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# Achieving benefits with design reuse in manufacturing industry

Jarkko Pakkanen*, Petri Huhtala, Tero Juuti, Timo Lehtonen

*Department of Mechanical Engineering and Industrial Systems, Tampere University of Technology, P.O. Box 589, FI-33101 Tampere, Finland*

* Corresponding author. Tel.: +358-503433751. *E-mail address:* jarkko.pakkanen@tut.fi

**Abstract**

This paper is based on a research project for improving performance of companies in manufacturing industry in introducing new products. One section of the project relates to design reuse, and therefore this article presents a literature review to this theme. Goal of the paper is to present how design reuse can be defined and supported. Our results emphasize focusing on designing products so that reusable sections can be separated from varying sections because of customer specific needs. Five industrial cases discussed in the paper highlight also that operations, processes and IT support needs to be adapted with reusable designs.


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*Keywords:* Design reuse; product variety; product variety management; product development; product design; design practice; design techniques

## 1. Introduction

Products are designed and produced to fulfil certain observed needs. These needs are changing because of several reasons such as different users, alternative ways to operate with products, limitations and social values. By taking these sources for difference into account, a variety of products is formed [1]. It has been summarized that product variety describes the range of products the company can offer within a certain period of time in response to market demand [2].

Variety is not a positive issue every time. Increase of product variety increases costs in product design, production, warehousing, sales and services. On the other hand, challenge of variety is wider than product variety only. Varying occurs during the life cycle of the product and it relates also to logistics and services before and after sales.

Product variants can be managed by designing new variants or by modifying existing variants according to new requirements and scaling existing products or their modules and components [1]. In the field of variety management, this paper focuses especially on design reuse in manufacturing industry. Reuse of existing elements in designing enables several benefits such as it can increase R&D efficiency and enable improving of operations because of increased repetitions and learning [3]. Design reuse is a broad term. The aim of the paper is to present as an introduction what kind of principles and concepts exist in the context of design reuse and what kinds of practices support designing and using reusable product elements. Thus the paper includes two research questions (RQ's):

RQ1. How to define design reuse?
RQ2. How to support design reuse in manufacturing industry?

To answer these questions, we combine literature review with findings from industrial cases as the main research method in this qualitative study. First the literature is studied in Section 2. The goal is to clarify how design reuse is typically understood and categorized. The purpose is also to find out what kinds of issues are linked with design reuse. Therefore the literature review section contributes especially to RQ1. The review is made by using mainly Scopus (www.scopus.com) databases.

The paper aims also to contribute to research on design reuse by presenting good practices and challenges found from manufacturing industry and analyze these in regard to the findings from the literature review. In Section 3, five cases are briefly presented. In several cases, a company has found out that although the current way to operate is possible in its


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business environment, the operations included in offering products to customer needs to be developed in order to stay competitive. The goal is to describe what kind of tactics have been applied and seen positive in enabling benefits with design reuse in cases. Finally, concluding remarks are given in Section 4.

## 2. Literature review on design reuse

This section includes review on design reuse. Benefits are studied first. After that, drawbacks and challenges are discussed. Categorizing design reuse to design by reuse and design for reuse is considered also. Then, product development tactics that contribute to design reuse are presented. Other views are presented after that. Finally, conclusions are presented about the studied literature including answer to RQ1.

### *2.1. Motivation and benefits with design reuse*

In projecting manufacturing industry the whole engineering function can become a bottleneck in delivery projects of products [4]. Doing overtime work, hiring more personnel or negotiating longer delivery times to solve the effects of overload are not sustainable solutions and do not solve the cause of overload, but systematic design reuse is a better solution for improving productivity [4]. This means that increasing profitability can be challenging for manufacturing company if design reuse and commonality aspects in the product range of a company are not considered. Weak consideration of design reuse may cause challenges such as high cost of engineering and quality problems eventually in a final product because of delivery specific solutions.

Several benefits have been reported related to design reuse. Design reuse helps to reduce effort and risks, supports avoiding errors and uncertainties in development and in this way reduces developing costs and time, helps to familiarize production staff with the product design and helps customers to maintain familiar ways to use and maintain the product [5] [6]. These will lead to cost reductions, faster time to market, shortened testing and quality improvements.

It has been shown in modularization, product family and product platform context that it is possible to provide customer specific product variants while also getting benefits with design reuse [7][8][9]. Design reuse by utilising product families and product platforms enables offering variety without radical increase of costs [10]. These aspects related to design reuse are discussed more in Section 2.4.

### *2.2. Drawbacks and challenges with design reuse*

Despite several benefits, also drawbacks have been discussed. Design reuse might prevent innovativeness and lead to design fixation [11]. Categorization of factors which are often preventing design reuse to five groups have been presented: engineering, cognitive, motivational, organizational and environmental factors [5]. Examples to these groups are summarised in the following based on [5]: Engineering aspects include for example obscure design rationale. Cognitive factors consider that there is a risk that designers have bias towards identifying unfavorable aspects of another's design. Motivational factors highlighted that early phases of designing optimizes typically material costs in the cases which [5] studied. Organizational factors focus often on that the product elements include case specific sections instead of being standard designs. Another important organizational factor is also to understand differences in authorities between project managers and functional managers. From project schedule viewpoint, time is a major driver in preventing designing reusable elements. Environmental factors consist typically from aspects arising from clients and their values.

### *2.3. Design by reuse and design for reuse*

Basically, the main prerequisite in design reuse is to make designs reusable and then store these reusable elements so that they can be found [12]. Design reuse can be categorized to design for reuse and design by reuse. Design for reuse includes identification and extraction of possible reusable knowledge fragments and enhancement of their knowledge content whereas design by reuse means using of existing concepts in new design situations [13]. Design for reuse enables reuse library that includes reusable knowledge and requires identification, rationalization, extraction and storing of reusable fragments of knowledge of a specific design domain based on knowledge concerning past designs or artefacts [13]. In other words, design for reuse is enabler of design by reuse.

From engineering perspective designing a reusable element requires more time than one of a kind element, because designer has to make sure that the element can be used also in other product variants and not in a single case only. This kind of designing and reuse is discussed more in the next section.

### *2.4. Design reuse highlighting different product development tactics*

From design for reuse perspective, this paper emphasizes product designing that enables and supports designing a reusable structure for a technical system and its variants. According to literature review summarized in Table 1, modularization, product platform development and product family development are the main approaches that support this objective, but also parametrization, standardization, product configuration and ontologies are discussed. In the following, the main aspects of these are presented.

Parametric design is one way to support reuse by increasing commonality between variants [1][14]. CAD and CAE approaches are discussed from the viewpoint of component reuse and parametric design based on geometric models. Parameters embed design rules that are reused [12].

Standardization is enabler of reuse when the product or its elements do not need to consider variability [1][15][16]. Standardisation relates to product elements and interfaces between product elements [17].

Modularization is often presented product development strategy for increasing reuse in businesses in which different product variants are needed in order to fulfil customer needs. Modularization includes the defining of a modular

architecture including module and interface definitions in order to reduce the complexity in operations of a company [18]. Reuse of modules [1][16][19][20][21][22][23][24][25], parameters of modules [14], interfaces [16][17][20][26][25][27] and architectures [16][20][21][25] supports efficient designing of differentiated products.

Product platform development is close to modularization and product family development. A platform includes a collection of core assets that are reused to achieve a competitive advantage [20]. From platform perspective it is possible to reuse many kinds of things. Reuse possibilities include knowledge [1][20][24], functionalities [20], designs and design variables [20], architectural rules (see references in previous paragraph), people and relationships [20], processes [1][20][24], product foundation [20], technology [20], interfaces (see references in previous paragraph), modules (see references in previous paragraph) and subsystems, components and elements [1][20][21][24][27][28] and finally, single monolithic parts [20][22].

Product family development based on modularization or product platforms supports reducing different product elements [1][16][19][27]. Members of a product family can share for example modules and other elements related to product platforms. It is suggested that product platform and product family thinking, that is based on reuse, is the most suitable when the market diversity is medium [15]. If the diversity is low, standardized products are suggested [15]. Niche products are suggested when the diversity is high and economies of scale are low or medium [15]. Without product family thinking and defining variants separately results in huge amount of redundant data, weak relations between variants and inability to combine existing variants or create new ones and increased delivery risks because of unproved product elements [1] [28].

Succeeding in product designing that considers principles of modularization, product platforms and product family development enables product configuration. Product configuration as an activity means selecting suitable modules for customers with certain variability requirements [4][29]. The idea is that these requirements are defined explicitly in a company when modules and the whole product family concept are designed. Therefore, for each important variability requirement from a market segment perspective, a certain product variant based on predefined modules and product structuring principles must exist. This does not necessarily require that all the modules would be predesigned until the first order realizes in which these modules would be needed [25]. The idea is that at least structuring principles modules would have to follow would be predefined. This supports that suitable structures which do not harm the product family and the business objectives set to it could be designed accordingly. This kind of configure-to-order way to operate that is based on modular and configurable products supports increasing design reuse compared to engineer-to-order.

Ontologies are also discussed for representing components and parts to support reuse of product information [24]. Ontologies are knowledge bases that include structure of conceptualizations to define specific pieces of knowledge [30].

Table 1. Highlighted product development tactics for reuse and variety management according to the studied literature

| Product development tactic | Supporting references |
|---|---|
| Parametrization | [1] [12] [14] |
| Standardization | [1] [15] [16] [17] |
| Modularization | [1] [14] [16] [17] [19] [20] [21] [22] [23] [24] [25] [26][27] |
| Product platform development | [1] [15] [20] [21] [22] [24] [27] [28] |
| Product family development | [1] [15] [16] [19] [27] [28] |
| Product configuration | [4] [25][29] |
| Defining ontologies | [24] [30] |

### *2.5. Other views on design reuse*

Information systems should support the ability of designers to reuse. Design reuse systems should highlight how knowledge is stored, represented, found and used [11]. For example if standard catalogue components should be used, the main task is how the fittest is found and selected [11]. Design methods can be considered as design reuse methods because fundamental principles are reused although specific design instances are defined each time [12]. Also the concept of shared understanding and knowledge representation relates to design reuse [31]. According to [12] it is important to understand product and lifecycle steps and concepts, data elements and relationships between these concepts.

### *2.6. Summary of the literature review and answer to RQ1*

Definition of design reuse has similarities with the product platform definitions as presented by [20] for example. In the following paragraph, an answer to RQ1 is concluded.

Successful design reuse is beneficial for both a company and its customers. Definition of what can be reused is broad. Therefore the company has to clarify the elements or assets related to the products whose reuse could bring benefits. Design reuse requires reusable solutions. This leads to separation of design for reuse and design by reuse. These two categories are often combined in publications in which design methods, such as modularization methods, are presented. Typically design methods related to modularization, product family development and product platform development represent design for reuse approach. Design by reuse is more about using reusable structures. For this area, product development aspects such as product configuration are considered relevant when variants are needed.

Based on the literature review and our empirical observations, Figure 1 presents a scenario of how the consideration of design reuse may proceed in a design task. Figure includes six questions which have been numbered in order to make the figure easier to read. The sequence of questions might vary and the consideration process might not be as linear in reality as this hypothetical scenario suggests. The first question considers availability of reusable elements at all. To enable design reuse, designers have to have access to reusable elements and the elements needs to be easy to

find. Maintaining of knowledge about reusable solutions is needed to support reuse. This relates especially to question 4-5 in Figure 1. Finally if reusable design element is found and it is considered suitable in a particular design task, benefits with reuse can be achieved.

This figure is used in comparing different cases in the next section. Issues in figure 1 are also relevant from IT perspective. When IT systems consider design by reuse aspects such as configuration knowledge clearly, this can make for example work of sales personnel easier, because they don't need necessarily very detailed understanding about compatibilities, but for example product configurators can facilitate selecting the most optimal product elements based on predefined rules.

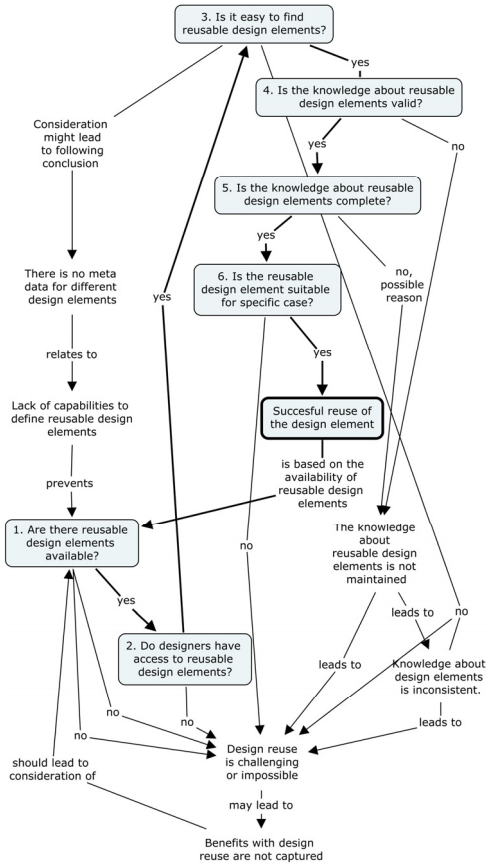


Fig. 1. A scenario of considering design reuse in a design task

## 3. Cases in which benefits with design reuse have been pursued

This section considers five cases from manufacturing industry in which design reuse have been pursued by mostly considering modular product family development. The purpose of the cases is to reveal what kinds of benefits have been achieved. The cases are disguised to respect the sensitive nature of the results. In all the cases, yearly production volumes are from low to medium (decade: hundreds). Size of a series can be even one.

In earlier publications [9][25], we have considered partitioning logic, set of modules, interfaces, architecture and configuration knowledge as the key engineering concepts in modular product family development. Partitioning logic describes reasoning for a certain module division based on business and customer environment. Set of modules are building blocks for product variants, whereas interfaces enable interchangeability and independence of modules. Architecture describes how modules and interfaces compose a product. To support sales in reusing modular structures, configuration knowledge suggests particular set of modules when specific customer needs exists. These key engineering concepts together with issues presented in Figure 1 are discussed in Section 3.6 when summary of the cases is made and RQ2 answered.

### *3.1. Benefits with design reuse: case company A*

Case company A is a globally operating company producing mobile machines for different product ranges and markets. To enable benefits with design reuse, the company has been adapting principles of modularization since the beginning of the millennium. We studied a product development project in which the company designed a modular product family based on existing designs in one of its product range to enable benefits with design reuse during 2013-2014.

In this case, key engineering concepts of modular product family development were considered successfully. Business impacts of modularization were positive in the case. The major impacts were captured in engineering resource consumption. The company reported that it managed to free engineering resources from delivery projects to actual product development from 15% to even 85%. These savings were largest in the studied product range, but the results of the development project were also beneficial in other product ranges and size classes, because similar design rationale could be reused. These benefits in other product segments were not recognized during the early phases of modularization. Despite benefits with design by reuse, the company reports it has still more potential in developing its operations further to support delivering modular products in order to reduce delivery time.

### *3.2. Benefits with design reuse: case company B*

Company B is a global system provider for companies producing engineer-to-order-oriented products. Changing interfaces, to which the systems need to adapt to, are traditional in the business. The company B had calculated that during the history its products had been adapted to tens of different interfaces, and therefore tens of different solutions had been offered also. Because of this, it was challenging to achieve benefits with design reuse. As in case A, a lot of engineering was needed during the delivery project of the system before the successful redesigning of the product.

In this case, the company was introduced to principles and benefits of modularization and configuration starting in the year 2008 and managed to redesign its product so that the first deliveries with new designs were made during 2011-2012. Redesign project was based on encapsulating the elements

which often vary because of customer needs from other product elements that could be standard. Resulting product architecture could be configured by using engineering configurator based on predefined parameters and rules and delivery specific engineering was not needed anymore. This kind of reuse of structuring principles of products saved engineering hours dramatically in the delivery projects. The company reported that the time needed for designing an order-based product decreased 80% maximum while achieving products with better quality.

### *3.3. Benefits with design reuse: case company C*

Company C produces customer specific products for global markets with different and changing needs. The company is familiar with the principles of modularization in achieving benefits with design reuse. The company C started a modularization project that considers the whole product range in 2013. The company has made component-level modularization before.

In the case C, the aim is to reduce operating costs with design reuse. Modular and configurable products are pursued. The company develops its operations simultaneously to product modularization. According to estimations made about the potential business impacts, the most of the benefits with design reuse are seen in engineering and subcontracting. Estimated cost savings vary between 15-30%. In some areas of the products, the needed time for mechanical engineering has already decreased 75% resting on the principles of modularization and configuration.

### *3.4. Benefits with design reuse: case company D*

Company D provides systems globally for engineer-to-order products made by other companies. The company D has started modularization during years 2009-2010. According to company personnel, it took four years to shift to new operating paradigm. After this, external consultation was not considered necessary anymore. During these years also IT systems such as CAD and PDM were modified to support the modularization and configurable products instead of unique solutions only.

In the case D, the main focus was on defining modules and their interfaces and creating a product configurator with configuration knowledge subsequently. The company also defined key performance indicators to monitor the usage of modular solutions. In this case, costs were estimated according to costs of creating new item numbers. As a result of modularization, reuse increased to 70-80% between different variants in the studied product segment. The company considers training of sales important in achieving good results with the new operating paradigm.

### *3.5. Benefits with design reuse: case company E*

Case E is ongoing and part of the future research. This case is presented here to reflect the challenge in case E to solutions defined in other cases and aspects presented in Figure 1.

Company E produces products that customers can adapt to their requirements by selecting suitable combination of product solutions from a large combination of options. During the years, a large number of different items have become a challenge for the company and the company considers that benefits with design reuse are achieved adequately only. Reported benefits with design reuse are not yet available from this case, but related to Figure 1, the company considers it has potential for increasing reuse capabilities in its way to operate and considering key engineering concepts of modularization.

### *3.6. Summary of cases and answer to RQ2*

Table 2 summarizes the results. Question 6 from Figure 1 was not considered in this table because it is always case specific inside each case during designing.

Table 2. Summary of cases A-E

| | **A** | **B** | **C** | **D** | **E** |
|---|---|---|---|---|---|
| **Current state of way to operate** | | | | | |
| 1. Are there reusable design elements available? | yes | yes | yes | yes | yes |
| 2. Do designers have access to reusable design elements? | yes | yes | yes | yes | yes |
| 3. Is it easy to find reusable design elements? | yes | yes | yes | yes | no |
| 4. Is the knowledge about reusable design elements valid? | yes | yes | yes | yes | no |
| 5. Is the knowledge about reusable design elements complete? | yes | yes | yes | yes | no |
| **Key engineering concepts in modular product family development have been defined in order to support design reuse** | | | | | |
| Partitioning logic | yes | yes | yes | yes | no |
| Set of modules | yes | yes | yes | yes | no |
| Interfaces | yes | yes | yes | yes | no |
| Architecture | yes | yes | yes | yes | no |
| Configuration knowledge | yes | yes | yes | yes | no |
| **Reported savings** | | | | | |
| Reduction of engineering hours (%) | 15-85 | 80 max | 75 max | n/a | n/a |
| Reduction of costs (%) | n/a | n/a | 15-30 | n/a | n/a |
| Level of commonality in variants | n/a | n/a | n/a | 70-80 | n/a |

To conclude, companies A, B, C, D managed to redesign their products to support design reuse better and also invested to their way to operate with reusable solutions. Case E is still ongoing and achieving benefits with design reuse is further.

The cases highlight the importance of five key engineering concepts. In the cases in which design information related to these engineering concepts have been defined successfully, clear benefits have been reported also. Therefore it can be stated that there is evidence that focusing on the defining of these key engineering concepts supports enabling of benefits with design reuse.

Although products could be designed modular, also investments to way to operate with reusable structures are critical in the long-term to maintain ability for design by reuse. To conclude our answer to RQ2, we state that design reuse can be supported by taking questions presented in Figure 1 and key engineering concepts in modular product family development into account.

## 4. Discussion and conclusions

The paper reviews design reuse. Design reuse means reusing designs whose reuse brings business benefits for a company (RQ1). We state that the main aspects in enabling benefits with design reuse in business environments in which product variety is needed are to focus both on designing products reusable and developing operations and support systems which facilitates using of reusable elements in product delivery projects as Table 2 summarizes (RQ2). Presented cases reveal that major benefits can be achieved at best when these are considered. This is another contribution of the paper bringing more insight to actual received impacts of design reuse reported in this field. One has to remember though that operating with reusable designs needs also yearly investments to maintain this capability up-to-date. As a limitation for this paper, support systems and IT perspective for design reuse in detail was considered very briefly and these are considered as part of future research. Also, our focus is to study link between way to operate and reusable designs in greater detail, as case E suggests.

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