by sequence of elements such that neighbouring elements share at least one feature (ie are similar in the sense of the tolerance group). Chains are a weaker similarity grouping than tolerance.
- *Versions* of the same product share many common features and have additional features without any specific relationship between those features
- *Ranges* do not share common features across the whole class, but parts of the designs share many features with each other. For example, a fashion garment collection shares common features among individual the garments. Every design is linked to others in the range through several shared features, thus acquiring the coherence of a range.

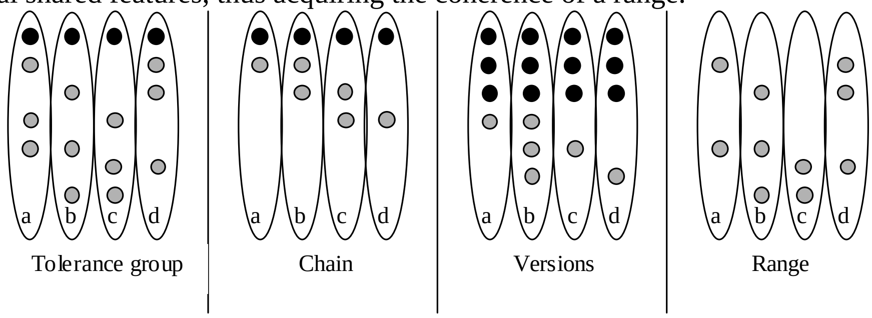

Figure 1. Different types of Similarity Groups

The chain is an example of perceived similarity not based on directly shared features. Thus removing an intermediate link can alter perception of similarity. For example if a link is removed, such as the *b*, *c* link in the chain in Figure 1, then the other objects, such as *a* and *d*, might not then be seen as similar. Often the links are tacit, for example through an historic link. The perception of similarity is also influenced by the relative distance of two objects to each other. For example, if a car of a different make is compared with two versions of the same make it appears different, but if all three are compared to a lorry they appear similar These and related issues are addressed in Earl and Eckert [2002]. However, this paper concentrates on the types of similarity rather than their structure.

3. Layers of Design Descriptions

In the course of a design project many different descriptions are generated: the project is defined through a progression from solution principles to descriptions of components. The design process is defined and changed as the design unfolds. Manufacturing instructions are generated and components are specified. These different layers reflect different participant viewpoints. When designs are compared on each of these layers, similarity has quite different meanings. Similarity is not necessarily determined in a binary way by the presence or absence of shared features but is often represented in terms of a 'distance' between the two designs being compared. This may be a composite measure of weights on shared (and distinctive) features. A new design will share many features on all layers with past and future designs. By understanding the similarity in the different perspectives or layers, the distance between products can be assessed and whether new tasks for generating genuinely new designs are required, or whether existing ones can be adapted.

3.1 The Layers

The different perspectives on design descriptions are illustrated in Figure 2 as layers with differing degrees of abstraction and types of information in the descriptions at each layer (Earl *et al*., 2001). Descriptions of individual components, such as a bill of materials, is concrete and specific, as well as being parsimonious. A complex product, such as helicopter or a car, has 10 000s and 100 000s of components. These are grouped into sub-systems to describe specific parts of a product. These groupings may be ambiguous, because components can belong to more then one subgroup. Individual components can be seen as features of the sub-system on a lower level of hierarchy. Products are often described in ways that are harder to capture. They may be broken down into functional descriptions, which during the progress of the design process have components assigned to them. A looser description may be in terms a series of product characteristics. Abstract descriptions of a product can include the solution principles employed in the product. These descriptions may not form a coherent picture in the absence of direct mappings between these descriptions.

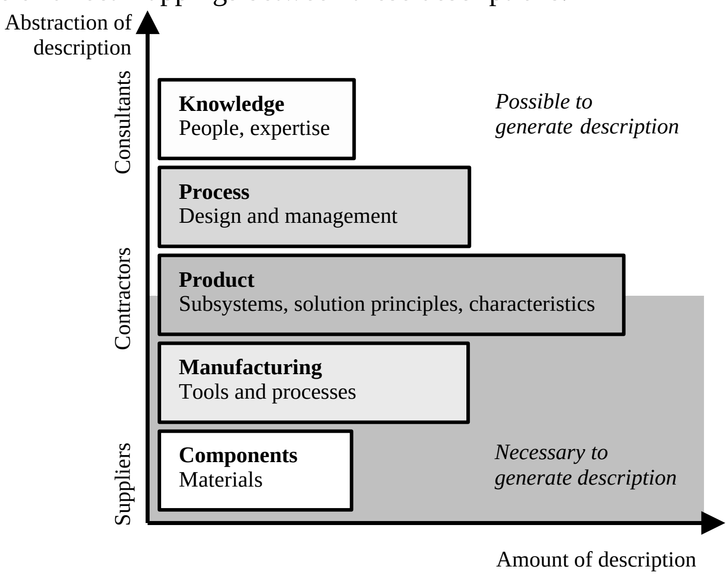

Figure 2. Layers of design description by abstraction and amount of description

A further difficulty in industrial applications is that they are often employed in parallel. Manufacturing processes are typically fairly standard and can be described in specific terms. Design processes on the other hand are much harder to describe. Industry plans and structures its processes in different ways according to the needs to individual designers, project teams and established company working practices [Eckert and Clarkson, 2002]. Designers often use task or activity descriptions with process milestones and lead-time constraints to structure their activities. Managers often concentrate on costs, relating these back to component descriptions. Process descriptions are fairly general and can rarely be specific, because of the uncertainty of design. Knowledge and expertise of the people working on a project is potentially applicable to many different design problems. Knowledge management practitioners and researchers find knowledge hard to capture. Distinguishing layers should help to categorize design knowledge, identify appropriate associations between problems and knowledge on each layer and help to place layer knowledge in the context of the entire design over all layers.

3.2 Development of Design Descriptions in the Design Process

As a design process progresses the importance of different types of descriptions changes. (See Figure 3). In the tendering stage of a large project, companies draw on the knowledge that designers and managers have from past projects about how they will solve the new problems presented in the invitation to tender. Usually an existing design as well as the process used to generate it (which may be a standard process) serve as a starting point. Manufacturing and component considerations primarily serve as constraints, requiring specified processes to be applied or components used. In the conceptual design phase the characteristics, functions and solution principles become clear. Associated design processes for the product are also identified. Key components with long lead times need to be ordered. Fundamental design decisions are often sufficient to allocate the major manufacturing resources. Detailed design follows more established processes and may require less creative knowledge input then earlier phases of design. As the product description is completed, more components can be ordered and the manufacturing process specified. Detailed manufacturing process knowledge is now required to set up the manufacturing facilities. The design acts as a constraint on the development of the manufacturing process.

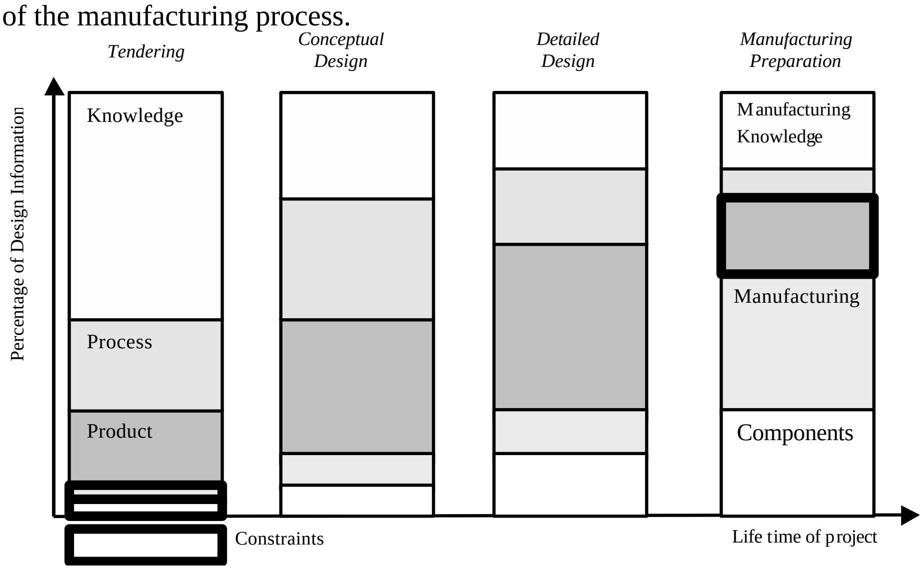

Figure 3. Design Descriptions over time

4. Similarity and Layers of Design Description

Similarity between products can exist on each of the layers. It has a different structure on each layer. This section considers similarity of designs on the layers. It also examines how these different aspects of a design can be used in other designs.

Similarity between *components* is, for the most part, only helpful, if the components are identical. Similar, but not identical components cause confusion in production and require additional storage. Thus companies actively try to standardise parts. Identical components across products lead to higher order volumes per part and unit cost reductions. The *manufacturing* of products sharing the same type of components is similar unless the limits of a process are reached. These "cliffs" in manufacturing processes can be deceptive and lead to large unexpected costs. Similarity on a *product* level needs to be assessed independently for different aspects of the product: sub-systems, functions, characteristics and solution principles. Similarity in one aspect at the product layer does not lead to similarity in other aspects. For example similar functions and similar solution principles can be consistent with different product architectures. It is also important to consider the relationships among different aspects on the product layer. For example functional trade-offs can remain essentially the same across several different products, although product architecture varies significantly; or the weight ratio between parts can change when the parts remain the same.

Processes can be almost generic across many types of product. They follow the stages of general design process models such as the classical idea generation – conceptual design – embodiment design - detailed design models. High level product models often define the tasks within the processes. For example a car has an engine, a power train, an undercarriage etc. and accordingly have high level tasks of “design the engine”, “design the powertrain”, “integrate engine and powertrain” etc. Tasks, at a more detailed level can also consist of generic activities, such “construct part in CAD system” or “run evaluation”. Processes at intermediate levels share procedures, individual tasks and have common strategies with which these individual tasks are combined. These processes remain 'hidden', internal to the project team. They are tuned specifically for the capabilities available. The same person might speed activities up significantly while another person might take just as long. The savings that can be made by sharing tasks and repeating similar tasks are hard to predict. Some tasks become faster by repeating them, if they involve for example problem solving strategies that need to be developed, while other such as the construction of a FEA mesh remain constant for a capable user of analysis software. On a *knowledge* layer products can be seen as similar if they require the same knowledge and expertise to design or produce them. Here similarity is not primarily a property of the product, but of the people available to generate it and the context in which they work. Capability as well as access to relevant knowledge and information are critical factors.

As the layers are closely linked, similarity on one layer induces similarity on other layers. As an example, consider the process, product and manufacture layers. Each sub-system on the product layer has a process with which it is generated and a process with which it is manufactured. If subsystems are similar, then the processes are likely to be similar. However, manufacturing processes are determined by the product to a greater extent than design processes. During the design process a trade-off between layers need to be considered. A component with a better strength might take longer to design. Incorporating new results from manufacturing research might require greater design effort.

5. Conclusion

Every design project is embedded in the context of other product developments (current, past and planned) in the company (Figure 4). Products are often developed in ranges of closely related products. They can have a bearing on other products in the company by sharing components, subsystems and solution principles as well as design and manufacturing processes. This may lead both to competition for resources as well as potential savings. If products are competing then their similarity might be reduced through differentiation. Some companies hope that by standardising on one layer, e.g. the design process or component layer, other layers will exhibit greater similarities and lead to overall savings.

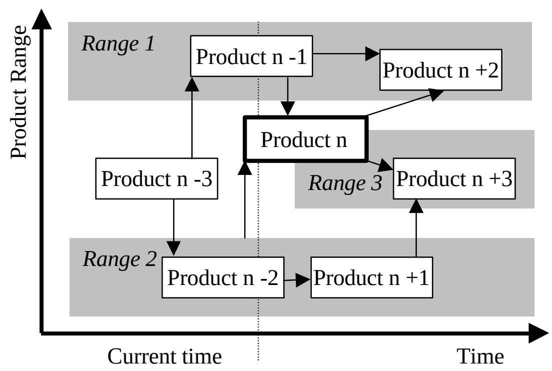

Figure 4. A product in context

Efficiencies from sharing features between products can arise both in the management of processes and in the product itself. Standardised processes reduce the risk of projects running over time and budget and give the participants a sense of direction. By sharing tasks, such as market research direct savings can be made while other tasks are speeded up through repetition. Direct savings can be made by the reuse of existing parts but there is a fine line between lower part development costs and higher costs of integrating and modifying reused parts [Gerst et al. 2001]. However, the greatest saving lies in the understanding and insights into the product and process that similarity analysis brings to designers. They learn how to solve and avoid problems from similar products. They can assess part or whole products including market acceptability. Some of this is best achieved through products designed by the same people or within the same organisation, but others can be achieved through an analysis of similar products on the market, as is common practice. With suitable expertise and insight, product similarity can be utilised across products from completely different fields. Inspiration is often the recognition of similarity in diverse objects and processes. However similarity is only an advantage, if it is understood correctly. Superficial similarity between designs without a knowledge of context and the rationale behind their creation can be misleading. Similarity of designs has many facets. We examined several of these through a layer model. Similarities on each layer are represented by shared features with induced similarities between layers.

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