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SUPPORTING VALIDATION IN THE DEVELOPMENT OF DESIGN METHODS

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1. Introduction

The here presented paper is the attempt to link together thoughts that have been made in different parts of science. Design science as a relatively young scientific discipline has come up with a large variety of methods to support designers in engineering processes. At the same time, different authors have called out for order in the methodology of research within the design science, for taxonomies, for indicators of good practice and more. With the vision of one generally accepted framework as a research paradigm for the years to come, one of the essentials will be to provide test and validation methodology for newly developed design methods. A very important step has been made by [Blessing and Chakrabarti 2009], as they developed and introduced "Design Research Methodology" (DRM). This paper will show that although DRM gives a broad background and solid information on good scientific practice in the design science, it still lacks sufficient support for design scientists in the creation of applicable evaluation and validation of newly developed design tools and design methods. A model and first thoughts on support on a more concrete level are presented that can be integrated into the already existing DRM and will be combined with Albers' integrated Product Engineering Model (iPeM) [Albers and Braun 2011].

2. Design science and research methodology today

This paper will suggest a generalized model for the validation of new design methods or design support. An important aspect is to make it compatible to the already existing DRM [Blessing and Chakrabarti 2009]. This will allow to move one step closer to a widely accepted research paradigm for design science as has been called out for by [Reich 1995], [Fulcher and Hills 1996], [Cantamessa 2003], [Horváth 2004] and others. In the following paragraphs, we will therefore very briefly summarize some major aspects of the current scientific state of design science and its research methodology.

2.1 Design research

As design science is a relatively young branch of science, it has only been for the past decades, that scientists have started to acknowledge the demand for more systematic approaches and to inspect design research methodology more closely. See for example [Reich 1995].

Criticism of design science

Fulcher & Hills demand amongst other scientists for "a clearer understanding of the field as a whole and a sharper definition of goals and agreement on methods" as this could enhance performance [Fulcher and Hills 1996].

As a reaction to such statements, there have been publications of abstract thoughts from a rather philosophical point of view, debating what the proper research methodologies in design sciences should be, whether or not they should stick to the "orthodox sciences' approaches" and whether design science should be seen as science at all [Reich 1995], [Fulcher and Hills 1996]. All conclude that design science does belong to the scientific world and is especially difficult since it has not yet fully matured and there have been parallel streams of investigations, not using a common terminology or a shared methodological framework, see for example [Cantamessa 2003].

Recommendations for design science

However, there have also been first recommendations for general research approaches and strategies within the design science. [Fulcher and Hills 1996] draw attention to the "potential partners of Design Science", stating that i.e. management science and computer science deal with similar difficulties in their research methodologies. [Reich 1995] offers a series of guiding questions for researchers to help reflect one's own research. [Horváth 2004] has analysed the various subcategories of design research and proposed an order to offer a foundation to identify future developments and streams within design science, while [Cantamessa 2003] did an empirical study analysing the type of research being published at one of the major conferences on engineering design. He found five categories of design research:

- Empirical research, in which researchers analyse real-world design processes.
- Experimental research, in which researchers purposely set up design processes in a controlled environment.
- Development of new tools and methods for supporting the design process or elements of it.
- Implementation studies, in which researchers discuss the real-world deployment of innovative methods and tools.
- Other, which includes papers dedicated to theory and education.

Transfer to industry

Jänsch and Birkhofer have amongst few others published their research concerning the teaching of design methods and their transfer to industry [Jänsch and Birkhofer 2007].

Validation of design support

Research aiming at providing support for design researchers can be found at [Frey and Dym, 2006] who analysed how validation methods could be adopted from medical research. [Bender 2003] deals with the design of suitable design for the evaluation of design methods while others deal with creativity assessment, an important aspect when evaluating design methods.

2.2 Design research methodology

In the following, when the authors use the term DRM, it refers to the methodological approach as proposed by [Blessing and Chakrabarti 2009]. When referring to the general topic of scientific research methodology in the context of design science, we will use the term "design research methodology".

The by far most extensive work on this topic has been done by [Blessing and Chakrabarti 2009]. They also give a wide-ranging overview on the current state of research methodology in design science and have developed a comprehensive framework – DRM. Apart from sound theoretical background they even provide methodological support in terms of checklists and methods such as the "Reference Model" and the "Impact Model". DRM organizes design research in four major stages:

- Research Clarification
- Descriptive Study I
- Prescriptive Study
- Descriptive Study II

An overview of the main objectives and deliverables of each stage is given in Table 1. These steps do not have to be conducted in a purely sequential manner. "As we indicated […], the example does not show the many iterations and the parallel execution of stages that are part of reality. Neither does it show that the starting point can be in any of the stages, and that it is possible, in an individual project, to concentrate on one or two stages only.” [Blessing and Chakrabarti 2009].

Table 1. The four stages of DRM (compare [Blessing and Chakrabarti 2009])

Research Clarification (RC)	
Objectives	Deliverables
Identify goals, focus; main research problems, questions and hypotheses; relevant disciplines and areas to be reviewed, and the area in which the contribution is expected;	Current understanding and expectations: Initial Reference Model; Initial Impact Model; Preliminary Criteria.
Develop Initial Reference and Impact Models	
Identify preliminary set of Success Criteria and Measurable Success Criteria for later evaluation	Overall Research plan: research focus and goals research problems, main research questions and hypotheses relevant areas to be consulted approach (type of research, main stages and methods) expected (area of) contribution and deliverables time schedule
Provide focus for the DS-I stage in finding main contribution factors to, hinder or prohibit success;	
Help focus the PS stage on developing support that addresses those factors that are likely to have the strongest influence on success;	
Provide a focus for the DS-II stage for evaluating the effects of the developed support against the goals of the research.	
Descriptive Study I (DS I)	
Objectives	Deliverables
Obtaining a better understanding of the existing situation by identifying and clarifying in more detail the factors that influence the preliminary Criteria and the way in which these factors influence the Criteria;	Completed Reference Model
	Success Criteria
	Measurable Success Criteria
Complete the Reference Model including the Success Criteria and Measurable Success Criteria;	Key Factors, that: describe the existing situation and highlight the problems show the relevance of the research topic clarify and illustrate the main line of argumentation point at the factors that are most suitable to address in order to improve the situation;
Suggest possible Key Factors that might be suitable to address in the PS stage, as these are likely to lead to an improvement of the existing situation;	
Provide a basis for the PS stage for the effective development of support that addresses those factors that have the strongest influence on success, and can be assessed against the Criteria;	Updated Initial Impact Model;
Provide detail that can be used to evaluate the effects of the developed support in the DS-II stage.	Implications of the findings for the development of support and/or for the evaluation of existing support.
Prescriptive Study (PS)	
Objectives	Deliverables
Use the understanding obtained in DS-I or DS-II to determine the most suitable factors to be addressed in PS (the Key Factors) in order to improve the existing situation;	Documentation of the Intended Support: Intended Support Description: what it is and how it works; Intended Introduction Plan: how to introduce, install, customise, use and maintain the support as well as organisational, technical, infrastructural pre-requisites; Intended Impact Model;
Develop an Impact Model, based on the Reference Model and the Initial Impact Model, describing the desired, improved situation that is expected as a consequence of addressing the selected Key Factors;	
Select the part of the Impact Model to address and to determine the related Success and Measurable Success Criteria;	Actual Support: workbook, checklist, software, etc.
	Documentation of the Actual Support:

Develop the Intended Support, that addresses the Key Factors in a systematic way, and to realise this to such a level of detail that an evaluation of its effects can take place against the Measurable Success Criteria;	Actual Support Description; Actual Introduction Plan; Actual Impact Model;
Evaluate the Actual Support with respect to its in-built functionality, consistency, etc., – the Support Evaluation – in order to determine whether to proceed to DS-II to evaluate the effects of the support;	Results of the Support Evaluation; Outline Evaluation Plan.
Develop an Outline Evaluation Plan to be used as a starting point for the evaluation in DS-II.	
Descriptive Study II (DS II)	
Objectives	Deliverables
Identify whether the support can be used for the task for which it is intended and has the expected effect on the Key Factors (Application Evaluation);	Results of the Application Evaluation Success Evaluation;
Identify whether the support indeed contributes to success (Success Evaluation), i.e., whether the expected impact, as represented in the Impact Model, has been realised;	Implications and suggestions for improvement for: the Actual Support; the Intended Support, its concept, elaboration and underlying assumptions; the Actual and Intended Introduction Plan including introduction, installation, customisation, use and maintenance issues; The Actual and Intended Impact Model; The Reference Model; The criteria used.
Identify necessary improvements to the concept, elaboration, realisation, introduction and context of the support;	
Evaluate the assumptions behind the current situation represented in the Reference Model, and the desired situation represented in the Impact Model.	

As Table 1 shows, the scope of DRM is very broad. It is the only framework that deals with all aspects of design research methodology scientists in this field need in order to do their research work systematically. Any scientist facing a research project that deals with the development of design support can benefit from applying this approach.

DRM as in the form it was published in 2009 has evolved for almost two decades. "A preliminary version of DRM was developed as early as 1991 […]" [Blessing and Chakrabarti 2009]. However, it is still relatively young compared to research methodologies in other disciplines and therefore should be subject to scientific discussion and improvement. Although DRM does offer checklists and instructions on some of the major steps (i.e. "Reference Model", "Impact Model" and so on) it emphasizes the importance of evaluation without offering much guidance. It divides the evaluation of the support into three steps:

- "Support Evaluation"
- "Application Evaluation" and
- "Success Evaluation."

"Support Evaluation involves continuous testing during the development of the design support to ensure that the Actual Support is developed to such an extent that it can be evaluated in DS-II. […] Application Evaluation, […] aims at assessing the applicability and usability of the support [and] Success Evaluation aims at assessing the usefulness of the support, i.e., how successful the support is in achieving the formulated aims." [Blessing and Chakrabarti 2009].

While there is some guidance as to when, how and why the Reference Model and the Impact Model need to be updated, there is no concrete support on how to set up evaluation experiments for the three stages of evaluation. „Support development is usually not a direct derivative of the findings from DS-I or DS-II, but involves a highly creative and imaginative design process." [Blessing and Chakrabarti 2009].

2.3 The integrated product engineering model - iPeM

The integrated Product Engineering Model (iPeM) has been developed and introduced by [Albers and Braun 2011]. It serves as a meta model for describing, planning and controlling product engineering processes. It incorporates not only a phase-oriented view on the engineering process, as most process models do, but also an activity based view. Hence, one of the key features is the activities matrix, describing engineering processes with activities of Product Engineering and Activities of Problem Solving, typical of design and design-related activities (see Figure 1).

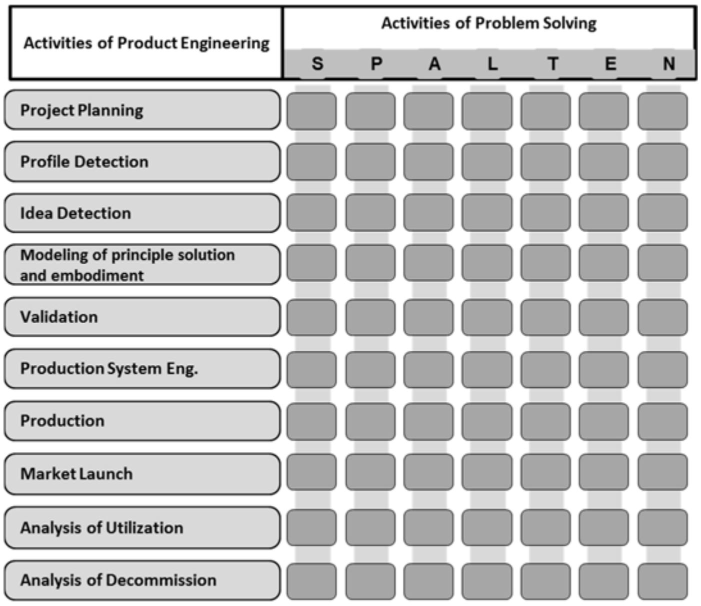

Figure 1. Activities matrix of the integrated product engineering model (iPeM)

It has been suggested to be used to link design support (tools and methods) to the engineering process, so the designer can look for support according to where she is in the process [Albers and Muschik 2010]. And those who dvelop design support can store the support acording to where in the process it might be useful for a later user. This will be an important link to the validation of newly developed design support.

3. Framework for the validation of design methods

In the following section, we will introduce a model that illustrates the emergence of design support. It is based on observation in design science and will integrate both Cantamessa's structure of research work and DRM. Its purpose is to serve as a guideline for deriving the necessary steps when validating a design support.

We have shown in Section 2 that there is a lack of support on how to set up and conduct evaluation experiments in DRM. The following thoughts and model are a suggestion and could after scientific discussion be added to DRM in order to improve support evaluation. The model itself will not yet support the conduction of scientific experiments, but it will help identify the main targets of the support and hence the necessary steps to be evaluated.

3.1 How does the development of new design support occur?

Figure 2 shows a model of how design support can be developed integrating Cantamessa's order and terminology. There is two general "starting points" (I). There can be a demand for design support - difficulties in practice are observed and design scientists try to come up with possible solutions to minimize the difficulties (II). Alternatively, (2) design scientists observe how a certain designer or design team successfully solves a problem or type of problems. They then try to describe and generalize what the designer or design team have done (best practice) and come up with a design support that resembles the designer's best practice in order to offer the solution to other designers (II).

Both starting points are of an empirical nature, as they represent an observation of a situation occurring in reality, both lead to the development of new design support. Independent of the starting point, the developed design support then needs to be tested for evaluation (III). If the experimental

work supports the hypothesis and assumptions made in II, one can go on to the next step and study how this new design support can be implemented in industrial real-live situations (IV) and how it can be taught to students (V).
At closer inspection, the left side showing a demand-driven development can be compared to what in epistemology is called deductive reasoning. Here one develops a theoretical approach, making assumptions about what might help solve the problem and then trying to confirm this by experiment and observation. The right side shows some typical elements of inductive reasoning, where a successful pattern is generalized to a theory that is assumed to be true as long as it is not proven wrong.

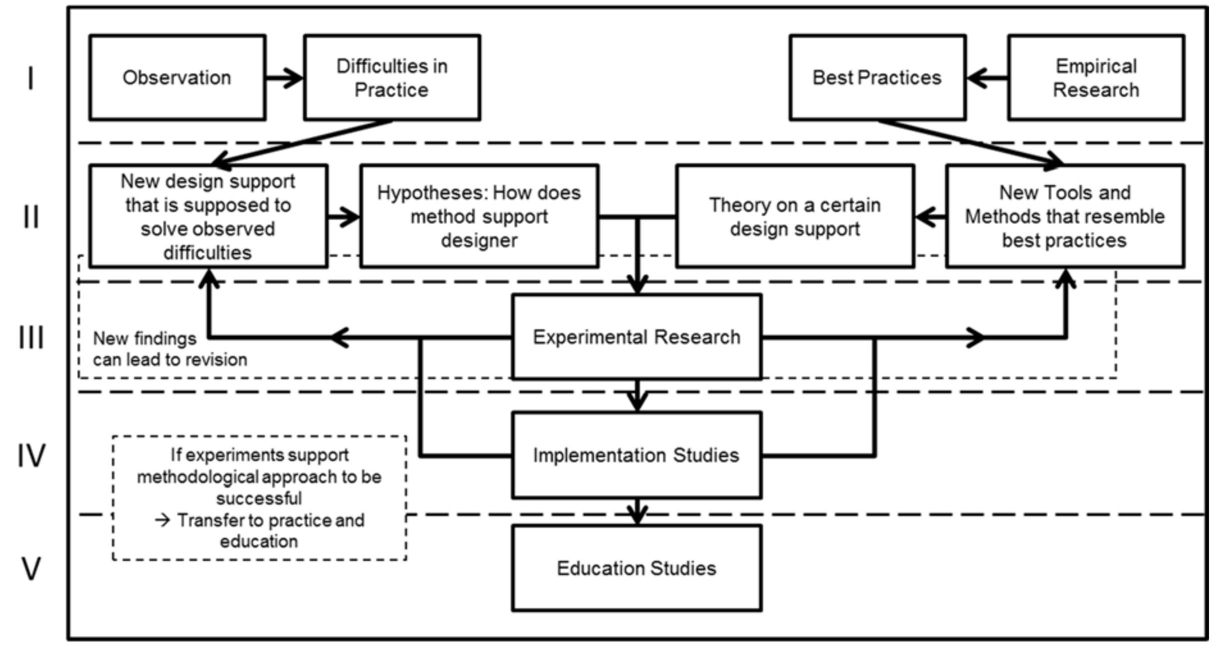

Figure 2. Development of design support

Table 2 shows the five subcategories of design science according to [Cantamessa 2003] as described in section 2.1. The five categories are again found in the five layers of Figure 2.

Table 2. Five subcategories of design science according to Cantamessa

I	Empirical research, in which researchers analyse real-world design processes.
II	Development of new tools and methods for supporting the design process or elements of it.
III	Experimental research, in which researchers purposely set up design processes in a controlled environment.
IV	Implementation studies, in which researchers discuss the real-world deployment of innovative methods and tools.
V	Other, which includes papers dedicated to theory and education.

3.2 Linking the model to DRM

Obviously, a direct allocation between the steps described in the model and in DRM is not possible. Both include iterations and activities during one step. Activities can also sometimes be associated to a later step as well. Identifying success factors before the actual development of the tool can be assigned

to both the development and the later evaluation (DS II in DRM). This is why Table 3 is not aiming to show direct correlation between the two approaches but to point out similarities.
So what [Blessing and Chakrabarti, 2009] describe as “Research Clarification” can in large parts be compared to what happens in empirical research or industrial observation when difficulties or best practices are identified. DRM demands to compare one’s observations to the current state of literature. This is not an inconsistence, since any empirical research can and should be accompanied by a review of literature. The objectives described in DRM’s “Descriptive Study I” deal with the key factors of the support’s influence and integrating them into a reference model as a basic visual layout showing how the support is supposed to help. This is quite comparable to the development of hypotheses on how a method works and includes the first steps of the development itself. This is completed in the “Prescriptive Study”, where also the key factors for a following experimental evaluation are being identified. Finally, in “Descriptive Study II” experimental evaluation is considered together with the next evaluative step, the implementation out of the lab and into a realistic environment.
What is not explicitly part of DRM is the study of how to teach the new design support, although indications for a successful transfer of the support to students might possibly be derived from DS II.

Table 3. Comparing DRM and the proposed model

		Research Clarification	Descriptive Study I	Prescriptive Study (PS)	Descriptive Study II
Observation	Empirical Research	■			
Difficulties in Practice	Best Practices	■			
Support to solve observed difficulties	Support that resemble best practices		■		
Hypotheses: How does method support designer	Theory on the design support		■	■	
Experimental Research				■	■
Implementation Studies					■
Education Studies					

4. Implications for the validation of design methods

We have shown that the model in Figure 2 is compatible to DRM and derived from Cantamessa’s order. The next step will be to derive indications for the main factors to support scientist in the setup of experiments for their evaluation of design support.
As there is different ways, how the development of design support occurs, this will most likely result in differences concerning the evaluation.

Support evaluation for demand driven development of design support

Although it is only a preliminary step for further evaluation, the scenario of demand driven support development, is extremely important. When setting up experiments, it will be crucial for the researcher to understand the cause and effect of the difficulties observed in practice. It might even be helpful to do preliminary testing by trying to resemble the difficulties in an isolated environment beforehand.

Support evaluation for design support derived from best practice

If the methodological support is derived from observation of successful actions, it is by far less crucial to evaluate whether or not these actions offer support. However, in order to generalize, it is most important for the researcher to find out why the actions help the design engineers. So emphasis in this case should be on the study of cause and effect.

Application evaluation for demand driven development of design support

In a demand driven design support, evaluation of the applicability starts with no experience. Some critical questions should therefore be discussed – preferably with the designers with whom the difficulties in practice where observed – before conducting any elaborate experiments:

- In a situation where the difficulties occur, are there sufficient resources available to make use of the proposed support?
- Who would be applying the support?
- Which information is available to that person/team?

Only if the proposed support appears to be within those boundaries, does it make sense to start setting up experiments for the identified target group, with the clarified information and assigned resources. Otherwise, the scientist will be developing a support that will eventually turn out to be inapplicable during the implementation studies in state IV.

Application evaluation for design support derived from best practice

In this case, the researcher can benefit from the prior experience of those, that where being studied, when the best practice was identified. Instead of conducting large experiments, the researcher should present the suggested approach to the design engineers from whom the best practice was observed and inquire whether or not the proposed support resembles what they originally did. If so, the focus of Application Evaluation should not be mainly on the mere applicability but it should be evaluated how well the suggested support is understood and hence applicable by potential users that do not have any experience with the approach yet.

Success evaluation

Being the most extensive and most difficult part of the whole evaluation, Success Evaluation will not be very different whether the support's origin is demand or best practice. Its goal is to find out if the support really does lead to the expected success in a realistic environment. In order to provide valid data and avoid bias, the researcher has to evaluate in several setting (for example different companies). Even though the support has proven to be successful in at least on setting, the setting the best practice was observed in, the benefit for the final evaluation is rather small. However, the researcher can analyse the original setting as a starting point for the evaluation and try to find settings that purposefully vary certain elements. For example, if the best practice was observed in a young, medium sized company, it would be most interesting to assess its usefulness in a young small company, a medium sized company with a long tradition, and so on.

Isolating the activities the support aims at

In addition to the indications that can be gained by taking into account the origin of a design support, it should also be considered, that each design support has a certain purpose and is therefore supposed to support the designer in a limited number of design activities within the engineering process. As the integrated Product Engineering Model by [Albers and Braun 2011] provides an activity based view on the engineering process, we suggest using the meta model in the development of a new design support to describe, which activities the support is supposed to address in what type of engineering process (reference model of the engineering process). This way, during evaluation, this information can be used:

- To identify suitable interview partners and test persons in support evaluation. This will be designers assigned to that particular activity in the iPeM's Resource system.
- To include the right amount of detail into experiments especially for Application Evaluation. Reconstructing what type of information is available at the targeted point in the engineering process, which resources are necessary and interact with which other resources will help to focus the experiment strictly on what should be evaluated, hence reducing real life application to the necessary minimum , making it much easier to control the experiment.
- To identify suitable engineering projects and companies especially during success evaluation. If the proposed design support is described within an example process – a reference model of

the engineering process, the support is supposed to improve – the researcher can use this reference model and search for similar process models allowing for better control of the success evaluation.

5. Discussion

The model presented in section 3 seems promising for several reasons:

Compatibility

The model is compatible to Blessing's and Chakrabarti's DRM so future work does not have to be wasted on determining which model is better, but scientist can focus on the further integration of the model into the more comprehensive approach DRM, thus adding value to the existing DRM.
It seems also compatible to how design research occurs naturally, since the five layers are deducted from Cantamessa's empirical observation. However, Cantamessa's study was published 8 years ago and uses data from more than 10 years ago. It would be interesting to repeat the study with later conferences and also to follow Cantamessa's own conclusions and repeat the study at different conferences, eliminating possible bias.

Usefulness

Although the work presented here only contains first thoughts on how to make use of the model, we could show that it helps organise evaluation strategies on a more concrete level than is provided in DRM. Obviously, more thought has to be put into possible evaluation steps and overall strategies, that have to be tested in exemplary projects that develop design support of some kind. The same can be said about the inclusion of the integrated Product Engineering Model iPeM.

Applicability

In order to make the model and the integration applicable, step by step guidelines and checklists will have to be developed. Those next actions are on the author's research agenda.

6. Conclusion

In this paper, we could show that DRM is a powerful approach and we conclude that its development and presentation to the public was a necessary step for design science, scientist have been waiting for. As is natural in science, other researchers will study a new approach, acknowledge its merits and criticize wherever they see room for further improvement, which is what we tried to do with the suggestions presented here.
Apart from identifying room for improvement, we presented some first thoughts on how to improve design research that will now be developed further and are open for scientific discussion.
We invite researchers in design science to apply the approach and to provide feedback about the value it gives to their research. We want to encourage researchers in design science to structure their work according to either our approach or any of the other approaches presented in chapter 2. Also, we invite fellow researchers working on design science methodology to suggest alternatives to our approach and compare them to existing approaches and our work, ultimately developing one commonly accepted design research methodology.
While this paper is at the current state rather theoretical and primarily addresses researches, we should also discuss its potential impact on education and industry.
What we learned for our design education is that part of the characteristics of any design support is its origin – best practice or observed practical problems. When teaching, it might be beneficial to teach not only the contents of the design method but also to discuss its origin, making the context of applicability more comprehensible for the students. As students are the future practitioners, the teachers of design science should also raise the students' awareness that it could be their future best practice as well as their future difficulties in practice that will lead to new and improved design support hence ensuring the continuous improvement of design methodology.

The message to practitioners is that according to this framework, day to day engineering design work can become the starting point of valuable scientific projects. Both the observation of difficulties in practise and the observation of best practices can be the starting point of a new design support. Therefore we encourage close cooperation between design science and industry. Keeping the two apart too far may just be one of the reasons, why so much valuable research in design science lacks consequent application in practice and remains thoughts and theory. The message to practitioners is that according to this framework, day to day engineering design work can become the starting point of valuable scientific projects. Both the observation of difficulties in practise and the observation of best practices can be the starting point of a new design support. Therefore we encourage close cooperation between design science and industry. Keeping the two apart too far may just be one of the reasons, why so much valuable research in design science lacks consequent application in practice and remains thoughts and theory.

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