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Using the Contact and Channel – Model for the methodical development of lightweight solutions

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Abstract
In literature there are several lightweight approaches, such as conditional, conceptual or material lightweight design. But the challenge for the designers is to use the suitable lightweight approach and to develop a lightweight solution for their product. In this paper, an approach for a method which supports the designer in a systematic finding of lightweight solutions will be presented. In order to realise a method for developing lightweight solutions, the Contact & Channel - Model will be adapted.

Keywords: Design method, Design for X, Design for Mass, Lightweight Design, Contact & Channel – Model.

Introduction

There are several lightweight strategies presented in literature such as material [1], shape, bionic, constraint-driven, conceptual, system or manufacture lightweight strategies [2-5]. But there is still the challenge how to use these approaches to design for lightweight. First, designers have to analyse parts, assemblies or the whole product, which they want to optimise or design in accordance with lightweight. After analysing the product, designers have to choose and to use the suitable lightweight approach for their problem. Subsequently, they have to interpret the lightweight approach for their problem to derive lightweight solutions. A method to support designing for lightweight makes it possible for inexperienced designers to find solutions. For experienced designers it supports a systematic finding of a multiplicity of solutions, thus they can choose the most suitable solution for the problem.

Problem statement and goals

To start with the analysis, Albers [11] recommends the application of the Contact & Channel - Model (C&C-M) since it helps the designer to build up a detailed understanding of the design problem. The C&C-M describes technical systems connecting function and shape and to analyse them systematically [9]. But there is neither a method which helps to choose the suitable lightweight strategy nor a method to systematically derive lightweight solutions. The question arises, *how to methodically support designers in systematically and not randomly finding lightweight solutions*. The C&C-M consists, beside the analysis phase, of a synthesis phase which can help in finding solutions for design problems [9]. In using this potential of the C&C-M, the following hypothesis can be formulated. *Designers get supported in finding lightweight solutions more systematically by using the adapted C&C-M which consists of lightweight strategies and principles transferred into the C&C-M and implemented into the procedure of the C&C-M*. The objective of this paper is to respond this main research question. Therefore, several lightweight principles and strategies will be described by means of the C&C-M. In addition, the transferred lightweight principles and strategies will be implemented into the procedure of the C&C-M. Thus, the procedure will be extended to be applicable for design for lightweight. The paper will be concluded in applying the developed method to an example.

State of the art

Lightweight design

There are several lightweight strategies formulated in literature of lightweight design. Kopp [2] stated that system lightweight design is a superior lightweight strategy which recognises the interaction of system components and the overall reduction of mass. In system lightweight design or also called conceptual lightweight design [6] the mass of single components can be increased, but the overall mass of the whole system has to be decreased [2]. In order to reach this aim, material or shape lightweight design can be applied. In the material lightweight design specific heavy materials get replaced by specific lighter materials with better material properties [3]. Thereby, function determines material selection [1]. The shape lightweight design provides design principles, suitable profiles and clearly identified force transmission paths which lead to lighter products [3]. Another lightweight design strategy, which exhau
sts the technological possibilities to integrate functions with minimal use of material and connections, is the manufacturing lightweight design. Constraint-driven lightweight design addresses the question, if there are excessive securities and loading requirements and if there can be a better geometric environment for the lightweight part to be integrated [7]. Another lightweight strategy is the bionic lightweight design which uses solutions of living organisms in order to develop human technical improvements and innovations [8]. Klein [3] defines principles in order to design for lightweight. One example for these principles is the *call for direct initiation of force and for the balance of force*. These principles are defined as rules and presented in examples for unfavourable and favourable solutions.

Contact & Channel - Model

The Contact & Channel - Model is a model to optimise products. The method describes technical systems by the two core-elements Working Surface Pairs (WSP), which consist of two Working Surfaces (WS) in contact, and Channel and Support Structures (CSS), which are volumes between two WSP as it is shown in Figure 1. The CSS connect the WSP with each other and transport energy to fulfil a function. Albers [10] defines symbols to describe properties of the WSP and CSS like the direction of acting forces or the aggregate state of the material of the CSS. Structures which fulfil no active function are Remaining Structures (RS). The method of the C&C-M comprises an analysis and a synthesis phase. In the analysis phase the considered system gets modelled and the technical backgrounds get cleared. The synthesis phase consists of four meta-rules (MR): Adding WSP and CSS (MR1), removing WSP and CSS (MR2), changing properties of WSP (MR3) and changing properties of CSS (MR4) [10]. Albers [11] points out that the analysis of the C&C-M is important for lightweight design because it helps to generate an understanding of the design problem. Ottnad [12] describes one aim of the lightweight design in the reduction of RS. But both do not show up how the C&C-M can be used for systematic synthesis of lightweight solutions.

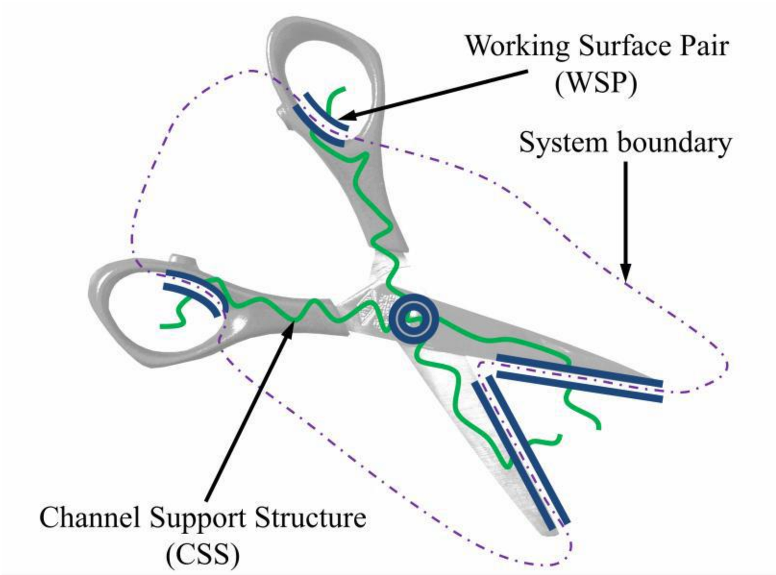


Figure 1 Elements of the Contact & Channel - Model

Deriving lightweight solutions

For using the C&C-M for the development of lightweight solutions, first, some promising strategies and principles of lightweight design have to be implemented in the C&C-M. Hence, conclusions are drawn for further development of the procedure of the C&C-M. This systematic procedure supports designers in systematic deriving of lightweight solutions.

Lightweight design strategies implemented into the C&C-M

System lightweight design

The fractal character of C&C-M could be used for system lightweight design. The C&C-M supports analysis and adaption of technical systems. This allows a review of system coherences more easily. It is also easy to change between a detailed breakup and the whole system [9].

One approach of the system lightweight design is the integration lightweight design. The integration lightweight design has the aim to integrate functions with respect to the lowest effort of material and lowest effort of connections. Thus, integration lightweight design aims on the reduction of CSS and WSP. In order to realise this, functions must be summarised and realised by the remaining CSS and WSP. The C&C-M incorporates this in MR2.

Material lightweight design

In MR3 and MR4 properties of CSS and WSP get modified. Thus, the meta-rules include the material lightweight design, which is also a modification of the material and, by that, the modification of properties of the CSS and WSP. In order to realise this, the most important material properties like the density, the elastic limit and the elastic modulus have to be described as properties, e.g. as symbols, in the C&C-M.

Shape lightweight design

Shape lightweight design consists of several approaches to realise a lighter product, e.g., reducing bending load by replacing it through tensile and compression load. This will be realised by adding CSS and WSP to build up a kind of framework. Furthermore, approaches of the shape lightweight design can be transferred into the C&C-M. This is shown by transferring the lightweight design principles in the following sections.

Constraint-driven lightweight design

The constraint-driven lightweight design has to be respected in the procedure of the C&C-M by extending the system boundary because this strategy analyses the boundary conditions to optimise the mass of the product, e.g., by reducing unnecessary requirements. Since only product properties within the system boundary can be changed in the C&C-M, the procedure has to be extended by a fifth meta-rule, which allows an extension of the system boundary. This rule has to extend the system boundary in areas which have influence on the property that has to be changed. Thus the WSP and CSS can be changed in order to realise a better actuating variable, parameter or boundary condition, e. g., a better joining surface for the part.

Lightweight design principles

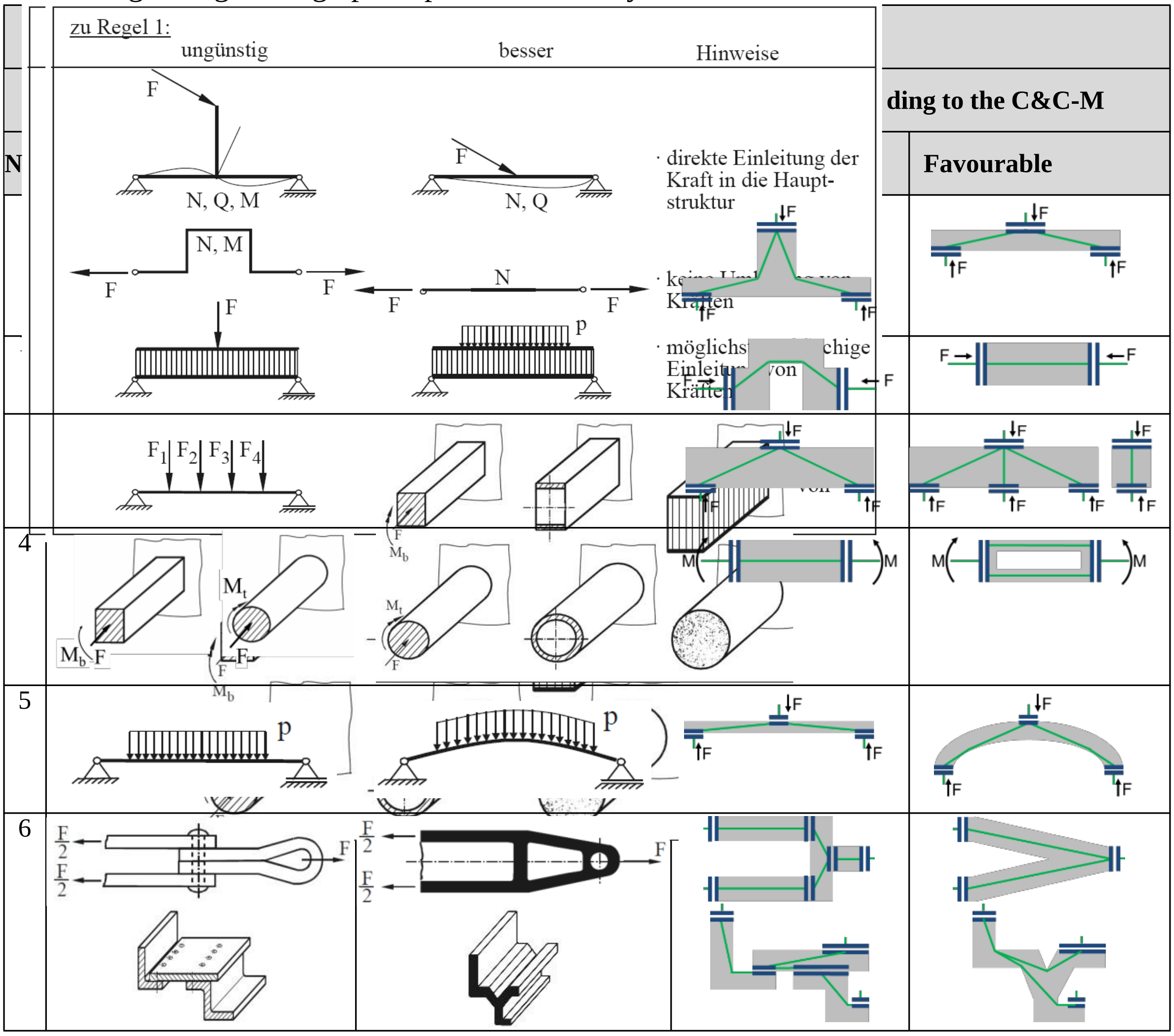
Removing the remaining structures

As Ottnad [12] already states, one aim of lightweight design is to reduce RS. Therefore, the rule to remove RS was defined and integrated in MR2.

Direct force transmission and force balance

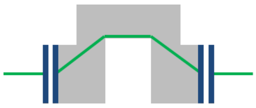
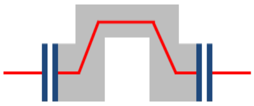
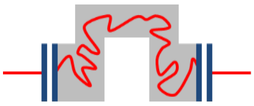
Table 1 shows the lightweight principles of Klein [3] on the left and the implementation of these rules into the C&C-M on the right.

Table 1 Lightweight design principles described by the Contact & Channel - Model



As rules No. 1 and 2 state, the forces must be directly initiated into the main structure and not be deflected. In order to implement this into C&C-M, the CSS must be shortened if this is possible. There is a problem because of the missing definition of length of CSS in C&C-M. Therefore, a definition of length and course of CSS have to be defined. The CSS in this definition describe a qualitative course of the force in order to support the designer in optimising the part. In order to realise this, CSS will be defined to start and end in the centre of area of WS, as shown in Table 2. Between these two points CSS will be defined to take the shortest way through the part. With this qualitative definition of the course and thus of the length of the CSS, it is possible to apply rules No. 1 and 2 in Table 1. This definition of CSS is not exactly the same as the definition of the course of the forces within the part in each case.

Table 2 Definition of the course of the CSS

correct	**incorrect**	**incorrect**
		

Another rule for design of force transmission is that forces must be directly retained, for example with a bearing (see Table 1, rule No. 3). Transferred into C&C-M each force must be retained directly and on the shortest way, e.g., by one more WSP and CSS.

Realising a big geometrical moment of inertia
Table 1, rule No. 4, shows one more design principle. It says that, if a part has a bending load, hollow cross-sections should be preferred to realise a high moment of resistance [3]. Transferred into a principle for C&C-M, this means, that CSS should be divided, so that they are further away from bending axis.

Using the natural supporting effect by buckling
The bending and buckling stiffness of plates and panels can be raised by cambering these structures [3]. This is shown in Table 1, rule No. 5. The following rule implements this principle in the C&C-M. It states, if bending or buckling stiffness of a part is critical, CSS should be cambered.

Preferring the integrative principle
The reduction of assemblies reduces mass, assembly and connection effort (Table 1, rule No. 6) [3]. MR3 and MR4 of the C&C-M support the systematic realisation of the integrative principle. These rules ask for reduction of WSP, CSS and lead to the integrative principle.

The further developed C&C-M for lightweight design (C&C-M-DfL)
The principles transferred into the C&C-M in the last section have been integrated into the procedure of the C&C-M, as it is shown in Figure 2. The principles are allocated to the fitting meta-rule. Thus, designers have a systematic procedure to optimise products with respect to lightweight design. The procedure consists of the analysis of the C&C-M which supports designers to acquire a deep comprehension of the product. The synthesis phase of the procedure supports designers in systematically deriving solutions. The included lightweight design principles help designers in applying steps of the synthesis with the aim to develop lightweight solutions. This further developed procedure is called in the following “the procedure of the Contact & Channel - Model for Design for Lightweight (C&C-M-DfL)”.

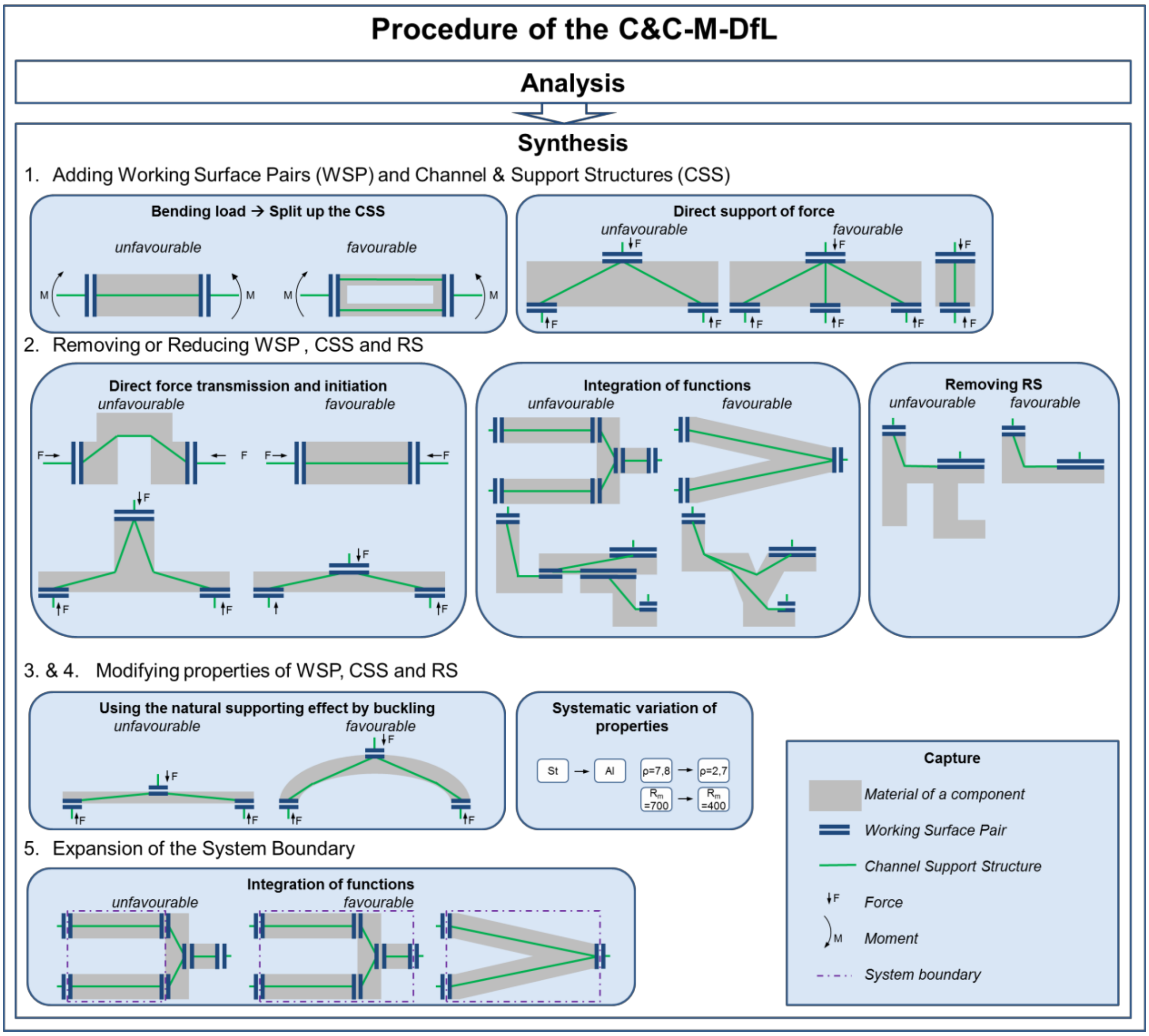


Figure 2 C&C-M-DfL as extension of the C&C-M

First evaluation on the example of a Formula 1 racing car rear wing

The procedure of the C&C-M-DfL, as shown in Figure 3, could be used to develop lightweight solutions for a rear wing of a Formula 1 racing car, as suggested by Frey [13]. This can be seen as a first evaluation regarding applicability and usefulness. First, the problem statement has to be cleared (Stage 1). One aim is to keep the fulfilment of function, which means to realise the same down force, another is to reduce the mass (Stage 2). The third stage is the modelling of the rear wing in the C&C-M (Stage 3). In Stage 4a the MR1 is applied, which results in a direct conjunction of force initiation and force transmission (Stage 4a). MR2 leads to Stage 4b in which CSS and WSP are reduced and removed. In Stage 4c CSS which are orthogonal to force initiation are buckled to use natural supporting effects. After these stages of creating solutions, a solution has to be selected. In this case solutions out of Stage 4a and 4c are combined to get the solution of Stage 5. The solution of Stage 4b is contradictory to the goal to keep fulfilment of function, because it reduces the active area of the rear wing and thus it reduces the down force. Stage 6 shows that some of the Formula 1 racing teams did the same optimisations at their rear wings.

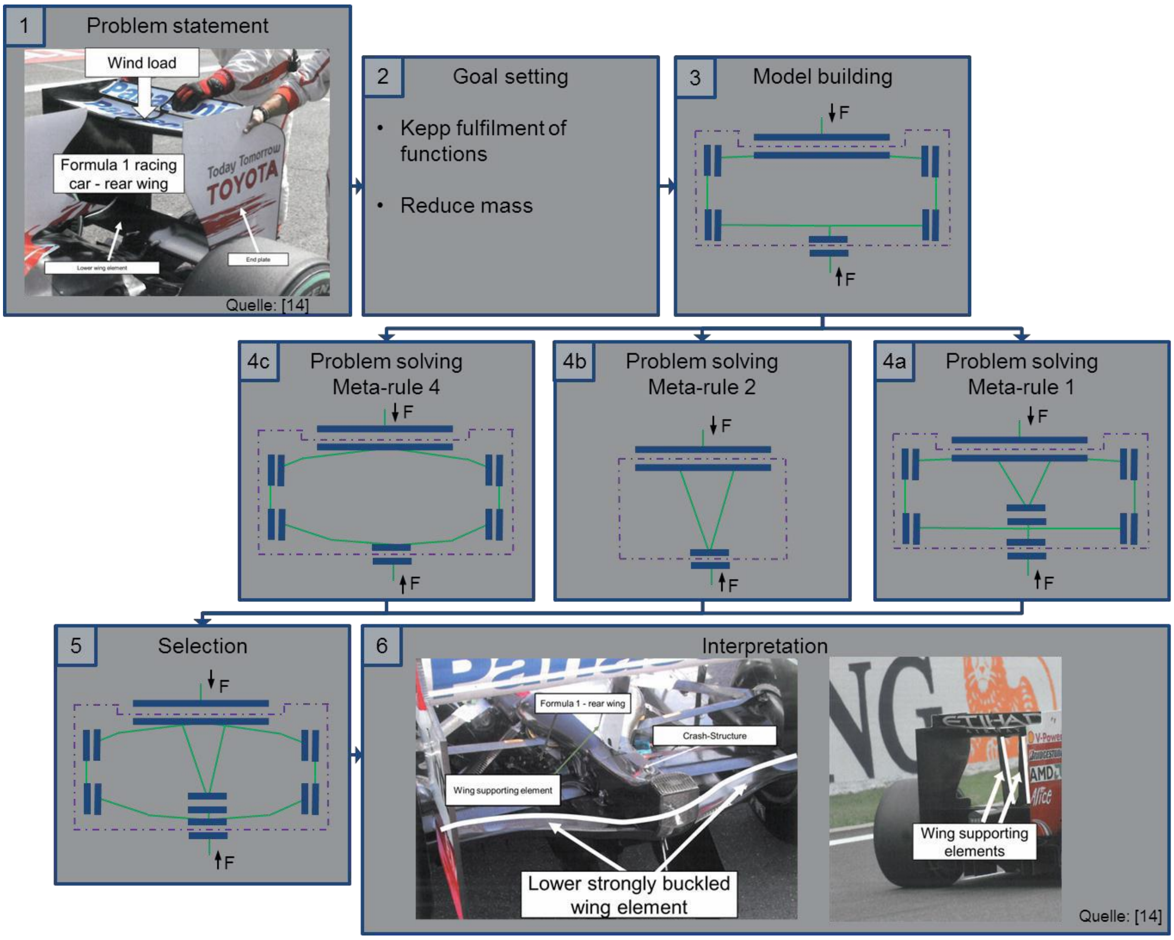


Figure 3 Optimising a Formula 1 racing car rear wing by means of the C&C-M-DfL

Discussion

The C&C-M is chosen as basis for a method for deriving lightweight solutions, as it supports designers in developing several solutions outside the field of lightweight design. Thus, designers are supported in systematically and not randomly finding lightweight solutions. Finding several solutions allows designers to select a suitable solution for their conditions. Thereby, inexperienced designers are supported in finding lightweight solutions.
The transfer of lightweight principles and strategies into the C&C-M is only presented on some promising examples. The transfer of other principles and aspects of strategies has to follow. Furthermore it is possible that some principles and strategies can not be integrated into C&C-M. One should not expect, however, that the application of the C&C-M-DfL produces always perfect lightweight solutions without interpreting and with blind application of the method. Furthermore, the method with the implemented principles and strategies should support designers in their creative process in developing ideas for a lightweight solution. These produced solutions also must be assessed by all criteria which the product has to fulfil. As shown at the example in some cases solutions can be combined. It is always essential that the lightweight solution described in the C&C-M has to be interpreted. Thus, the difficulty is to transfer modelled solutions back into solutions for the real products.

Conclusion

The Contact & Channel - Model for Design for Lightweight is a concept for systematic deriving of lightweight solutions. It is created by further developing the C&C-M. Thus, lightweight strategies and principles are transferred into the C&C-M. Also, the C&C-M is extended by a more detailed definition of the course of the CSS, by further steps of the synthesis phase and by some rules in order to optimise the C&C-Models for design for lightweight. The presented approach has to be further developed and several iterations of evaluation have to be done to transfer the approach into an applicable and useful method. But it is shown that the approach could support designers in deriving lightweight solutions.

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