SUPPORTING EARLY STAGES OF DESIGN METHOD VALIDATION - AN APPROACH TO ASSESS APPLICABILITY

Eisenmann, Matthias;
Grauberger, Patric;
Matthiesen, Sven

Karlsruhe Institute of Technology

ABSTRACT

Design method validation is an important research activity in method development. But the design method's applicability is often left out in validation, although it is a necessary step and it enables further validation steps. Currently, there is a lack of support for the assessment of design method applicability. We present an approach to provide support for iterative studies on three aspects of design method applicability. We evaluate the approach in a single case study. In the study, we investigate the applicability of a method for model building in analysis, in three iterative steps of the approach. Application of the approach produced valuable insights on the method applicability. The results show how aspects of applicability can be assessed using the presented approach. Therefore, the approach can contribute to the standardisation of design method validation, especially for early stages of validation, which is currently discussed in the community.

Keywords: Research methodologies and methods, Design methods, Evaluation, Design method validation, Experimental design research

Contact:
Eisenmann, Matthias
Karlsruhe Institute of Technology
IPEK - Institute of Product Engineering
Germany
matthias.eisenmann@kit.edu

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1 INTRODUCTION

Design methods are one of the key results of design research. They combine the experience of experts in procedures and tools to support design and product development. As any result of research, design methods should be validated before application in practice. Methods are developed to support design engineers in practice so it would be reasonable to conduct validation in their target environment applied by the target group. However, there are a multitude of aspects that possibly influence outcomes of method application in practice, which cannot possibly all be considered at once. Therefore, design method validation needs to be focussed to make an insightful investigation possible. The need for focus in validation of research results is also stressed by Isaksson *et al.* (2020). One way to address this issue is by using a controlled laboratory setting, where a focussed assessment is possible. But, the necessary choice of the most relevant aspects for assessment at the appropriate stage of method development and validation poses a challenge for researchers.

A collection of studies concerned with the uptake of methods in industry (Chakrabarti and Lindemann, 2016) illustrates that the attractiveness and readiness for application strongly influence the uptake of design methods in practice. Blessing and Chakrabarti (2009) describe *usability and applicability* as factors to be considered in design method development and validation before assessing *usefulness*. It seems logical, that a design method needs to be applied correctly in order to fulfil its purpose as intended. In this view, design method applicability is to be seen as a necessity for the investigation of design method usefulness. Additionally, without investigating the application of design methods, it may remain unclear during further validation of *how* the method contributes to its assigned purpose. However, the focus in validation of design methodology is in most cases on usefulness (Motte and Eriksson, 2016) rather than on aspects concerning applicability.

This is why this contribution aims at supporting the investigation of design method applicability by presenting a research approach. As the authors see design method applicability as a necessity for further method validation, the presented approach focusses on early phases of validation in a laboratory context. We therefore conclude on the following research question:

RQ: How can design method applicability be assessed in early stages of method validation?

The paper is structured as follows. Section 2 analyses approaches and existing support in design method validation to clarify the need for support. Section 3 presents our approach to investigate design method applicability. Section 4 describes how the approach was applied to conduct a study on the applicability of a design method for model building in analysis. Followed by the study's results focussing on learnings concerning the design method under investigation as well as the assessment of applicability in Section 5. Those results are discussed in Section 6 to put the approach in the context of design method validation.

2 SUPPORT FOR DESIGN METHOD DEVELOPMENT AND VALIDATION

There are multiple approaches addressing the issue of validation of design research results and therefore design methods as part of those results. Eckert *et al.* (2003) describe in their **spiral of applied research** the development and evaluation of methods. They stress the difficulty of predicting results of method introduction in industry and argue that this can only be addressed by validating research results at each stage of development. However, they provide no detailed approach on how to do so as this is not the aim of their contribution.

Pedersen *et al.* (2000) focus specifically on the validation of design methods in their presentation of the **validation square**. The validation square contains a stepwise description on how to validate design methods focussing on *effectiveness* and *efficiency*. In the first steps of design method validation, the validation square focuses on theoretical investigations. To do this, the authors propose to represent the method using flow-charts which visualise the in- and output of each method step. This can be seen as an investigation of design method applicability on a theoretical level. Gericke *et al.* (2017) suggest that, in order to apply a method, the description of a method should contain the core idea, the representations of design information used as well as the procedure. This resembles a similar view to Pedersen *et al.* (2000) as the representations of design information are comparable to the in- and output and the procedure is comparable to the suggested method steps. Beckmann and Krause (2013) further detail this approach by presenting a notation to visualise steps of design methods containing additional information. So far, the presented contributions describe requirements for design method applicability but do not clarify how and when this is to be investigated.

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Beckmann *et al.* (2016) describe a stage of description and preparation of the new design methods in advance of a transfer to industrial practice. This resembles activities concerning design method applicability, which are not specified further as the contribution focuses on industrial application. The Design Research Methodology - **DRM** (Blessing and Chakrabarti, 2009) gives more detailed advice by putting the evaluation concerning internal consistency of methods that is called *support evaluation* in the *prescriptive study stage* which deals with development of the method. Blessing and Chakrabarti (2009) also define *usability and applicability* as criteria that should be ideally investigated during development, followed by a more thorough evaluation at the beginning of the evaluation stage (*descriptive study II*). They recommend to use pilot studies to ensure a proper introduction and applicability of the design method. However, it is not described in detail how a pilot study concerning design method applicability is to be designed, which aspects of applicability are to be investigated and how they can be operationalised.

Motte and Eriksson (2016) present a **methodology evaluation framework** to address the need for validation of aspects apart from usefulness. Concerning applicability, they define six different characteristics relevant for interaction of a methodology with the method user: *simplicity of use, suitability, adaptability, abstractness, learnability* and *attractiveness.* The framework aims at providing a comprehensive checklist with aspects to consider when developing a methodology. Those aspects are also relevant for design methods as Motte *et al.* (2018) show by applying the framework on a design method. However, the framework does not give advice on how to assess the presented characteristics on applicability. To use them for assessment in studies, they need to be operationalised.

Apart from theoretical evaluation, design method applicability should also be assessed in participant studies. There is only a small number of studies which explicitly operationalise and investigate design method applicability in validation. One example can be found in Nelius and Matthiesen (2019) who operationalise applicability of their presented method by how detailed the form for documentation was filled out by the participants. Additionally, they reviewed think aloud protocols to identify whether the participants followed the method's procedure. Kroll and Weisbrod (2020) also explicitly evaluate the applicability in addition to the effectiveness of their developed method. They define four different metrics based on the framework of Motte and Eriksson (2016), which they combine to reach a conclusion on the method's applicability: *ease of teaching*, *ease of understanding*, *ease of use* and *extent of being followed correctly*. Their main sources of data are subjective evaluation, questionnaires and design reports, which are mostly interpreted to obtain qualitative results. Those examples of operationalisation in participant studies can be used as a basis for applicability assessment in early stages of design method validation.

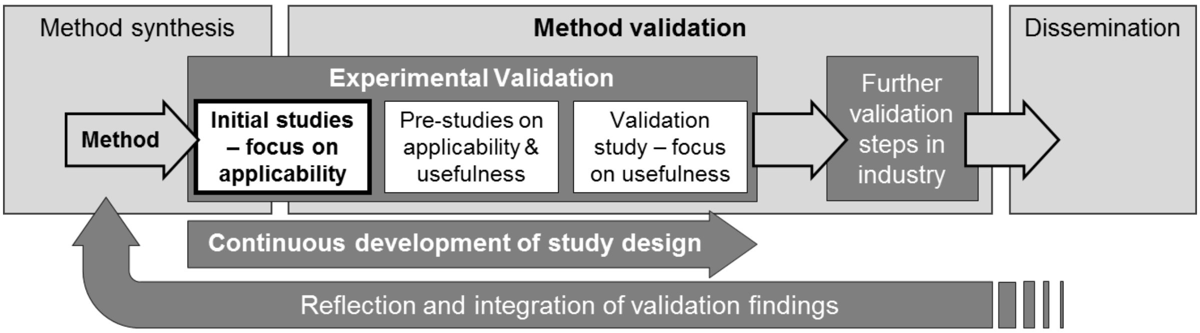

Figure 1: Process of method development and validation. The focus of this contribution on "initial studies focussing on applicability" is highlighted at the connection between method synthesis and method validation.

Summing up, design method applicability should be initially assessed in early phases of design method validation, which take place in an experimental context (see Figure 1). Design method applicability should be assessed first at the connection between method development and method validation (Blessing and Chakrabarti, 2009) as it is a necessity for further validation steps. There remains a lack of detailed support for those initial studies which integrate applicability in the validation process and enable the development of a study design further experimental validation.

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3 AN APPROACH TO ASSESS DESIGN METHOD APPLICABILITY

Based on the findings from literature and own experiences in design method validation studies, the authors have developed an approach to assess applicability in the early phases of design method validation. In our approach, we focus on the following metrics for design method applicability defined by Kroll and Weisbrod (2020), who used the framework of Motte and Eriksson (2016): *ease of understanding*, *ease of use* and *extent of being followed correctly*. *Ease of teaching* is left out, because it does not relate directly to the method or the use of the method. The developed approach is visualised in Figure 2. It consists of two cycles addressing *applicability assessment* and *design method applicability*. The approach and steps within are described in more detail in the following.

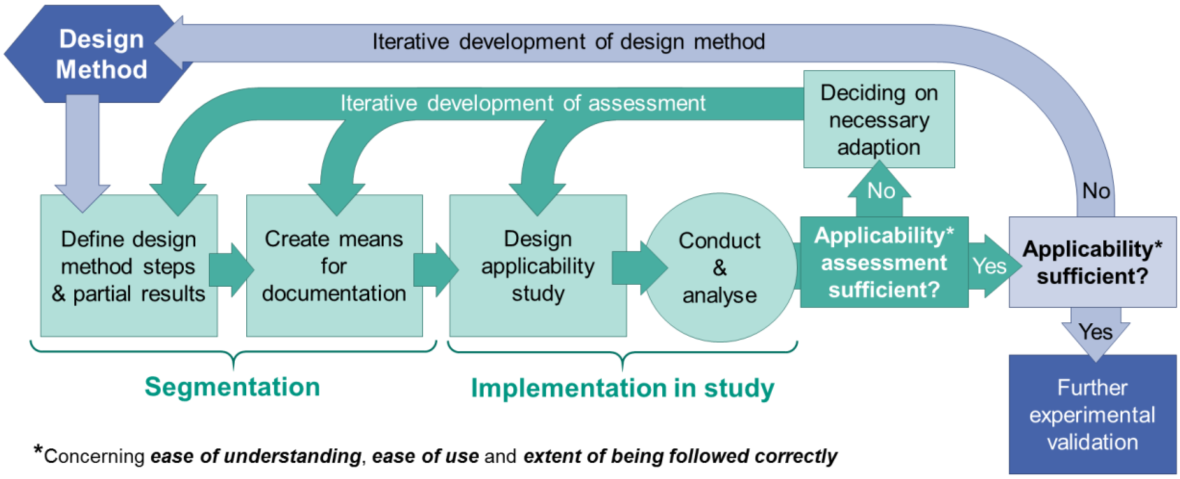

Figure 2: Approach to assess applicability in initial studies of design method validation. The inner iteration cycle (green) aims at developing appropriate applicability assessment, the outer cycle (blue) aims at developing the design method to higher levels of applicability.

3.1 Segmentation

Following the argument of Pedersen *et al.* (2000) and Gericke *et al.* (2017), a necessary step in design method validation is a detailed description of the method and its procedure. This aims at checking internal consistency and making visible how the core idea of the method is to be carried out. It includes the definition of design method steps and the corresponding results as well as means for documentation.

3.1.1 Define Design Method Steps and Partial Results

The definition of concise steps in the method's procedure enables a better *ease of understanding* and promotes a higher *extent of being followed correctly*. Also, this promotes the detailed description of the method's procedure as the method developer is encouraged to think about activities which are necessary to reflect the method's core idea and to achieve its purpose. Therefore, it is crucial to not only define *what* to do, but also *why* this specific step contributes to the method's purpose. For more complicated methods consisting of a high number of steps which use a multitude of different sources of information and produce different outcomes, a more detailed visualisation of the steps as proposed by Beckmann and Krause (2013) seems appropriate. A detailed visualisation also fosters *ease of understanding*.
By defining an outcome for each performed step in the procedure, the contribution of the step to the method's purpose becomes tangible and can be visualised as proposed by Pedersen *et al.* (2000). The result should be linked directly to the means of documentation (see Section 3.1.2), because a detailed documentation enables the assessment of applicability respective to *extent of being followed correctly*.
The deliverables are: (1) a description of the method's steps, (2) the results each step aims to achieve and (3) what consequences those results have on the following procedure.

3.1.2 Create Means for Documentation

Means for documentation highly relates to the representations of design information as described by Gericke *et al.* (2017). Usually, design method steps transform, condense or expand design information in order to reach a final result. The means for documentation are to be created according to the kind of

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transformation, condensation or expansion that takes place in the corresponding method step to make the process visible. For example, a step directed at selecting between alternatives should enable documentation of different alternatives, reasons for the decision reached and the result of the decision. Also, if one type of representation is transformed during one step, this might require different means of documentation. For example, when a step is directed at finding a design solution concept, this might include the documentation of requirements as well as graphical representations of possible concepts to address those requirements. An appropriate documentation also enables assessment of the *extent of being followed correctly*.

The deliverables are: A description on how to document the results of each method step and possibly tools to do so, e.g. a template for failure mode and effects analysis or a description on what aspects to highlight in a technical drawing during functional analysis.

3.2 Implementation in Study

Initial studies on design method applicability should take place in the laboratory. The method readiness is at this stage insufficient for an application in practice. As proposed in DRM (Blessing and Chakrabarti, 2009) applicability should be investigated accompanying method development. An applicability study is to be seen as a necessity for further design method validation concerning usefulness and acceptance.

3.2.1 Design Applicability Study

Choice of study design. The study should resemble a possible study design for later validation stages as to prepare for further validation. Like this, the study design can be continuously developed (see Figure 1). It is frugal to choose an experimental study design, because it allows to compare how differently participants deal with design tasks with and without the design method or with benchmark methods. Also, experimental research is necessary in design method validation before continuing to implementation studies (Marxen and Albers, 2012). An overview, what aspects need to be considered in designing experiments for design method validation is given in Üreten *et al.* (2019).

Choice of participants. To initially investigate design method applicability, participants should be inexperienced in the presented task as well as with the method under investigation or similar methods. For once, participants with higher levels of experience tend to have a lower need of methodical support, because they apply implicit strategies similar to methods instead (Daalhuizen and Badke-Schaub, 2011; Eisenmann and Matthiesen, 2020). Additionally, if the participants already know similar methods, application might be easier for them as for users without this experience. The number of participants should be kept on a level which can be directly observed by researchers to make working with the method as visible as possible in every step.

Choice of design task. As mentioned before, it is of high relevance that the study participants have a need for methodical support that can be addressed with the design method under investigation. Therefore, the task for method application has to be chosen carefully according to difficulties of the participants.

Method introduction is crucial for *ease of understanding* of the design method. Therefore, during this early stage of design method validation the presentation, explanation and practice of the method should be carefully considered. Method introduction can possibly be simplified up to the point where a sheet which describes the method is sufficient, but this is only possible by investigation of *how* potential users understand the method.

3.2.2 Conduct & Analyse

Data acquisition on design method applicability should be mostly qualitative as the main goal is to understand the *how* and *why* of participants' understanding and use of the method. This includes interviews before and after applying the method, questionnaires and observation. Recording the whole study is often useful as every reaction of a participant might yield information on the method's applicability. Also, every piece of participants' documentation should be collected and researchers can encourage participants to choose other means to document their thoughts, like sketches.

The demand to be qualitative is also true for data analysis, because it involves a high level of interpretation of participants' behaviour and statements as well as the collected documentation. Analysing the documentation allows to identify critical method steps as the *extent of being followed correctly* becomes visible.

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3.2.3 Decision on the Need for Adaption

Based on the study's results, researchers need to decide whether adaptions concerning the applicability assessment (inner cycle in Figure 2) or the method itself (outer cycle in Figure 2) are necessary. Results need to be interpreted to make this decision, because each result can relate to the assessment, the method itself or even both. In the interpretation of results on method applicability Üreten *et al.* (2017) differentiate between two types of difficulties: user-dependent and method-related. User-dependent difficulties need to be interpreted to decide on adaptions either in the study design or in the method description. Those difficulties can relate to *ease of understanding* of the method or the design task (e. g. caused by choice of vocabulary). Another aspect can be the *ease of use* which might originate from the means of documentation or skills of participants. Method-related difficulties should be further differentiated to identify the cause in method description or introduction, means of documentation or the fit of design task with the method's core idea.

4 MATERIALS AND METHODS

The presented approach was applied to conduct a study investigating applicability of model building with the Contact and Channel Approach (C&C²-A) (Grauberger *et al.*, 2019). In order to reach an appropriate level of applicability assessment, the inner cycle of assessment development (see Figure 2) was run through three times.

Study design. A crossover design was chosen, because it is planned to further validate the method later on in experimental validation using this design. Two different technical systems were used as stimuli to enable observation of applicability for different stimuli. In the first step of the crossover design, each participant analyses one of the two technical systems without the method. This is followed by an introduction of the design method and an analysis of the second system using the method.

Design Task. The task for all participants was a functional analysis of the systems as this is the core activity for C&C²-A model building: "Which embodiment parameters have a major influence on the desired function of the shown system?" The design task remained the same for all three iterations.

Participants. As outlined in Section 3.2.1, inexperienced participants are to be preferred for initial studies of applicability. Therefore, students of mechanical engineering were chosen as participants. 4 undergraduate students took part in the first iteration. In each of the following iterations, 2 students with a bachelor's degree in mechanical engineering participated.

Data Collection took place by recording the whole room on video. Additionally, participants were observed directly by one researcher per participant. The researchers took notes on the participants' behaviour during method introduction and application. Participants were asked to document every step on means of documentation provided. All means of documentation the participants used were collected. After completing the task, participants were interviewed in the whole group.

Data Analysis. All collected data was analysed and discussed qualitatively. Analysis of *ease of understanding* was focussed on observational data from method introduction as well as statements from the interview at the end. *Ease of use* was mainly targeted by interpreting the participants' documentation during the second task as well as the interview at the end. Assessment of *extend of being followed correctly* was conducted by analysis of means for documentation as used by participants.

5 RESULTS

By applying the presented approach, applicability assessment was conducted in three iterations. The following presentation focuses on results which triggered an adaption.

5.1 Segmentation

5.1.1 Definition of Method Steps and Partial Results

C&C²-A includes key elements and basic hypotheses which allow analysis of relations between embodiment and function in mechanical systems (see Figure 3, left). However, this only provides the necessary language and rules for model building rather than a procedure. This is because steps were defined to support the use of C&C²-A (see Figure 3, right) for model building.

This definition of method steps was completed in Matthiesen (2021) before conducting the applicability study. The steps themselves were not adapted during the three iterations. In Iteration 1, it became visible

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that a preliminary step of “describing the function of the system at hand” was very difficult for the participants. As this step was considered not to be part of the core idea of the method, the system’s function description was given in the tasks of Iteration 2 and 3. Additionally, step a) “Definition of modelling purpose” was difficult for all participants, but they all ultimately succeeded in performing it. Step a) is essential for model building, because it gives focus in the following steps. Therefore, step a) was not modified for further validation.

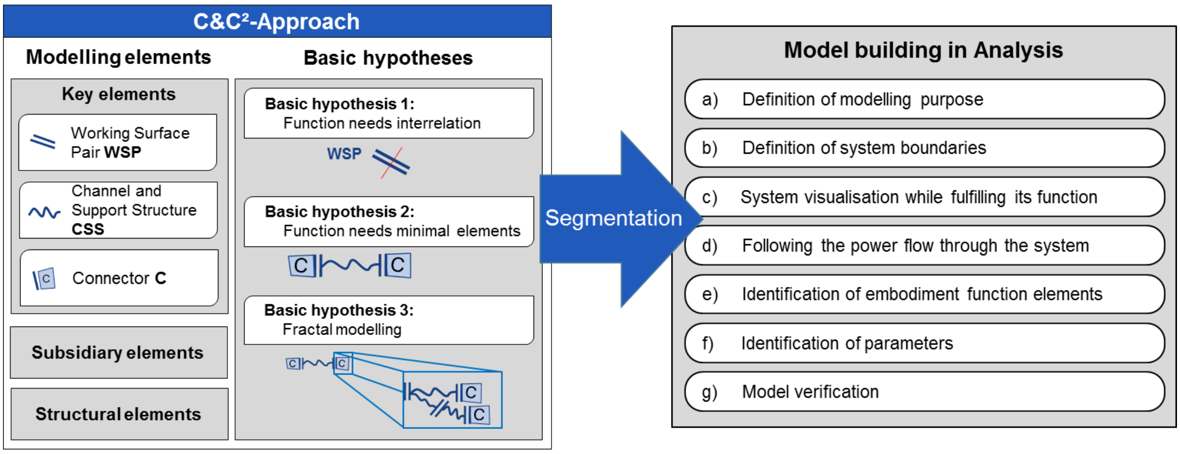

Figure 3: C&C²-Approach (left) and defined steps for model building using C&C²-A (right) (Matthiesen, 2021)

5.1.2 Means for Documentation

For Iteration 1, a technical drawing of the system under investigation was chosen as means for documentation for all method steps. It was assumed after the experience in Iteration 1, that the selected systems were easy enough to understand, because all four participants were able to identify relevant parameters in a short time without explicitly applying the method. After adaption of the stimulus for Iteration 2 (see Section 5.2.1) participants needed to find an appropriate visualisation of the system themselves. Therefore they were given the advice to document each of the method’s steps on sheets of paper provided. This made the identification of critical steps in Iteration 2 very challenging, because it was often not visible by documentation what caused the non-use of the method provided. This is because, for Iteration 3 a template was created with one page for every method step. Participants were asked to fill out the template step by step. By observing the participants it became visible, when they were discarding one of the template sheets without writing anything down. As this did not happen in Iteration 3, the template was considered appropriate to be used for further validation steps.

5.2 Applicability Study Design

The purpose of model building using C&C²-A is to support in the analysis of technical systems by abstracting the embodiment through the approach’s key elements. Therefore, a representation of the system is required as a starting point for analysis.

5.2.1 Provided System Representation - Stimulus

The overall task of all three iterations remained the same, but the information provided in the form of a system representation was changed (see Figure 4) as a result of the findings:

In Iteration 1, we used technical drawings as design representation (see Figure 4, left). All participants were able to rapidly identify the critical parameters of the technical system without even applying the method. By interviewing the participants, it became clear, that the drawing used already simplified the system too much. This enabled the participants to identify the relevant parameters directly by looking at the drawing without explicitly using the proposed method. Therefore they did not see a need in using it. This indicates that finding an appropriate visualisation of the technical system is a critical step in model building using C&C²-A.

Adaptions were made for Iteration 2: The design representations were changed to 3D-PDFs of the full technical systems (see example in Figure 4, middle). With this adaption, participants had to find an appropriate 2D visualisation for further analysis themselves. This resulted in a system-dependent output

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in Iteration 2: Participants struggled with finding a visualisation in step c) with one of the two systems provided and therefore were not able to proceed with the method application as intended. This resulted in a low performance concerning the identification of critical parameters. In the interview following Iteration 2, the participants stated they struggled with finding a fitting cross-section as well as with finding the most relevant part of the system as a whole.

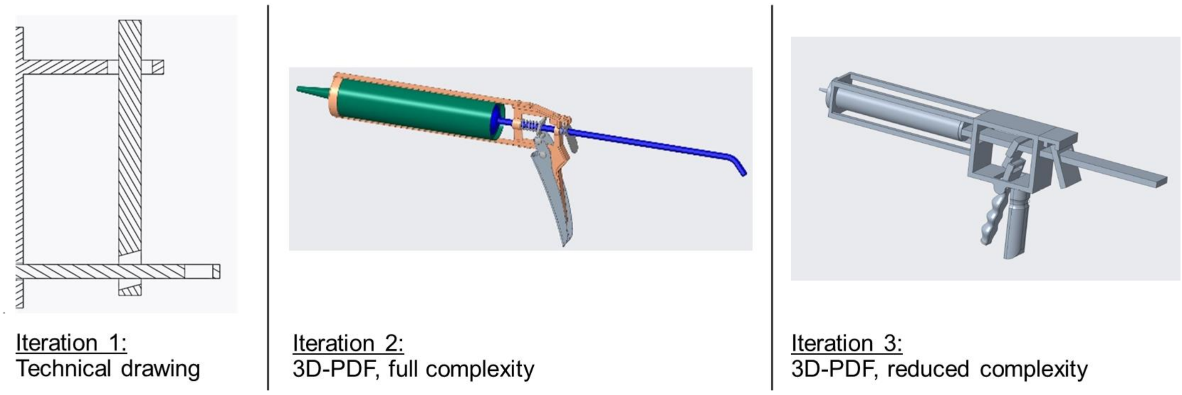

Figure 4: Development of system representation. Shown is one of the study's systems.

This resulted in further adaption of the stimulus for Iteration 3: The system representations in 3D-PDF were simplified in their geometry to allow a faster recognition of an appropriate visualisation (see Figure 4, right). Both participants in Iteration 3 were able to find an appropriate visualisation and were able to perform an analysis using the key elements of C&C²-A.

5.2.2 Method introduction

An essential part of design method applicability is the *ease of understanding* which is strongly influenced by how the design method is introduced. This includes textual, visual and verbal components of introduction. For Iteration 1, the focus was laid upon being as concise as possible. The introduction shortly named the key elements of the approach and illustrated the steps to be undertaken using a simple example. The introduction as a whole lasted about five minutes. Participants received a short documentation of the simple example on a one pager. In the interview following Iteration 1, participants stated, they had understood the core idea of the method but did not know how to actually apply it. Additionally, they did not see a need to apply the method as described in Section 5.2.1.

Method introduction in Iteration 2 was modified to foster method understanding. An example task on a third system was added, which the participants worked on guided by the researchers. Like this, participants could apply the method once with the support of the researchers, before applying it themselves. Both participants in Iteration 2 were not able to build a model using C&C²-A. As outlined before, this was supposedly caused by a more complex stimulus (see Section 5.2.1). Statements in the interview following Iteration 2 align with this view. Both participants had understood the method, but struggled in finding an appropriate visualisation. Additionally, the participants' solutions documented during the guided method application showed a low level of detail. This was attributed to the chosen technical system for introduction. This is because, method introduction was slightly adapted for Iteration 3 by changing the technical system for guided method application to a system that required more attention to detail.

In Iteration 3 both participants were able to create models using C&C²-A with a fitting degree of detail during guided method application as well as during the given task after introducing the method.

6 DISCUSSION

6.1 Assessment of Design Method Applicability

The presented approach made it possible to assess the three aspects of design method applicability *ease of understanding*, *ease of use* and *extent of being followed correctly*. It was developed to address the research question: *How can design method applicability be assessed in early stages of method validation?* By applying the approach, insights could be gained related to the assessment and optimisation of these aspects:

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Ease of understanding. By interviewing participants at the end of each iteration, it could be differentiated between a lack of understanding and other causes of a non-application. Additionally, through defining method steps, participants were able to describe more precisely which part they did not understand. Like this, method introduction could be modified to reach a better *ease of understanding* by including a guided application.

Ease of use. Close observation of participants during the pilot studies made their problems during application visible. By dividing the method into concise steps, these problems could be narrowed down. In one case, the problems could be attributed to a single, critical method step. The identification of this critical step caused adaptions in the means for documentation as well as to the stimulus.

Extent of being followed correctly. Creating means for documentation for each method step enabled a close investigation of how participants actually applied the design method. The *extent of being followed correctly* is influenced by the previous factors *ease of understanding* and *ease of use* as well as the participants' need to actually apply the method. Therefore, the extent of being followed correctly might be useful to assess design method applicability in further validation steps.

The presented findings are subject to certain limitations. The illustration of the approach using a single method in three iterations of a small scale study is not sufficient to claim its usefulness for assessing applicability of design methods as a whole. However, we argue that the approach contains elements which are relevant for all methods described in concise steps with corresponding results. To assess applicability in an early stage of design method validation, an adaption of difficulty and design representation is necessary which might cause large differences from the actual context the method was developed for. In the view of the authors, this is a necessary step to make early investigation possible. This gap between application in studies and in practice should be closed later on in the validation process.

6.2 Method related Insights

By applying the presented approach in three iterations, aspects concerning the applicability of C&C²-A model building in analysis could be identified. By dividing the method into concise steps, identification of a critical step became possible. This needs to be considered in future method application and validation, e.g. by additionally supporting this specific step. By adapting method description and introduction as well as the design representation used, participants were finally able to create C&C²-Models themselves by following the prescribed method steps correctly. The applicability of C&C²-A model building seemed appropriate to move forward to pre-study experiments with a larger number of participants which can include the method's usefulness as a new dimension of validation.

6.3 Implications for Design Method Validation

The goal of this contribution was to present and illustrate an approach to assess applicability in design method validation. In our view, main insights concerning method readiness can be gained by investigating design method applicability in early stages of design method validation. This investigation is often very challenging, because it requires an abstraction of context far from industrial application to make studies in the laboratory context possible. This especially relates to the design task, design representation and method users. Created means for documentation in the form of a method template can be used for further validation steps. Especially if the template is independent from the system under investigation. It needs to be considered that adaptions of method steps change the method itself and might cause an optimisation of the method on the study's task. However, it is the researcher's responsibility to ensure, that the method's core idea and scope is not lost during validation.

The design method under investigation in this contribution consists of a relatively small number of elements and activities. It is assumed, the more complicated the method the more effort will be required for method introduction in order to ensure a high level of understanding and to promote ease of use. By selecting specific design tasks for investigations in the laboratory, including a fitting design representation, insights on the method's actual scope or necessary adaptions can be gained. By assessing applicability according to the approach presented, method scope coverage and method introduction can be focused for further validation and dissemination.

In the state of the art it remains unclear, which research methods and what kind of evidence are necessary for a successful design method validation (Gericke *et al.*, 2017). This contribution focuses on one of the first activities in design method validation and puts the approach on how to conduct this step

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to discussion in the community. Therefore, the approach can contribute to the discussion on standardisation of design method validation, especially for early stages of validation.

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