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Validating a Design Method to Improve Collaboration in Distributed Product Design – What Needs to be Considered?

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Abstract

One promising approach to deal with the increasingly complex and volatile conditions of product design is to work in distributed teams. However, this also poses new challenges that can result in efficiency and effectiveness losses. To overcome these challenges, the EDiT method - Enabling Distributed Teams - is currently being developed to enable distributed teams to identify and exploit improvement potentials in collaboration. To develop design methods that address the needs of their intended users, continuous and iterative validation during the whole method development process is of particular importance. This enables design methods to be adapted to the needs of their users at an early stage and to be further enhanced in a target-oriented manner. The question arises, what needs to be considered in supporting the continuous and iterative validation of the EDiT method. To address this need, this contribution focuses on the development of a process model that supports the method developer with the continuous and iterative validation of the EDiT method. To generate an understanding of what needs to be considered in supporting the validation of the EDiT method based on existing frameworks for method validation, three partial models were examined using a literature review, expert interviews, and a questionnaire. Each partial model yielded one key result: six paradigms outlining the validation of design methods, target relations to illustrate the interrelationships of the influences of the EDiT method, and nine requirements that are placed on a process model for the validation of the EDiT method. The underlying theoretical assumptions generated by the three partial models were eventually integrated into the process model. Finally, the results can be used to continuously improve the EDiT method while simultaneously demonstrate its benefits, to ultimately provide the potential for increased method acceptance in practice.

Keywords: Distributed design, collaborative design, design methods, design method validation, EDiT method

1 Introduction

Against the background of the shift from conventional products over mechatronic solutions towards intelligent, cyber-physical systems (Advanced Systems), the degree of dynamic interconnectedness and interactive socio-technical integration in product design is constantly growing (Dumitrescu et al., 2021). To cope with this complexity, companies are increasingly relying on digitization, interdisciplinarity, and product design in (global) networks. One result of this transformation is the increasing need for collaboration in distributed design teams (Lindemann & Kern, 2016). While this provides companies with the opportunity to face the rising needs for the development of Advanced Systems, it also poses challenges that are reflected in the dimensions of technology, organization, and people and potentially impacts the efficiency and effectiveness of product design activities negatively (Duehr et al., 2020). The EDiT method (Enabling Distributed Teams) that is currently under development, addresses this potential threat. Based on the identification of improvement potentials, problem-specific measures can be defined, implemented, and evaluated to improve distributed collaboration of product design teams. However, design methods can only employ their full potential if they are designed from the very beginning to meet the needs of their future applicants (Birkhofer et al., 2005). The early and continuous validation of design methods thus plays a decisive role in the process of method development (Badke-Schaub et al., 2011). While some validation studies for the EDiT method already exist, validation activities used therein are specially designed for their scope and are thus limited to specific validation environments and test cases only. Therefore, the focus of this contribution is to build on elements of existing frameworks to support the validation of design methods taking into account the characteristics of distributed product development. As a result, a process model will be presented, that supports a continuous and iterative validation of the EDiT method.

2 State of the research

2.1 Design methods to improve distributed product design

One promising approach to dealing with the increasingly complex and volatile conditions in product design is to work in distributed teams. To meet arising challenges like a loss of information or an increase in the effort required for coordination activities (Bavendiek et al.; Kuster et al., 2011), those teams should be supported continuously to improve their collaboration. Methods like *SCRUM*, *Kanban*, *Continuous Improvement Process*, or *Design Thinking* (Atzberger et al., 2020; Grots & Pratschke, 2009; Schnegas, 2019; Schwaber & Sutherland, 2012) are frequently used to support product design tasks. However, they do not focus on the specific characteristics of distributed product design.

EDiT - Enabling Distributed Teams closes this gap. As a method that supports the identification and exploitation of improvement potentials of distributed collaboration in product design teams, it provides situation-specific guidelines, resources, and tools to improve distributed collaboration (Duehr et al., 2021). The method includes four successive phases that are iteratively run through. The aim of the *first phase* of the EDiT method is to identify potentially critical activities and to recognize potentials for improvement in the different fields of action of distributed product design (Albers et al., 2020). In the *second phase*, measures are identified to exploit the potential for improvement based on the root causes of the problems identified in the most promising fields of action. The goal of the *third phase* is the individual implementation of measures to develop the identified and selected improvement potential. Finally, the goal of the *fourth phase* lies in the evaluation of the measures as well as in the application of the method, including review and learning activities. 16 requirements needing to be fulfilled were identified for the EDiT method (Duehr et al., 2021). These requirements are specific to a method or group of methods, and reveal the distinctive features inherent to the validation in distributed contexts. Requirements are not only an important prerequisite for the development of the method but also serve as a basis for its validation. For example, requirement U1 of the EDiT method is concerned with comprehending influencing factors of distributed product development which requires a validation, that addresses the particularities of distributed product development. Some of the requirements have already been investigated in validation studies conducted in the field with some of them being confirmed (Duehr et al., 2022). However, no systematic approach has been pursued yet to examine the requirements holistically.

2.2 Validation of design methods

Even though the benefits of method application in product design have been empirically proven, a hesitant transition of methods from research into practice can still be observed (Gericke et al., 2016). The literature indicates low acceptance of design methods as a reason for this (Reiß, 2018, p. 88). The insufficient adaptation of methods to the needs of their intended users can be named as one problem (Reiß, 2018, p. 89). As a consequence, methods often have an insufficient level of flexibility and adaptability (Pahl, 1994), a high level of abstraction (Braun & Lindemann, 2004), and are lacking tool support (Birkhofer et al., 2005). Early and continuous validation during the method development process plays an important role in addressing these problems (Badke-Schaub et al., 2011). However, studies show that this is not sufficiently considered or even not considered at all (Barth et al., 2011; Cantamessa, 2003). The biggest challenges when validating design methods involve the human as an object of observation, as well as the volatility of possible product design environments and problems (Eisenmann et al., 2021). This complexity and uniqueness of each design situation complicate the repeatability of validation activities for design methods (Reich, 2010). As a consequence, validation activities in practice quickly reach their limits due to a large number of influencing factors, many of which cannot be controlled (Vermaas, 2014). Especially when considering team processes, there is the challenge of variables that are difficult to measure (Reich, 2010). As a result, an objective evaluation of the benefits and efforts of a method application is only possible to a limited extent (Pedersen et al., 2000; Zanker, 1999). Moreover, method validation often focuses solely on investigating and evaluating applicability (Eisenmann et al., 2021). Nevertheless, some approaches can be found in the literature that deal with the validation of design methods to overcome the aforementioned challenges such as the *Validation Square* according to Pedersen et al. (2000), the Concept Map according to Üreten et al. (2019) as well as the *Design Research Methodology (DRM)* according to Blessing and Chakrabarti (2009). The DRM proposes a validation based on three types of evaluation criteria: success evaluation, support evaluation, and application evaluation (Blessing & Chakrabarti, 2009). Based on the existing frameworks, Duehr et al. (2022) specifically address the characteristics of distributed product design by developing a procedure for validating the EDiT method in field studies. However, the developed approach was specifically designed for validation studies in the field, so it lacks transferability to other research environments.

2.3 Continuous validation in product design

In general, literature dealing with validation in the field of product development is primarily concerned with the validation of technical systems rather than design methods. Albers et al. (2016) refer to validation as a central activity in the product design process. One notable model to characterize the activities of validation was introduced with the system triple of product engineering (Ropohl, 2009). It describes product design as a continuous interaction of three systems. Including the designers and the design activities, the *operation system* is simultaneously developing two different systems: the *system of objectives* and the *system of objects* (Albers et al., 2011). Within the system triple, validation consists of three activities (Albers et al., 2016): The *evaluation* serves to examine the elements of the system of objectives from the stakeholder's point of view and is carried out predominantly subjectively based on personal perceptions. *Objectification* involves comparing elements of the system of objectives with the expectations and needs of the stakeholders, e.g., through customer integration. In this, a connection between quantitative measures and the subjective feelings of the stakeholders should be established. Finally, *verification* checks the conformity of the elements of the system of objectives with those of the system of objects. Validation of technical systems is to be understood as a continuous activity that is performed by constantly comparing the product's objectives with the current increment of the system of objects (Albers et al. 2016a). In its entirety, product design can thus be viewed as a sequence of creation and validation steps in a continuous cycle. A selection of the subfunctions and subsystems to be validated is made by defining a validation objective (Klingler, 2017). The execution of validation activities takes place in the form of a test. This includes a test case, a test environment, and a test interpretation and serves to verify the previously defined objectives, requirements, or hypotheses (Ebel, 2015).

3 Research methodology and research objective

The state of research indicates that many frameworks already exist to support validation activities of design methods and many more of technical systems. However, these frameworks alone do not provide sufficient support for the validation of the EDiT method, as they do not sufficiently address the characteristics of distributed design situations as well as the iterative applicability in different research environments and different design teams which all show very unique improvement potentials. The question arises, what needs to be considered to support continuous and iterative validation of the EDiT method based on existing frameworks. Therefore, the goal of this contribution is to develop a process model for the validation of the EDiT method based on existing validation frameworks that support continuous and iterative validation while taking into account the specifics of distributed product design teams. Using the process model, method developers shall be enabled to perform continuous and iterative validation of the EDiT method during the entire method development process at different maturity levels, under different validation foci, and in different validation environments. Thus, the following research questions will be answered:

- What needs to be considered in supporting the continuous and iterative validation of the EDiT method and which requirements are derived from this?
- What should a process model look like, that supports the continuous and iterative validation of the EDiT method by meeting the identified requirements?

To address the first research question and to generate an understanding of what needs to be considered in supporting the validation of the EDiT method, three partial models according to Ebel (2015) were examined using a literature review, expert interviews, and a questionnaire (cf. Figure 1). Each partial model yielded one key result. The *model of environment* characterizes the boundary conditions of a process model for the validation of the EDiT method and characterizes relevant areas of influence on a superordinate level. First, the existing literature on the topics of distributed product design and validation of design methods was examined. For this purpose, 19 relevant contributions between 1997 and 2021 were included and analyzed concerning boundary conditions, opportunities, and risks of method validation in a distributed setting. On this basis, a questionnaire guideline was developed, which was used to interview 11 experts with a scientific or industrial background in one-hour semi-structured interviews. As a core result, 6 paradigms were formulated, which can be understood as a high-level rationale regarding the validation of design methods and as base for the process model to be developed. The *model of objectives* shows hierarchical target relations that follow from the development of a process model for validating the EDiT method on higher-level goals. In order to validate the individual target relations, literature was examined. Unresolved target relations were queried separately in an online questionnaire in which, besides the participants from the expert interviews, additional individuals with experience in the validation of design methods were approached. The questionnaire was completed by 13 participants. Lastly, the *model of requirements* maps all the necessary requirements that are placed on a process model for the validation of the EDiT method. This is the partial model with the lowest level of abstraction of the three. Once again, the literature was examined first. Subsequently, the expert interviews (identical to the interviews for the model of environment) were used to reduce the pool of requirements identified in the literature to a number of nine. For this purpose, requirements mentioned across experts were identified and compared with those identified from the literature and formulated in a uniform manner. These nine requirements represent the key result of the model of requirements.

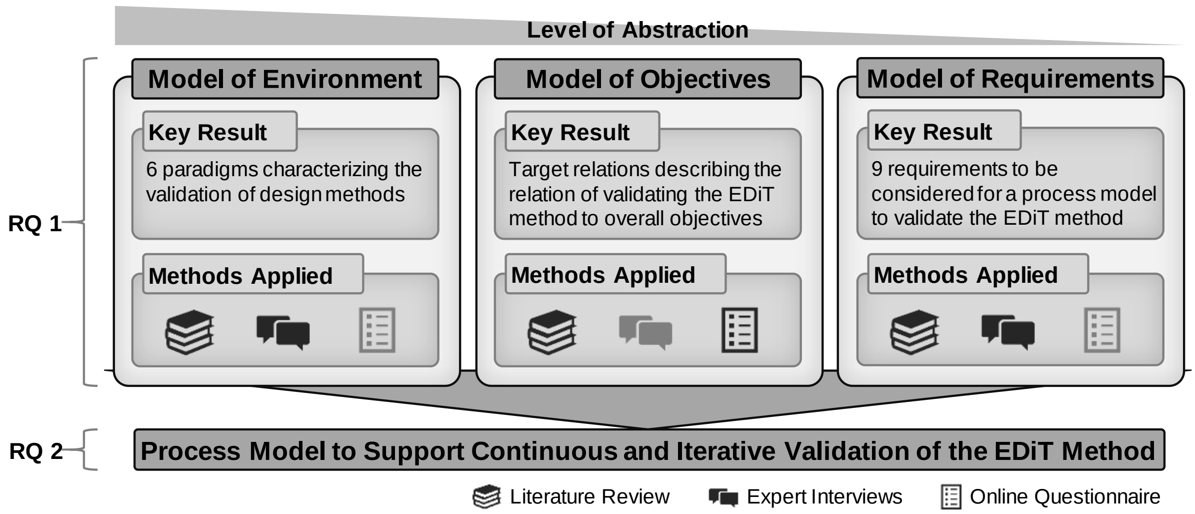

Figure 1. Overview of the three partial models with their key results and methods that have been used.

The underlying theoretical assumptions generated by the three partial models were afterward operationalized by conceptualizing a process model for the validation of the EDiT method (cf. chapter 5).

4 Paradigms, target relations, and requirements that need to be considered when validating the EDiT method

The key result that emerges from the model of environment comprises a set of six paradigms. They reflect a fundamental perception about what needs to be considered when validating design methods shared by multiple experts questioned in the interviews that also serves as a synthesis of fundamentals discussed in existing frameworks. The paradigms thus represent a rationale that should be considered as a foundation for developing a process model for the validation of the EDiT method and read as follows:

Paradigm 1: Every validation activity has a limited scope defined by the validation goal: Every validation study comes with certain boundaries and constraints that limit the quality of its results. Defining the validation goal ensures that the scope of a validation activity is chosen in a way that meaningful conclusions can be drawn for a given set of boundary conditions. Formulating the validation goal might depend on the given level of maturity of the method, the specifics of a given validation environment, etc.

Paradigm 2: Requirements to be met by the design method are the starting point of every validation study: A key element in the validation of design methods is the examination of the extent to which previously defined requirements placed on a method are being met (verification). In this context, requirements can be applicable across several methods, e.g., a high degree of user-friendliness of the method is almost always a favorable requirement. However, requirements that apply specifically to the design method under investigation are particularly interesting. One such requirement for the EDiT method would be the improvement in the efficiency of the distributed product design team.

Paradigm 3: Validation activities are to be executed in a representative validation environment and based on a realistic test case: A validation activity is particularly insightful if the selected validation environment and test case represent the conditions under which the method will later be applied as closely as possible. For this reason, the validation of design methods in the field is favored by many of the experts consulted.

Paradigm 4 - The examination of the contribution to success resulting from the application of the design method is a central aspect of validation: In many cases, the validation of design methods is qualitatively driven and is obtained by questioning method applicators regarding their subjective perceptions. However, a successful method validation should above all focus on evidence of the added value provided by the method application to prove an appropriate effort-benefit ratio. This cannot be supported by subjective, qualitative evidence alone, but should be based on objective quantitative measurements.

Paradigm 5 - Validation activities are to be carried out from the beginning and continuously throughout the entire development process of a design method depending on the level of maturity: Validation is understood in the literature and by experts as a cycle of analysis and synthesis activities with the goal of continuous enhancement of a design method in iterations. Validation activities should be pursued from the very beginning of the method development to capitalize lower effort through early adaptations compared to later ones. By doing so, an early alignment of the method to the needs of its applicants can be ensured.

Taking into account the shared characteristics of the preceding paradigms, a sixth, superordinate paradigm was formulated:

Paradigm 6 - For the validation of design methods, patterns and principles from product validation can be adopted: The validation of products and the validation of design methods reveal many similarities, which are reflected in fundamental mindsets and approaches. That is why when considering the paradigms, it becomes apparent that by slightly reformulating them, the paradigms can also apply to product design. Thus, for the consideration of the validation of methods, models and methods of validation from the product design literature, e.g. the extended system triple, can be adopted.

As the key result of the model of objectives and to eventually define measurable success factors of the EDiT method, hierarchical target relations were created, analogous to the modeling guidelines of an initial impact model of the DRM (cf. Figure 2). These are tailored towards the

EDiT method and allow to establish a causal relation between methodical support of the validation of the EDiT method through a process model and higher-level goals like the improvement of the product quality through various intermediate levels. The degree of abstraction decreases from the bottom to the top as does the potential to validate the target relations experimentally. By establishing the target relations, it is possible to conclude higher-level goals based on lower-level, but easier to measure goals.

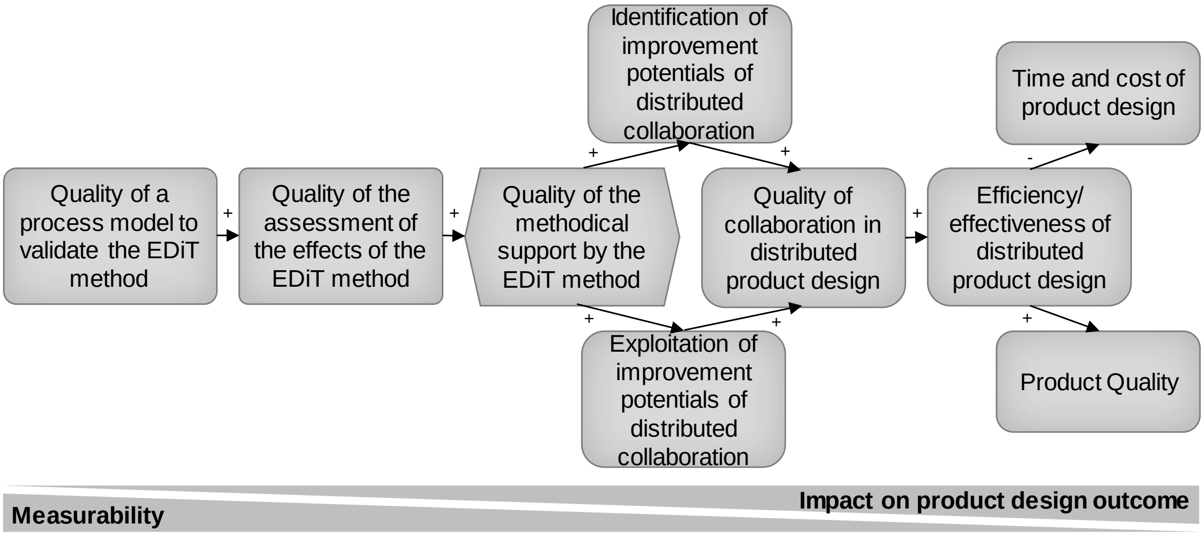

Figure 2. Target relations of the EDiT method. + symbolizes a positive and – a negative influence following the direction of the arrow.

As a key result of the model of requirements based on the expert interviews, 9 requirements were derived (cf. Figure 3) that are placed on a process model for the validation of the EDiT method. However, such a process model can only exploit its full potential if the requirements are understood and implemented correctly. The addressing of the requirements in the process model is described in chapter 5.

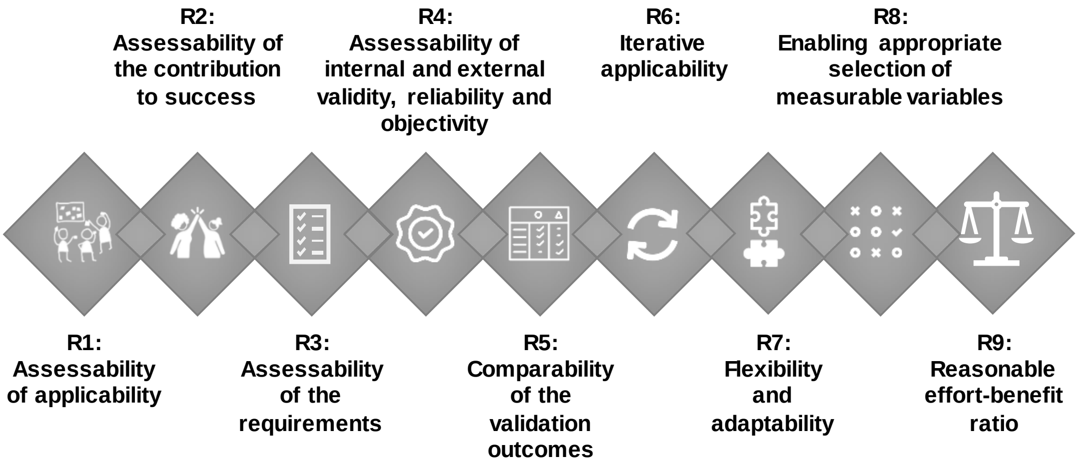

Figure 3. Requirements of the process model for the validation of the EDiT method.

5 Addressing the requirements: A process model to validate the EDiT method

Based on the paradigms of method validation, the target relations of the EDiT method as well as the requirements, the process model for the validation of the EDiT method was developed (cf. Figure 4). The theoretical foundation for the process model is represented by the model of the extended system triple introduced in the state of research.

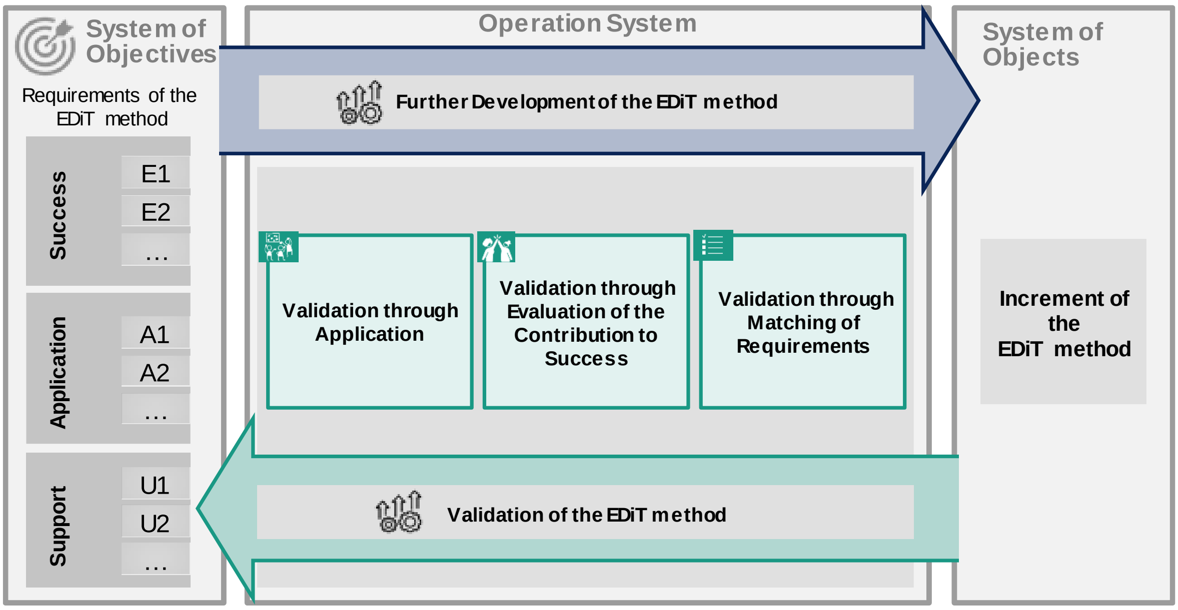

Figure 4. Implementation of the requirements in a process model for the continuous and iterative validation of the EDiT method.

Accordingly, the process model consists of four overall central components:

- the system of objectives of the EDiT method based on the requirements of the EDiT method
- the process of validation based on three categories in the operation system,
- the further development of the EDiT method in the operation system and
- the increment of the EDiT method to be validated in the system of objects.

The model describes the validation and further development of the system of objects of the EDiT method as a continuous interaction of the system of objects with its system of objectives via the components of the validation and further development in the operation system. Thus addressing requirement 6, the iterative character of the validation and further development of the EDiT method is emphasized. The system of objects of the EDiT method consists of the increments of the EDiT method already existing at the time of the validation, such as procedures, checklists, recommendations for action, guidelines, tools, and examples. As a further central component, the system of objectives of the EDiT method contains the mental conceptions and restrictions of the method already identified, defined requirements to the method as well as the needs of the design practice already determined. The system of objectives of the EDiT method is open-ended and is constantly extended and concretized in the context of the validation iterations also enabling the determination of an appropriate effort-benefit ratio (requirement 8). Based on the system of objectives of the EDiT method, the validation focus of the iteration is determined based on the 16 requirements for the EDiT method, the test case, the test environment, and the test interpretation. As the EDiT method evolves in the operation system, the revised system of objectives is continuously transferred to the object system, resulting in new increments of the EDiT method. Thus, the EDiT method is iteratively adapted, extended, and improved (requirement 7) leading to the *further development* of the EDiT method as a central component of the continuous and iterative validation.

The validation of the EDiT method is based on the three categories of validation: In the first category, *validation through application*, the application of the existing increments of the object system is defined and performed in the validation iteration to verify the applicability of the EDiT method (requirement 1). The core result of the validation through application is the qualitative feedback of the validation of the applicability through the application of the EDiT method. In the category of *validation through evaluation of the contribution to success*, the effect of the EDiT method is considered in addition to the process (requirement 2). Here, the validation of the method performance regarding the identification and exploitation of improvement potentials based on the target relations plays a central role. Consequently, this category includes the identification and selection of measurable variables as well as disturbing variables, the collection, and documentation of the variables as well as the evaluation of the results (requirement 8). The first core result of the validation through evaluation of the contribution to success is the identification of the individual potential for improvement. The second core result of the validation through evaluation of the contribution to success is the exploitation of the individual potential for improvement. The last category, *validation through matching of requirements*, represents a comparative element within different validation iterations of the EDiT method addressing requirements 3, 4, and 5. This category includes the subjective matching of the requirements of the EDiT method related to the support, the applicability as well as to the contribution to success of the EDiT method following the evaluation criteria of the DRM. In addition to the examination of the degree of fulfillment of those requirements, further recommendations for action as well as improvement potentials of the EDiT method can be derived continuously. The core result of the validation through matching of requirements is the assessment of the degree of fulfillment of the requirements of the EDiT method.

6 Discussion

The examination of the three partial models showed that the findings from the literature coincide with those of the experts interviewed and surveyed as well as with the fundamentals in existing frameworks in many cases. By using this mixed-method approach, a potential bias could be reduced. Nevertheless, some limitations remain as a result of this approach. First, it cannot be guaranteed that the contents of the partial models are exhaustive. For example, additional requirements could arise when consulting further experts. Secondly, no attention has yet been paid as to how the relevance of the individual requirements or paradigms can be assessed and how they potentially influence each other. Third, the interview guideline, as well as the questionnaire, were created based on the knowledge obtained from the literature. There is a risk that certain currently more focused aspects in literature were given more weight than others. The process model designed based on the insights from the partial models also comes with a limitation. Namely, the model was designed based on the investigated theoretical foundations. However, it remains to be seen whether these will also prove to be effective in practice. This can only be investigated by applying the process model in actual validation studies for the EDiT method.

7 Conclusion and outlook

This contribution focuses on the question of what needs to be considered in supporting the continuous and iterative validation of a method that supports the identification and exploitation of individual improvement potentials in collaboration of distributed product design teams (the EDiT method) based on existing validation frameworks, especially the DRM and concept map for design method experiments. Some core elements with strong relevance for distributed validation, which are not sufficiently taken into account in those existing frameworks (e.g. validation environment, tool support and data collection), were given special focus in the process model developed. By creating and investigating three partial models, paradigms, target relations, and requirements that need to be considered when validating the EDiT method were derived. A process model for the validation of the EDiT method addressing the requirements and based on existing validation frameworks was developed to enable a continuous and iterative validation and further development of the EDiT method eventually leading to the EDiT method meeting the needs of their future applicants. This will provide product developers access to a method that effectively supports their work in distributed teams. Subsequent activities are the validation of the model through the retrospective use of the model for past validation activities as well as for the planning and implementation of further validation activities. The process model for validation is next to be transferred from theory into practice by applying it under various boundary conditions like different industries, team settings, etc. Based on this, it should be closely evaluated concerning the nine defined requirements to verify whether the desired properties can be fulfilled and how the partial models and/or the process model itself need to be further developed. Additionally, validation with a longer-term time horizon will be assessed by the evaluation of a successful transfer into practice. As the last step, the transferability to other methods will be analyzed.

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