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Bridging the Gap Between Functions and Physical Components Through a Structured Functional Mapping Chart

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Abstract. Functional modelling can be challenging to integrate with physical CAD-modelling, since the natures of these representations are quite different. This paper presents a methodology seeking to bridge these representations in a product platform context. The contribution of this work is a pragmatic way to improve the connections between Functional Requirements and CAD models. It does so by structuring functions, features and components and by linking these through tags in CAD-models. The methodology thereby associates the CAD models to the functional knowledge used when creating them. The result is the functional mapping chart, which is illustrated by an example from the automotive industry.

Keywords. Functional modelling, product platform, functional mapping chart, design knowledge, CAD- modelling

Introduction

Functional modelling is an approach to describe products and platforms. By offering a structured way to organise functional requirements and design solutions it presents a way to describe complex relations in products and platforms. A strength of functional information is that it holds the rationale behind a design which is a key concept for knowledge about products and systems [1]. Functional information can be considered the core of a product and is not substantially changed over product generations. This is opposed to the geometrical information that is embedded in a Computer Aided Design (CAD) model; the product is the result of a design process but cannot in itself explain the rationale for why it is designed in a certain way.

A barrier for the application functional knowledge is that it sometimes is formulated as a vague or abstract description of design solutions that cannot be immediately embodied into physical components. Literature such as [2, 3] describe functional modelling but lack support for how to move from a functional description to a concrete solution that can be used as a basis for engineering design. It describes *what* must be achieved, but not *how* to achieve this in detail. For geometry, these details are defined by the CAD-model. A combination of the functional model and its corresponding product description in CAD would therefore be beneficial for increasing

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the product knowledge within an organisation. Even the simplest product family can consist of hundreds of unique components including special variants and discontinued parts. It is impossible for a designer to recall how every shape of each individual component contributes to the functionality of the overall product, which is the motivation for developing this new methodology.

The research in this paper is a spin-off from an earlier project carried out at an automotive supplier. The research method is based on a literature synthesis to form the methodology. Data from the company is then used to illustrate it.

The purpose of the methodology is to improve the product development process by linking CAD models to the functional knowledge used to design them. The objective is to present a feasible approach to visualise and structure key information from the functional model and map this onto a CAD model, thereby providing the benefits of a functional approach in practical design work.

1. Literature review

The literature base on platform scoping is mainly focused on detailed design, associated with parametric CAD. This research instead focuses on a phase in-between functional modelling and detailed design. It contributes with a way to link functional requirements to concrete CAD- design, seeking to support this with a functional product platform approach. The focus of the paper is to develop support for concrete embodiments of physical components based on the Configurable Component framework. Therefore the literature review is limited to literature in the field.

1.1. Functional modelling

Functions are often confused with solutions. This work follows the view of Andreasen [4], where a motor is not considered a function but rather a design solution fulfilling the Functional Requirement *provide kinetic energy*. A hallmark of functional knowledge is its generality as opposed to knowledge sealed in a product feature, or “function carrier” [5], that cannot easily be extracted whilst it has been transformed into an physical component.

Products and platforms can be modelled according to the Function-Means (F-M) methodology [4, 6, 7]. This is a technique for functional decomposition and concept generation of systems and products. It presents a systematic way of arranging functions and solutions to functions in a hierarchic tree structure as depicted in Figure 1. It is an object-relational model that describes the Functional Requirements (FR) for the system and what Design Solutions (DS) that can be used to meet these requirements.

Creating the functional model is a creative work, zigzagging between FRs and DSs where a chosen technology will render specific sub-requirements.

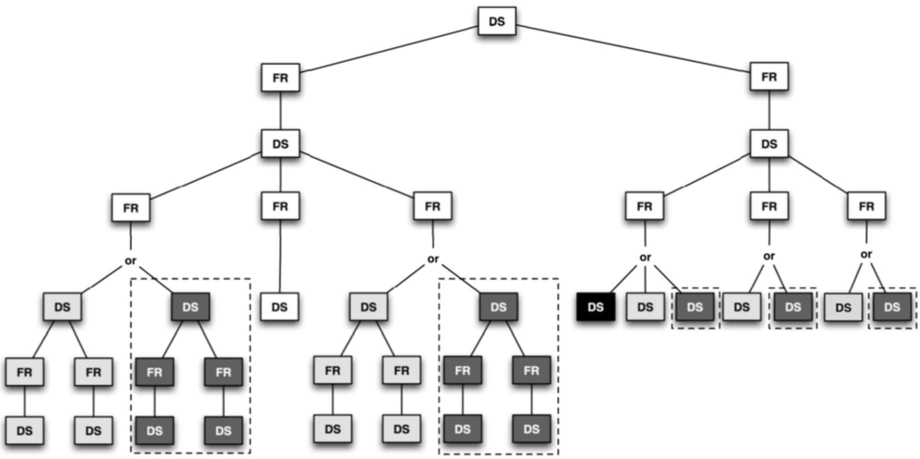

Figure 1. The white objects are present in all configurations and the shaded objects are present in some. The dashed branches represent alternative configurations. In order for the Functional Requirements to be fulfilled, all embodying Functional Features must be mapped to components. Redrawn after [8].

The tree ends at the detailed level [9] as Functional Features (FF), which is the name of the last DSs before embodiment. Note that for the FRs to be fulfilled, all FFs must be mapped to components and used.

1.2. Mapping functions and physical components

An extension of F-M modelling to support the development of product platforms is the Configurable Component (CC) framework [10] that presents an object oriented approach of modelling platforms. In this context Levandowski, et al. [11] introduce the concept of components to describe how functions can be allocated to the physical artefacts that realise the desired functionality. The authors introduce a model of components in the product and manufacturing system and outline a process for its use.

A result of the mapping is seen in Figure 2. Here, several types of mappings of functions to physical components are displayed. When several FFs are mapped to a component, function sharing occur, which is characteristic of integrated architectures [12]. An example is given in Figure 2 at the dashed arrows marked with B. Here two FFs are allocated to the component, the Airfoil-shaped vane. The component uses strut segments that convey mechanical loads and the geometry of the outer surfaces turn the swirling flow of the Low Pressure Turbine. Figure 2 also shows how the circumferential flanges FF is realised by three physical components.

The CC framework is supported by the Configurable Component Modeller (CCM) that can model the objects and relations in the CC´s [13]. It is used in the design phase to instantiate different product family members from a platform model and exports these as design parameters to CAE software. However, the software is not supporting detailed design work in the process of embodying detailed FFs into physical components.

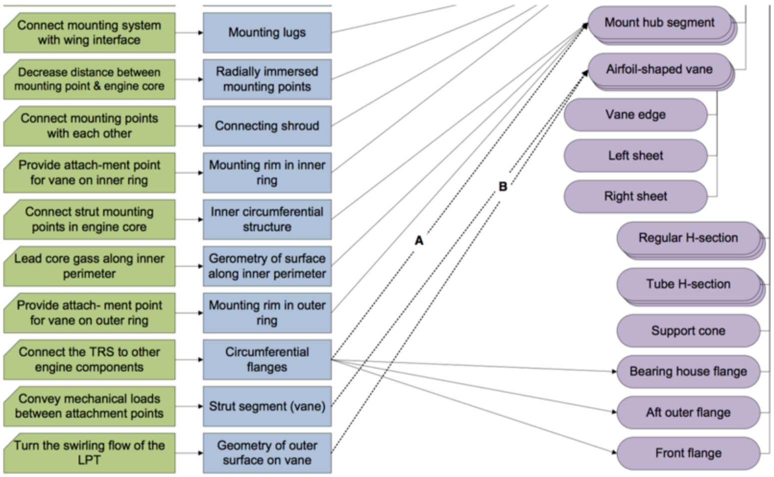

Figure 2. Extract of the mapping of Functional Features in an aerospace component. A physical component can carry several Functional Features as seen in A, as well as dividing a Functional Feature between physical components as shown in the bottom of the figure. After [11].

2. A methodology to support the design of physical components through functional modelling

This work presents a methodology that helps designers take advantage of the information residing both in a functional product / platform description and in product description data i.e. CAD. The methodology can be used with most CAD systems and be supported by platform modelling software such as CCM. It can also be used manually if no previous functional information exists by using traditional F-M methodology.

One reason for the difficulties encountered in the transition between functional representations and concrete solutions is the significant gap between a defined functional requirement and a physical component. This gap is bridged by the engineering design process and there is no simple solution to bypass it since it requires skill, experience, and creative design work. The ambition of the methodology is therefore not to fully bridge this gap, but rather to visualise and link the relations between functional models and CAD models.

Re-design can be caused by different reasons. If new functionality is needed due to changing customer preferences then the new FR will be needed which create a new branch in the F-M tree. If a new way to solve current functions is requested then a new DS is introduced, that, in turn may also create a new branch. From a functional view, the end result is the same, a new FF that must be embodied in a component. To fulfil an FR, all FFs that lie underneath it must be allocated to components.

2.1. Creating the functional mapping chart

The core of the methodology is the *functional mapping chart*. The suggested process to create the functional mapping chart goes through the steps of Table 1:

Table 1. The steps used to create the functional mapping chart.

Step	Description
1	A Function-Means tree is constructed representing the relevant parts.
2	The functional model is broken down to the concrete level in the Function-Means tree. This is the sufficient level at which the functional model can be transformed into a physical component.
3	The Functional Features at the concrete level are embodied into physical components.
4	A functional mapping chart is created. It visualises the Functional Features, the governing Functional Requirements and the name of the physical component or components that the Functional Features are integrated into.
5	All Functional Features must be used in the embodiment; otherwise the corresponding Functional Requirements are not fulfilled. This can be verified by using the functional mapping chart.
6	The Functional Requirements are used to tag features in the associated CAD model to pinpoint where functionality is created by the Functional Features. This enables traceability between the functional model and the physical components.

A F-M tree is constructed and one way is to follow the process given by Levandowski et.al. in [9]. The functional model is broken down to a sufficient level, at which the functional model can be transformed into a corresponding physical component. To fulfil a functional requirement, there must be a FF allocated to it. These are found at the concrete level in the F-M tree [9] representing the most broken down level. Functionality is handled by the FFs that are embodied into physical components, sometimes called function carriers [12].

Several FFs can be integrated in a component. This creates a potentially massive design space since each FF may be designed in several ways and also be distributed differently over components. Two different mappings of FFs to a sheet metal component are seen in Figure 3.

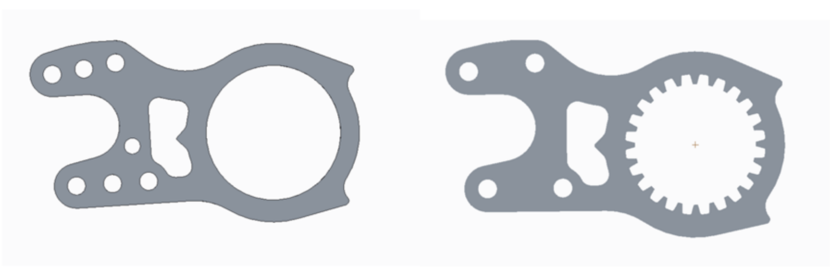

Figure 3. The FFs can be embodied in different alternative components, enabling a Set-based approach. The fulfilment of the governing FRs can be assessed through the functional mapping chart. As an illustration, the right variant also fulfils the FR "adjust back rest angle" through its internal gears.

The massive design space is suitable for a Set-based approach thereby creating sets of alternative architectures. A way to evaluate different architectures is presented in [14] and can be used to compliment the method described in this paper.

After going through the steps of the method the functional mapping chart can be created. It is based on a template that visualises the FFs, its governing FRs and the identification of the component that carry the FFs. Most of the information can be generated from the platform through the software CCM and exported to Excel. It can also be created manually by identifying what FFs that are satisfying which FRs and what components they are integrated in. The functional mapping chart is used to visualise and structure how FFs are distributed over components and to identify if some FFs are not allocated; all FFs must be used in the embodiment otherwise the corresponding FRs are not fulfilled. The functional mapping chart can also be used in a morphological approach as a creative tool in the embodiment process to distribute FFs over components in different ways.

3. Applying the methodology to an example within automotive design

The approach is illustrated by an example of mechanical design based on data from a previous study at an automotive sub-supplier. It illustrates a case of re-design of the sheet metal bracket in Figure 3 that is reused in different models of automobile driver seats in a part-based product platform. It is a part of the mechanism that adjusts the backrest angle. The seat consists of several hundreds of unique components. It is also part of a larger platform of seats so it is impossible for a designer to know all the features of each individual component. A part of the F-M tree is seen in Figure 4:

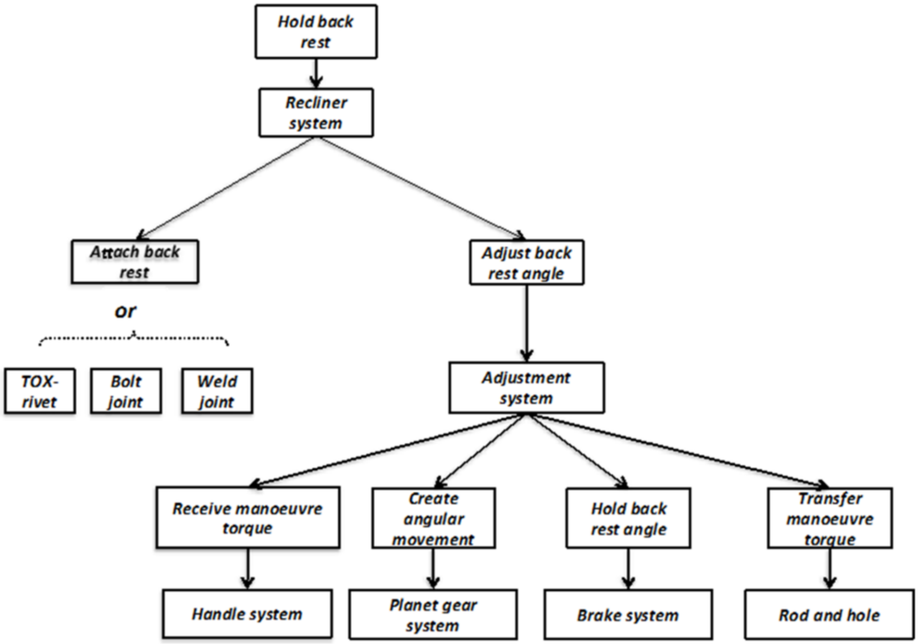

Figure 4. A functional breakdown of the Functional Requirement *hold backrest.*

In the presented case, the firm needs to reduce the weight of one product due to changing customer requirements. To fulfil the new requirements the designers decides to change the material in the seat frame from steel to aluminium so a steel component can no longer be welded to the frame and another joining method is needed. The sheet metal bracket is found in a plurality of different steel seats and therefore cannot be redesigned in aluminium so the firm decides to create a new bolt joint bracket. There are several fastening concepts used in the firm and the most common joining method is welding. In some applications the components are also riveted together or joined by bolts. The FFs that are used in the example are extracted from the functional model in CCM and adapted to the functional mapping chart as can be seen in **Figure 5**.

Functional Requirements	Functional Features	TOX rivet	Bolt joint	Weld joint	Handle system	Planet gear system	Brake system	Rod and hole
Attach back rest		●	●	●				
Recieve manoeuvre torque					●			
Create angular movement						●		
Hold back rest angle							●	
Transfer manoeuvre torque								●

Component Id	Functional Features	TOX rivet	Bolt joint	Weld joint	Handle system	Planet gear system	Brake system	Rod and hole
Current welded bracket				●		●		●
Current riveted bracket		●				●		●
New bolt joint bracket			●			●		●
Knob					●			
Friktion plate							●	

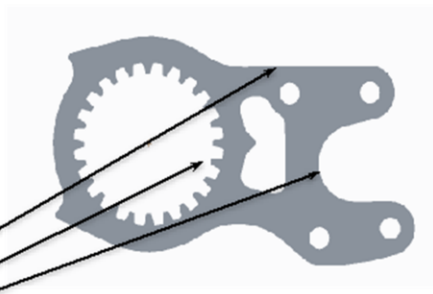

Figure 5. The functional mapping chart and its mapping of Functional Features to the bolt joint bracket. The Functional requirement governing these FFs can be tagged to the CAD model thus enabling traceability between the F-M model and the component.

A general guideline for finding the right level of functional breakdown cannot be formulated. This level is connected to the system borders and interactions with other components. The general methodology however, is to start with larger units and break down these further as needed. As an example the handle system in Figure 4 has several sub Functional Requirements. It must fit the users hand, enable an interface to the mechanism, withstand the manoeuvre forces and be securely positioned so that it does not fall off. All this functionality can be integrated into a single function carrier such as a plastic knob that in turn can be supported by its own functional mapping chart. The knob is not functionally connected to the bolt joint bracket and is not further elaborated in this example.

Following the identification and creation of FFs trough the functional breakdown, the FFs are transferred to the Excel template in Figure 5 where the FRs and their mapping to FFs and components also are visualised. A complete model according to the CC framework have additional interactions that can be used to suggest which FFs should be integrated into the same component but for brevity these interactions are not discussed here.

The FR attach backrest can be fulfilled by the three types of manufacturing methods. A strength of the methodology is that redundant FFs that solve the same FR can be visualised and enabled in the CAD-geometry of a component. This is shown in

Figure 6 as markings for all three joining FFs for the new bolt joint bracket. If one feature imposes limitations on the design, the functional mapping chart shows the consequences for other parts of the design if the feature is removed. It is therefore an active decision to delete a feature from the CAD-model rather than an unaware change in geometry. This is also an application of a Set-based way of working [15] building on the principle ensure feasibility before commitment which has proven to be an effective way to work [16].

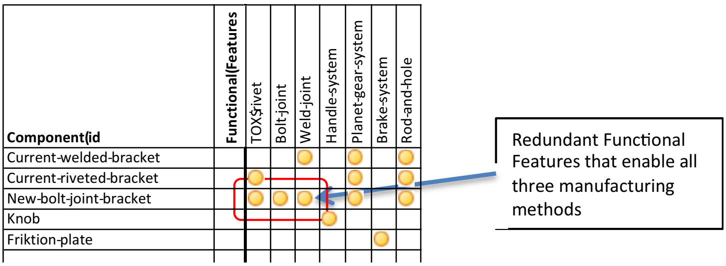

Figure 6. Redundant Functional Features are integrated in the new component in order to allow its use in different applications.

After deciding which FFs that should be integrated in the new component the CAD model can be created. Each FF is tagged with the identification of its governing FR thereby identifying the FFs in the functional model and its design rationale. Figure 7 shows the tags in the CAD tree.

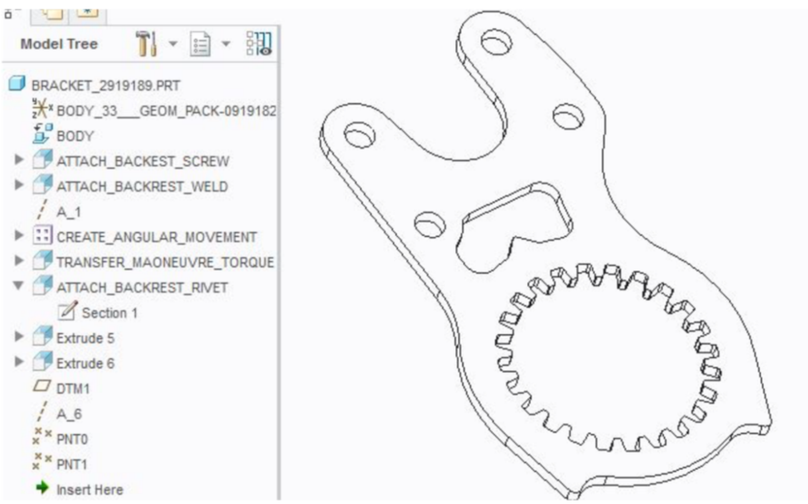

Figure 7. The Functional Features are tagged and visualised by renaming features in the feature tree of the CAD- system. This functionality exists in all major CAD-software, also in “featureless” systems. Note that there are three redundant FFs that solve the same FR, ATTACH_BACKREST. This is because the component is assembled differently in different variants.

Renaming the features is a manual process with a limited effort since each CAD model only has a few FFs to rename. It took less than 5 minutes to tag the whole model in the CREO software used in the example, which should be considered a small effort compared to the gains in traceability in the case of a redesign. To further structure the functional information, this could be collected according to the A3- methodology given in [17] to form a knowledge repository.

4. Conclusions

The presented methodology offers a new way to visualise, structure and link information between a functional model and a traditional CAD model. It does so by using a structured functional mapping chart to bridge these two types of knowledge representations.

The functional mapping chart clarifies why a component is designed in a specific way and links the CAD-model to the functional model. The chart identifies the CAD-features that are used to embody and fulfil the Functional Requirements. The methodology thereby supports the product development process by bridging the gap between the functional knowledge used to design a product and its related physical CAD representation.

The methodology can be applied to re-design, in structured innovation and for sustaining design knowledge:

- In order to efficiently re-design a new product, a deep understanding of the previous design is essential. Such understanding can be supported by the methodology in providing functional information that clarifies the reasons behind the design at different levels of abstraction.
- For structured innovation the methodology supports a morphological approach to visualise and to distribute functionality over physical components. The design space can therefore be systematically explored without the risk of overlooking any of the needed Functional Requirements.
- In a re-design context, product knowledge may be lost over product generations and through turnover of personnel. The methodology presents a way to improve this situation by enabling traceability between CAD models and the knowledge used to design them.

The contribution of this work is a pragmatic way to bride the gap between functional descriptions and physical components. The modelling software used in the example is beneficial but not necessary for using the methodology. It can be applied in a general case based on standard F-M methodology and the functional mapping chart. Moreover, the methodology can be used with any CAD-system that allows users to rename features i.e. a majority of existing programs, including “featureless” systems. A minor change in CAD-methodology may be needed to ensure that the Functional Features are properly clustered and can be directly identified in the CAD-tree.

The research is a work in progress and evaluation of the methodology by professional engineers in an industrial setting is left for future work. Also the applicability of the methodology in cases other than mechanical design is not explored. There are however, no fundamental hinders for the methodology to be applied to other areas since the modelling of Functions and Means and the establishment of corresponding functional mapping charts have a wide applicability.

Acknowledgements

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