NordDesign 2018
August 14 – 17, 2018
Linköping, Sweden

Model-based design guidelines for better knowledge transfer into industrial applications

V. Butenko, B. Gladysz, M. Maurath, A. Albers

IPEK – Institute of Product Engineering,
Karlsruhe Institute of Technology (KIT),
Kaiserstr. 10, 76131 Karlsruhe, Germany
sekretariat@ipek.kit.edu

Abstract

„If only we knew what we know"- this statement is well known and still stands for the situation of manufacturing companies today. The correct use of engineering knowledge in product design provides many advantages, but requires good knowledge management. Not only the availability and access to information sources should be guaranteed, but also its reusability due to the good explication. The most widespread form of knowledge transfer for engineering purposes in literature and in companies are design guidelines. The authors have analysed different design guidelines in the literature and found that they do not sufficiently support the transfer of knowledge to industrial applications.
In this paper, the authors will present a concept of design guidelines based on the Contact and Channel Approach (C&C²-A) that supports and improves knowledge transfer. The authors will examine how much improvement is possible compared to conventional approaches. For evaluation purposes, different forms of knowledge transfers have been developed and evaluated based on real application cases with experienced engineers. The evaluation was conducted based on the observation as well as semi-structured interviews with the participants.

Keywords: Design guidelines, Contact and Channel Approach (C&C²-A), knowledge transfer

1 Introduction

It is often not possible to communicate directly with experts due to different facts (distributed locations, longer business trips etc.) and to obtain the necessary information. Furthermore, it is not particularly smart and efficient if the knowledge is only tied to certain persons and is not centrally managed in the company by appropriate strategies. Therefore, the explication of knowledge and it‘s documentation in the form of information is an important factor for the non-personal knowledge transfer. This explication encourages the sharing of information with others while reading or observing and leads to knowledge building. Conscientious and meaningful documentation is a prerequisite for optimal knowledge sharing. The same contents can be documented in various ways: in form of text, illustrations with good and bad solutions, tables, formulas or their combinations. Although the same content is displayed, it is perceived differently by various people. How can this happen? Everyone knows and understands this statement: *Seeing once is better than hearing a hundred times.* The same applies to knowledge transfer. It is easier to understand the contents if they are shown visually by means of pictures or videos as if information is explained only in terms of text.

From this perspective, the authors have analysed different design guidelines in the literature and found that they do not sufficiently support the transfer of knowledge to industrial applications. The main reason for this is the insufficient information content due to short descriptions, unclear visualisations, etc. An industry survey in the form of interviews and questionnaires by the authors has confirmed this conclusion.

In this paper, the authors will present a concept of design guidelines based on the Contact and Channel Approach (C&C²-A) that supports and improves knowledge transfer. C&C²-A is a modelling approach, which integrates embodiment design and function into a single model. The result is a higher density of information and yet a high degree of comprehensibility due to the distinctly purpose-oriented nature of the model. Based on C&C²-A, the focus is on the functional- or failure-relevant system interdependencies, which are described at the level of energy, mass and information flows. For evaluation purposes, different forms of knowledge transfers have been developed and evaluated based on real application cases with experienced engineers: text-based, good/bad-comparisons as well as the C&C²-based models. In the study, the participants had to solve different engineering tasks and use the provided information. The evaluation was conducted based on the observation as well as semi-structured interviews with the participants.

2 State of the art

This chapter presents basic information on different form of information documentation to support knowledge transfer in product development. Widely used forms in companies and literature include design guidelines. This form of knowledge transfer is not standardised and is usually lived differently in companies. What is always similar is the form of content representation.

2.1 Design guidelines

Design guidelines have been in use for more than 60 years. They include experience from previous design solutions or research approaches and serve to document information about manufacturing restrictions, realizable geometries, good and bad design solutions, other aspects that must be taken into account in any case to avoid faults(VDI 2223 & VDI-Society Product and Process Design, 2004). Currently, design guidelines for the product development with different material groups like metals, plastics, ceramics or composite plastics can be found in the literature. Although the guidelines have been in use for a long time, their form of knowledge representation has hardly changed. What is very typical for the presentation of information are pictures of recommended and not recommended design with brief explanation (Elsner, Eyerer, & Hirth, 2012), (Michaeli & Wegener, 1990). However, the interviews with the industry representatives have shown that the current knowledge representation no longer meets their expectations and needs. On the one hand, this is due to the content in the design guidelines, but on the other hand to the representation of information itself (Butenko & Albers, 2018). A typical representation of the design guidelines is shown in the figure below.

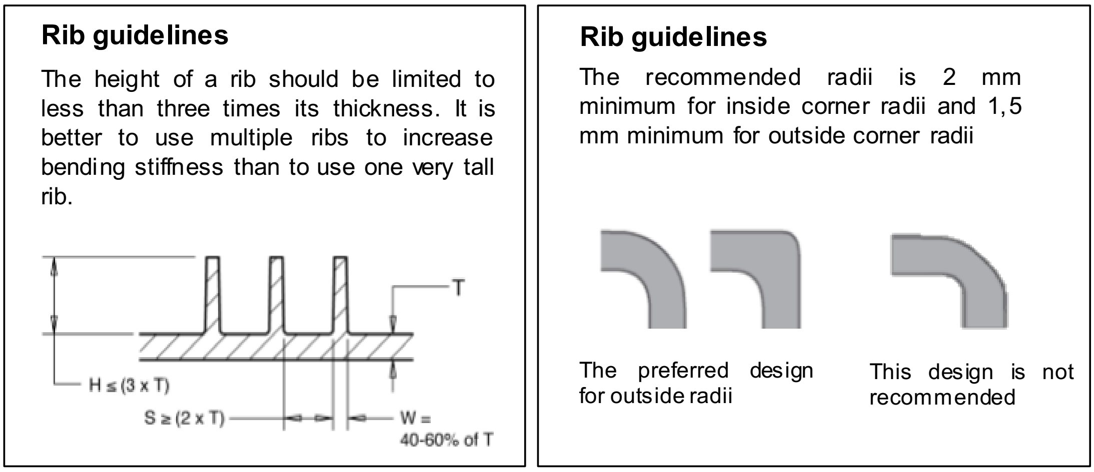


Figure 1: Design guidelines for rib design (Stratasys Direct, 2015, on the left side and European Alliance for SMC/BMC, 2007 on the right side)**;**

As can be seen in the figure, the contents are quite general and have a similar structure: short text and an example in the form of images. What is missing is the explanation with an example of what will actually happen if these recommendations are not taken into account? Why certain proposed solution is better than the other? The image representation especially in the right side is not self-explanatory but requires certain previous knowledge in this area.

2.2 C&C²-A for knowledge transfer

With the help of the Contact and Channel approach (C&C²-A) (Albers & Matthiesen, 2002), the embodiment design and effect and influences interdependencies of technical systems can be represented in an integrated C&C²-model, which in turn supports both analysis and synthesis activities in product development (Albers & Wintergerst, 2014). Apart from the rules set, the approach provides three basic elements: Working Surface Pairs (WSP), Channel and Support Structures (CSS) and Connectors (C).
With the help of these basic elements, which are defined (Matthiesen, 2002; Matthiesen, Grauberger, Sturm, & Steck, 2018) in the following, a so-called Wirk-Net (Albers & Wintergerst, 2014) is set up that describes the energy, material and information flows in the system and with its system environment. This way, both system functions and behavior at the level of physical and chemical effects and influences can be described.

> "**Working Surface Pairs (WSP)** are set up when two arbitrarily shaped surfaces of solid bodies or generalised interfaces of liquids, gases or fields get into contact and are involved in the exchange of energy, substance and / or information."
> "**Channel and Support Structures (CSS)** are volumes of solid bodies, liquids, gases, or field-permeated spaces that connect exactly two pairs of surfaces and allow the conduction of matter, energy, and / or information between them."
> "**Connectors (C)** integrate the properties, which are relevant to the effect and are located outside the design area, into the system view. They are an abstraction of the systems environment, which is relevant to the description of the function under consideration."

Such an exemplary Wirk-Net is shown in the following Figure 2 and describes the function "Visualise information with a ball-pen" (Gladysz, Spandl, & Albers, 2017). The individual C&C²-elements can also be assigned properties, as shown in the figure below, so that the system behavior is specified.

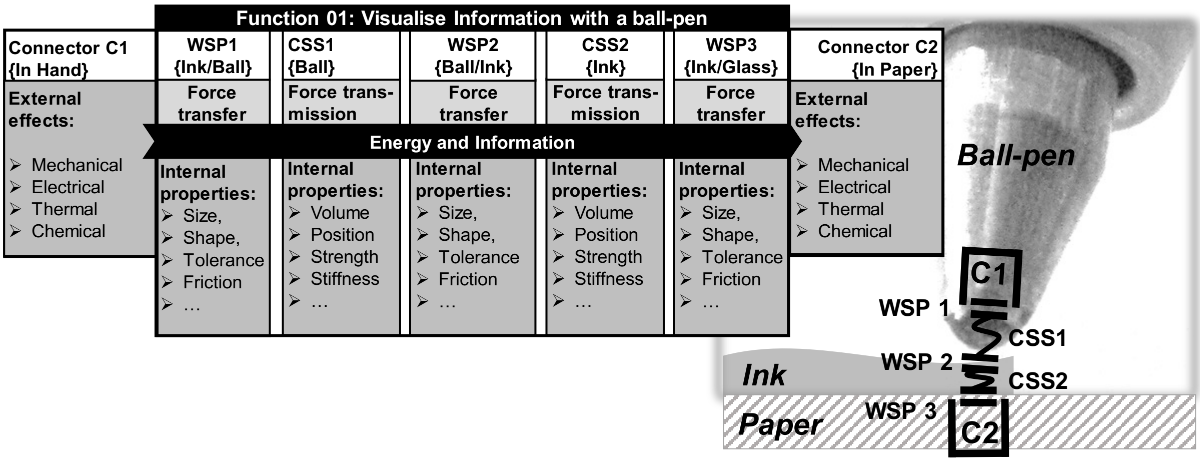


Figure 2: Exemplary C&C²-model for the function "Visualise information with a ball-pen" (Gladysz et al., 2017)

In addition to classical optimization topics such as Design for Reliability/Robustness as well as verification and validation support, the diverse fields of application of the approach also include knowledge transfer in particular. For example, the approach was used to develop a comprehensive model of the hybrid module for the 918 Spyder that described in detail the functional and system structure of the subsystem and served as a basis for the further development of the product architecture (Scherer, Albers, & Bursac, 2017). The resulting model was investigated in a study with 16 developers and it could be proven that the representation of the subsystem supports the knowledge transfer for various use cases.
Especially, in the current state of the art, there is no preliminary work on model-based design guidelines that integrate aspects of embodiment design and system behavior in order to support the knowledge transfer. For this reason, the authors of this article want to examine this potential in detail in the following study and show whether and how such C&C²-based models can be used in the context of design guidelines.

3 Research methodology

The analysis of the state of the art leads to the two following research questions:

1) Which form of information documentation (pure text, text with good and bad design solutions, model-based visualizations) is best suited for optimal knowledge transfer?
2) How does the desired form of information documentation differ from the experience of product developers?

To answer these questions, a semi-structured qualitative study was developed and carried out with employees at a Robert Bosch GmbH in Bühl. The objective of the study was to compare different forms of information documentation 1) information in form of text, 2) information in form of figures with good and bad design solutions and 3) information in form of model-based illustration of good and bad design solutions according to their suitability and applicability in different situations. To be able to compare these approaches with each other, the study participants were provided with concrete cases which they handled with the help of developed assistance. For this goal four cases with varying complexity were developed for different topics and application fields. Each case consisted of a concrete description of the initial situation and concrete questions. For each case, three documents were created that provide assistance in different forms. In addition, a fully structured questionnaire for assessing the suitability of different forms of information documentation was developed and filled in by study participants.

The following assessments were in focus: 1) efficiency of knowledge transfer, 2) transfer of functional knowledge and 3) information density.
In terms of efficiency, the quick understanding of the relevant information in the provided documents for the solution finding is understood. The "transfer of functional knowledge" means understanding of the interdependencies for the fulfilment of the function based on the provided information in the developed documents. The third point "information density", is a relative measure of the space required to describe important content.
In the evaluation sheet, the test persons had straightforward number of possible answers (very good, good, bad, very bad), to get a descriptive tendency. The three forms of information documentation were presented to the study participants in different order to counteract the information content of the previous document. Thus, each form was at least once at the beginning of the task. This gave the study participants different perceptions of the suitability of a form of knowledge representation.
The study design was qualitatively validated within the framework of pre-test and revised before the final study with the main target group. The target group in this study includes both experienced and less experienced design engineers at the Robert Bosch GmbH in Bühl. At the beginning of the qualitative study, first the motivation and the procedure of the survey were presented to participants during the group meeting. A briefing on the C&C² approach followed, as most participants were unaware of it. Here important basic elements and definitions such as active surface pairs, channels and connectors were explained and described with some examples. In addition, the application of this approach for knowledge transfer was briefly presented. When all questions were clarified, the study participant started working on the provided tasks. This was done by carefully reading the problem, studying the texts and illustrations and marking the questionnaire accordingly to each task. If questions about the task came up during processing, they were clarified directly in the dialogue. The duration of the task processing was between 30-45 minutes. Comments on each form of information documentation were documented to further evaluation of the study results. The following figure shows the described methodical procedure.

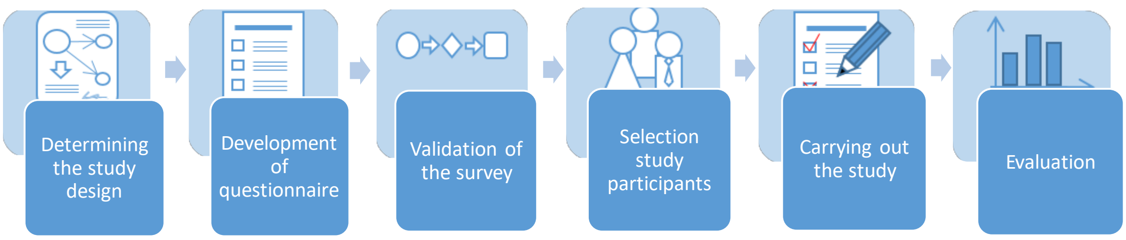


Figure 3: Methodical approach

4 Study design

In this chapter the study design with two selected examples of the cases and the different forms of information documentation are presented.

4.1 Case - Casting design

This is one of the simplest case used in the study. Two casting tools were presented, and the participants were asked to select and justify why certain variant is appropriate or not appropriate for the application, see figure below.

Closed tools in cast part

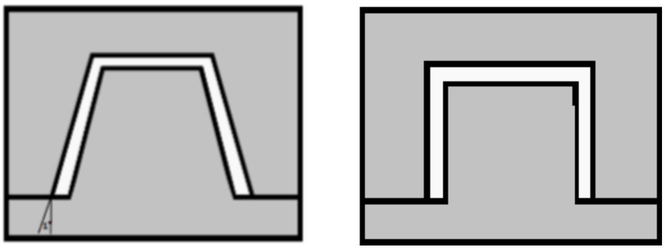


Figure 4: Casting tools

The following three forms of information were prepared differently and provided as support.

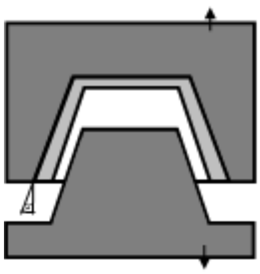
1. Text based

Casting design

In the case of a casting design, draft angles in the lifting surface must be provided in the component surface. Here, the product can be removed quickly and without damage from the mold. The larger the angle, the better the removal from the tool. If the workpiece is designed without draft angles, it is possible that it will be damaged during removal or not be released from the mold at all. Undercuts and cavities should be avoided as cores are very expensive as they provide extra work. They must be set correctly with a longer process time and removed or destroyed again after casting. Therefore, open cross sections with sufficiently large draft angles are to be preferred.

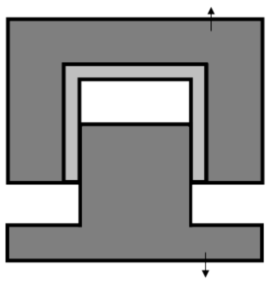
2. Illustration with good and bad design solutions

Recommend



Large draft angles ensure a good extraction.

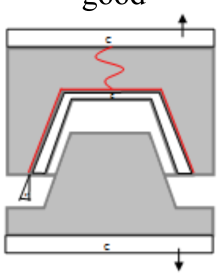
Not recommend



Without draft angles, the workpiece can be damaged or can not be released from the mold

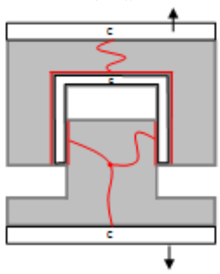
3. Model-based illustration of good and bad design solutions

good



Large draft angles ensure a good extraction.

bad



Without draft angles, the workpiece can be damaged or can not be released from the mold

4.2 Case - Montage of pressure compensation element

This second case is more difficult compared with the first one. In principle it is about a pressure compensation element, which is typically used for venting sealed housings. The element considered in this task consists of a plastic housing with a welded, watertight, air-permeable membrane. To seal the housing, an O-ring is used. A cover is attached to the plastic housing to protect the diaphragm. In the task, the test persons must describe which types of faults can occur during assembly and how these can be counteracted.

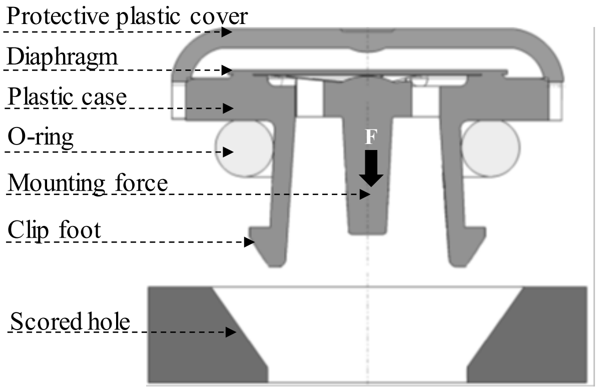


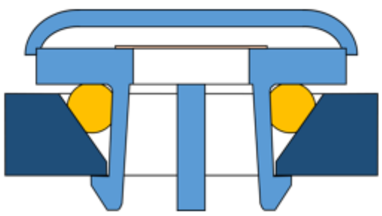
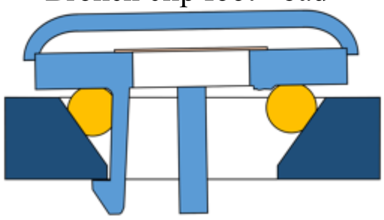
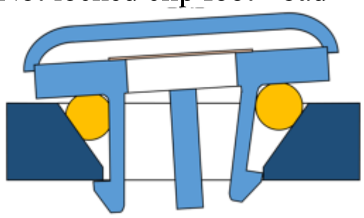
Figure 5: Pressure compensation element

Three forms of information for this task are presented in the following.

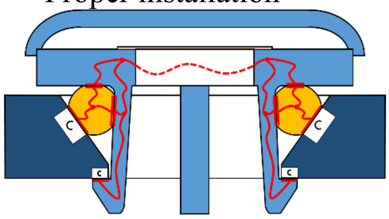
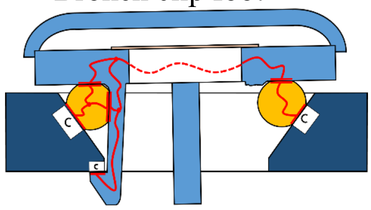
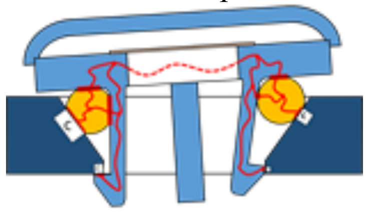
1. Text based

When mounting the pressure compensation element, a force is applied to the housing, which presses this element into a scorched hole. The clip feet are elastically compressed by the wedge-shaped snap connections and the bevel of the bore. By pressing in, the O-ring is squeezed and the feet are brought together until the snap connection can pass through the hole. Thereafter, the feet spring back to the original position, forming a positive connection with the edge of the housing bore. After mounting, the press-in force is removed. The crimped O-ring provides a permanent force opposite to the mounting direction. This force and the positive snap connection, the pressure compensation element is held in position. When mounting, make sure that the press-in force acts vertically and evenly on the housing. Non-centric pressing should be avoided. Here it can happen that snap-in feet can not hook in correctly or even break off due to excessive load. This can also occur with minor damage to the feet. A secure seal of the housing is therefore no longer guaranteed.

2. Illustration with good and bad installations

Proper installation - good	Broken clip foot - bad	Not locked clip foot - bad
		

3. Model-based illustration of good and bad installations

Proper installation	Broken clip foot	Not locked clip foot
		
Pressure compensation element mounted correctly and all feet are engaged. Sealing effect is realized.	Due to a non-centric press-in force, a clip foot is not properly engaged during assembly. Sealing effect not guaranteed.	Too high assembly forces or too fast pressing a clip foot is broken off. Sealing may not be guaranteed.

5 Study results and discussion

In the study, as presented in chapter three, experts evaluated alternative information documentation in design guidelines, which contained text, illustration in form of good and bad design solutions and model-based illustration. The experts evaluate these information objects with regard to efficiency of knowledge transfer, transfer of functional contexts and information density on the basis of a four-level Likert scale. The following Figure 6 shows the results of this evaluation in the form of a box plot diagram. The evaluation is divided into a group of experts and novices, so that recommendations can be made specifically for individual target groups on this basis.
In sum, it is noticeable that the model-based illustration, which integrate design and interaction, have in most cases been evaluated significantly better or equally well. In the second case in particular, the added value is most pronounced across all three categories.
In the category "Efficiency of knowledge transfer" there is a difference between the first and second case, especially for the novices. For example, the novices in the study rated the text-based information worse in the second case than in the first. Looking at the median value, it is noticeable that the evaluations ratings of both groups (experts and novices) are improving from text-based to model-based information in both cases.
In the category "Transfer of functional knowledge" there is a larger deviation in the first case. The text-based and model-based information are rated similarly, whereby the illustration-based information was rated worse. In the second case, the evaluation is again better from text-based to model-based information object.
In the third and final category "information density", the illustration-based information is assessed as tending to be insufficient. The text-based information is in second place and in first place again the model-based information. The differences between experts and novices are highest in the first case for model-based information.

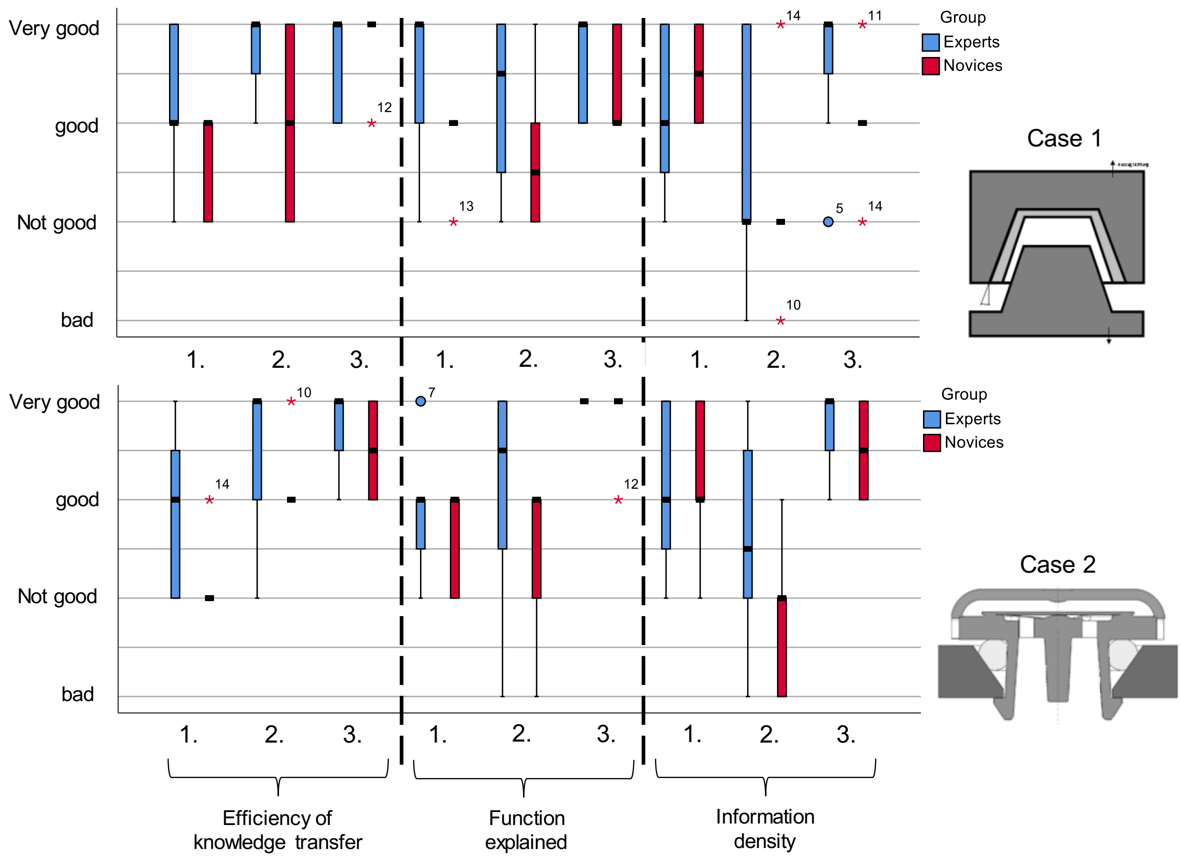


Figure 6: Study results for the two cases for text-based (1.), illustration-based (2.) and model-based (3.) information

1) Which form of information documentation (pure text, text with good and bad design solutions, model-based visualizations) is best suited for optimal knowledge transfer?

Based on the above results, the first question must be considered in a differentiated way. Thus, it could be shown that in both cases the users benefit from model-based information visualisation. But, this approach provides less added value in the first case than in the second one in which more complex interdependencies must be explained. Accordingly, the potential can be confirmed, but a recommendation for model-based visualisation can only be made in the case of sufficiently complex interdependencies. Such complex interdependencies can be defined, for example, by a minimum number of C&C² elements as well as the underlying system states.

2) How does the desired form of information documentation differ from the experience of product developers?

The differences in the evaluation of experts and novices are not large. With one exception, the median evaluation for novices is across the categories and cases slightly worse than the one for experts, but with a progressive curve from text-based to model-based information. For this reason, it can be concluded that both experts and novices benefit nearly equally wells. This speaks at least against the view that text-based and model-based design guidelines provide only for novices added value in knowledge transfer.

6 Summary and outlook

In this paper, the authors introduced a concept of design guidelines based on the Contact and Channel Approach (C&C²-A) that supports and improves knowledge transfer, due to integration of embodiment design and effect/influence relations into a single model. To evaluate the added value for development practice, a questionnaire study was conducted with experts in the context of which the experts were to use different form of information documentation to solve development tasks - from text-based to model-based visualisation.

The results have shown that the C&C²-based design guidelines on one hand require an extended introduction into the models but on the other hand improve the knowledge transfer by a measurable margin. Future research work, including a 12-year basic research project (IRTG) in the field of fibre-reinforced polymers, will build on these findings and further develop the model-based design guidelines proposed here.

References

Albers, A., & Matthiesen, S. (2002). Konstruktionsmethodisches Grundmodell zum Zusammenhang von Gestalt und Funktion technischer Systeme. *Konstruktion - Zeitschrift Für Produktentwicklung Und Ingenieur-Werkstoffe*, *54*(Juli/August 7/8-2002), 55–60.

Albers, A., & Wintergerst, E. (2014). The Contact and Channel Approach (C&C²-A): Relating a System's Physical Structure to Its Functionality. In A. Chakrabarti & L. T. M. Blessing (Eds.), *An Anthology of Theories and Models of Design* (pp. 151–171). London: Springer London. https://doi.org/10.1007/978-1-4471-6338-1_8

Butenko, V., & Albers, A. (2018). Improving the knowledge transfer from research to industry by developing demand-oriented design guidelines for fibre-reinforced plastics. In *28th CIRP Design Conference*.

Elsner, P., Eyerer, P., & Hirth, T. (2012). *Kunststoffe - Eigenschaften und Anwendungen* (8th., Edit). Heidelberg: Springer-Verlag Heidelberg.

European Alliance for SMC/BMC. (2007). Design For Success : A Design & Technology Manual for SMC/BMC. *European Alliance for SMC/BMC*. https://doi.org/10.1108/eb057042

Gladysz, B., Spandl, L., & Albers, A. (2017). A function- and embodiment-based failure analysis method for an in-depth understanding of failure mechanisms. In *Proceedings of the 21st International Conference on Engineering Design (ICED17)* (Vol. 4, pp. 239–248). Vancouver, Canada.

Matthiesen, S. (2002). *Ein Beitrag zur Basisdefinition des Elementmodells "Wirkflächenpaare & LEitstützstrukturen" zum Zusammenhang von Funktion und Gestalt technischer Systeme*. (o. Prof. Dr.-Ing. Dr. h.c. A. Albers, Ed.). Universität Karlsruhe (TH), Karlsruhe.

Matthiesen, S., Grauberger, P., Sturm, C., & Steck, M. (2018). From Reality to Simulation – Using the C & C²-Approach to Support the Modelling of a Dynamic System. In *28th CIRP Design Conference* (Vol. 28).

Michaeli, W., & Wegener, M. (1990). *Einführung in die Technologie der Faserverbundwerkstoffe,*. München, Wien: Carl Hanser Verlag.

Scherer, H., Albers, A., & Bursac, N. (2017). Model Based Requirements Engineering for the Development of Modular Kits. *Procedia CIRP*, *60*, 145–150. https://doi.org/10.1016/j.procir.2017.01.032

VDI 2223, & VDI-Society Product and Process Design. (2004). *Systematic embodiment design of technical products,*. Berlin: Beuth-Verlag.