

1.2 Motivation: Observations from a workshop on method use in engineering

In an effort to understand which design methods are used, the authors organised a workshop of the Design Society's Special Interest Group on Modelling and Management of Engineering Processes (MMEP) during the International DESIGN Conference 2016. The participants of the workshop were asked to name methods they teach and use during product development and in projects with industrial partners. During the workshop with more than 35 participants from academia ranging from PhD students to experienced professors, interesting observations were made: The participants listed more than 90 items. Many of these were not from engineering (e.g. personas, 6 hats, journey map) and many of the listed items are not what we considered as methods (e.g. CAD, MBSE, PDM, Risk Management, Simulation Models). During the workshop, it became apparent that the participants interpreted the term method in different ways and in a quite flexible way. The inconsistent use of the term by the participants raised the question to what extent the debates about method uptake refer to the same subject matter.

2 METHODS, TOOLS, AND METHODOLOGIES

Much of the confusion comes from disagreements about the relationships between methods, tools, and methodologies. These are exacerbated by differences of connotation in different languages and disagreements about the scope of these terms, and by changes in the meanings of 'method' and 'design methodology' over time.

2.1 So, what is a methodology, anyway?

"If you call it, 'It's a Good Idea To Do', I like it very much; if you call it a 'Method', I like it but I'm beginning to get turned off; if you call it a 'Methodology', I just don't want to talk about it" (Alexander, 1971).

The use of the word 'methodology' as a pretentious word for method (rather than the study of the methods used in a particular discipline) has been common for decades. The use of the terms 'design method' and 'design methodology' has changed over the years. During the design method movement in the 1960s apparently little distinction was made between method and methodology, while the term 'the design method' referred to the overall process of producing a design, considered as a whole.

"... the process of design: a process the pattern of which is the same whether it deals with the design of a new oil refinery, the construction of a cathedral, or the writing of Dante's Divine Comedy. (...) This pattern of work, whether conscious or unconscious, is the design method. The design method is a way of solving certain classes of problem" (Gregory, 1966).

"In recent years some attempts have been made to recognize and rationalize the design approach, and set up a universal and systematic design method (...) Some methodologies cover the whole of the design sequence, others concentrate on important parts of it and may be fitted into other methodologies to improve their probability of aiding the solution of engineering problems." (Eder, 1966).

Eder (1966) appears to have used 'methodology' to refer to a specific, homogeneous strategy, more abstract than a specific method; he describes six, of which 'experience' and 'incremental design' don't resemble methods.

In software development, the word 'methodology' has acquired a distinct meaning over the last four decades or so: a specification of an overarching approach to producing an artefact that specifies what the different activities are, what methods should be used to perform them, how to sequence them, what their information outputs should be, and (frequently) how to describe the information produced at each stage. This usage has become common in engineering, and is adopted by us here, but in both engineering and software lack of clarity and differing views remain as to how formal, detailed and prescriptive an approach to carrying out a design project needs to be to qualify as a methodology.

2.2 A historical perspective on the definition and use of terms

There are multiple definitions for method and methodology; which overlap to a certain degree, but are interpreted differently by different people. The different perspectives reflect the different origins and ambitions of design researchers.

Early researchers in Germany such as Redtenbacher and Reuleaux in the 19th century and others such as Bischoff, Friedrich, Hansen, Rodenacker, Roth, Koller and Hubka (mid to end 20th century) differed in their perspective on design research, thus on design methods and methodology. Different schools of thought on how to do engineering design developed at the different German engineering schools. The

schools differed in their understanding of engineering design as art or as science, which is reflected in the methodologies and methods they proposed. This still dominates current debates. The schools that aimed to treat design research as a scientific discipline similar to other disciplines such as physics were strict methodologists seeking precise and general scientific findings about how to do design (e.g. Rodenacker, Hubka); while the other extreme much more pragmatic researchers (e.g. Redtenbacher, Leyer) argued that designing is not a scientific activity. Between these extremes many design researchers (such as Pahl and Beitz) take a flexible stance on methods and methodologies, with a pragmatic interpretation of methodological contributions. Heymann (2005) provides a detailed overview of the history and evolution of German design research and design researchers.

These differing perspectives on design methods and methodologies are reflected in how different people interpret how methods ought to be used: as strict recipes that have to be applied without modification (strict perspective) or as recommendations that can be adapted if required (pragmatic perspective).

Pahl and Beitz (Pahl et al., 2007, German version p. 784) define a method as a “*systematic procedure with the intention to reach a specific goal*” (in German “*planmäßiges Vorgehen zum Erreichen eines bestimmten Ziels*”).

In the contemporary debate design methodologies are more clearly distinguished from design methods. Hubka (1982) defines design methodology as follows “*General theory of the procedures for the solving of design process [...]. Idealised conditions are usually assumed for the factors [...] influencing the design process and the model is intended to be valid for all types of design problem [...].*”

Pahl et al., (2007) define a design methodology as “*a concrete plan of action for the design of technical systems (...). It includes plans of action that link working steps and design phases according to content and organisation.*”

Other authors do not provide clear definitions of what they mean by method but outline their views by referring to instances of what they call method. While a method is how to do something, views differ on how prescriptive a way to do something needs to be to qualify as a method. Some design educators include any identifiable way to tackle a problem. Cross (2008) summarises all observable ways of working, which can be “procedures, techniques, aids, or ‘tools’ for designing” in the context of product development, as design methods. He uses the term method as a superset of many different entities but distinguishes methods from the term design methodology. French (1999) offers an even wider interpretation including “ideas, approaches, techniques, or aids” but he distinguishes them by maturity and width of applicability. Daalhuizen (2014) offers a newer annotation of the standard English meaning of the word 'method'. “*Methods are means to help designers achieve desired change as efficiently and effectively as possible.*”

Another term that causes confusion is 'tool'. While artefacts like software programs are clearly tools rather than methods, we have heard them listed as methods, implying that people are not distinguishing between using the tool and applying a method. Conversely, the distinction between ways to think and artefacts that support ways to think sometimes gets elided in the use of the word 'tool'. Birkhofer et al. (2002) clearly differentiate between design methods and tools. They classify tools as working aids, i.e. as means that support the application of a method. However, these terms cannot be looked at in isolation. They are used in the context of other terms.

2.3 A need for clarity

These definitions show that the terms method and methodology are used with overlapping meanings. While design methods are commonly seen as a subset of design methodology, it often remains fuzzy what is meant by the term method and how a method is different from a tool, a guideline or a heuristic. Even though the interpretations of the terms have changed over time and amongst different schools of thought, it becomes clear that they refer to different entities. As more and more research on methods was published, the heterogeneity of methods, tools and thinking aids increased, thus new terms were used in order to distinguish between different types of products produced by research on how to support designers.

A greater clarity about what various methods, tools and thinking aids offer would benefit various audiences: by aiding clear communication among design researchers; by facilitating the evaluation of design research by clarifying the claims made by the research; enabling the assessment of the appropriateness of the evaluation approach; and through the transfer of research results to practice.

3 METHODS AND TOOLS IN THE CONTEXT OF OTHER CONCEPTS

The need for clarity is increasing, as industrial practice is changing away from monodisciplinary products to multidisciplinary products. As a community, we need to engage with the terminology of related fields like software and electrical engineering, as design teams are usually multidisciplinary. Blessing and Chakrabarti (2009) draw the following conceptual distinctions to guide designers and to improve design practice as design support.

- Design approach/methodology.
- Design methods (different classes of methods distinguished depending on their primary purpose, e.g. methods for analysing objectives and establishing requirements, methods for evaluating and selecting support proposals).
- Design guidelines (including rules, principles, heuristics).
- Design tools (including hardware and software).

In the following (see Table 1) we propose descriptions of selected central terms and explain their interrelationships based on a review of relevant literature from engineering design and computer science. By this, we aim to represent the current interpretation of the terms as they are predominantly used for teaching and in literature that is read by scholars and industry experts alike.

Table 1. Explanation of central terms

Term	Explanation
Design methodology	In design, a clearly and explicitly articulated approach to producing designs for a class of systems, that specifies in more or less detail the activities to be carried out, the relationship and sequencing of the activities, the methods to be used for particular activities, the information artefacts to be produced by the activities and used as inputs to other activities, and how the process is to be managed, as well as (tacitly or explicitly) the paradigm for thinking about the design problem and the priorities given to particular decisions or aspects of the design or ways of thinking about the design.
Design process	In design, (1) A formally specified sequence of activities to be carried out in developing a particular design, or a class of designs, which will often be an application or customization of a methodology to a particular problem. (2) The actual sequence of activities carried out in the development of a design, which may correspond more or less well to any formally specified process.
Design method	A specification of how a specified result is to be achieved. This may include specifications of how information is to be shown, what information is to be used as inputs to the method, what tools are to be used, what actions are to be performed and how, and how the task should be decomposed and how actions should be sequenced.
Guideline	In design, a statement of what to do when, or what should be the case under particular circumstances. A should only be violated for good reason, with a careful consideration of the consequences.
Tool	An object, artefact or software that is used to perform some action (for example to produce new design information). Tools might be based on particular methods, guidelines, processes or approaches or can be generic environments that can be used in conjunction with many methods.

Thus, a design methodology is an approach that combines methods, guidelines and tools, each of which can exist individually, according to a process that organizes design activities, and the use of the methods and tools (see Figure 1). The application of methods and guidelines, and the organization and performance of the process, can be aided or enabled by the use of tools.

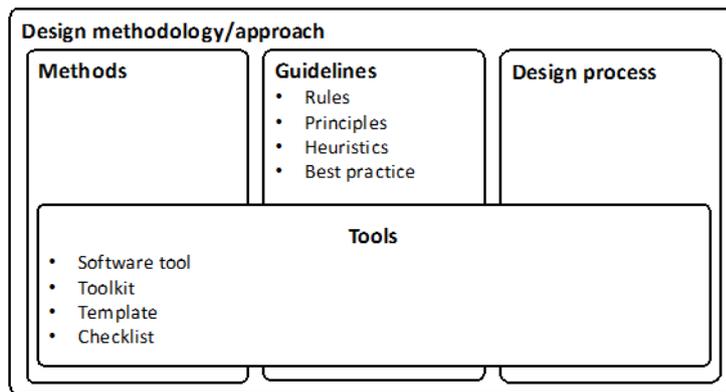


Figure 1. Relationship between central terms

4 WHAT WE NEED TO SAY ABOUT A DESIGN METHOD

Methods are proposed and interpreted with different degrees of prescription from procedures that need to get followed exactly to a loose collection of heuristics. In the strictest sense of a "foolproof" recipe, it becomes necessary to prescribe each of the steps precisely, unambiguously and in sufficient detail to assure that the method can be followed by everybody with a clearly articulated level of experience. If a method is interpreted as guideline or heuristic, then it is left up to the user to decide whether they want to adopt all or some of the aspects of the method.

What the method is intended to produce can range from possibly useful insights into a problem, to identification of requirements or evaluations of particular characteristics of a design or generation of potentially useful solution fragments, to rigorously justified design solutions. This is tightly bound to the theoretical grounding of the method and the claims made for the outputs of the method, as well as to the strictness of the procedures. It is also tightly related to what constitutes success for the application of a method, and how the method can be validated or demonstrated to have succeeded.

Most descriptions of methods do not make their theoretical claims and the level of prescription explicit. However, the following information, providing the rationale for method application, would be required to assess suitability and to apply a method:

- *The scope of a method:* What situation or product type is a method intended for? For example, many method descriptions make claims in terms of "design" or "engineering" in general, while others are targeted at particular sectors like automotive or aerospace. It is also often not clear whether methods are intended for use in original design, incremental design, or all design situations. Tacit assumptions about what designing involves are not articulated, and domain specialists may underestimate how different other kinds of design are.
- *The coverage within the scope:* Is the method applicable to all problems in the scope or only to some? There might be particular situations where methods are not applicable or required information might not be available.
- *Benefit expected from the methods:* The utility of a method can also vary from completely solving a problem to provide helpful insights. This of course varies with the situation in which methods are used.

The description of the intended use for a method is complementary to the description of the method itself, which comprises the core idea of the method, the representations in which design information is described, and the procedure (see Table 2). Core idea, representation and procedure build on each other (see Figure 2) and form the method, thus the method description should provide the necessary information about each element of the method as well as information about any tool implementation of the method if available or required.

The method description should provide, beside explanations of each element of the method, information about possible adaptations of representations and procedure that allow the method's use in different contexts, as well as information about the required rigour in the application of the method. Some elements of a method might allow adaptation while other elements should not be modified. Method users should be informed about such options and limits of adaptation.

Table 2. Explanation of terms – elements of design methods

Term	Explanation
Core idea	The basic principle, technique or theory that the method employs.
Representation	An object or other artefact that shows and stands for a target system, i.e. intermediate results and deliverable created by using the method.
Procedure	A description of the actions required to apply a method, for enabling the user of the method to do something more easily or with a sufficient guarantee of correctness, focusing on the sequence of actions and their completeness.
Intended use	A description of scope of a method, the coverage within, scope and expected benefit from using the method, informing the user about suitability of the method for a particular design task in a specific context.

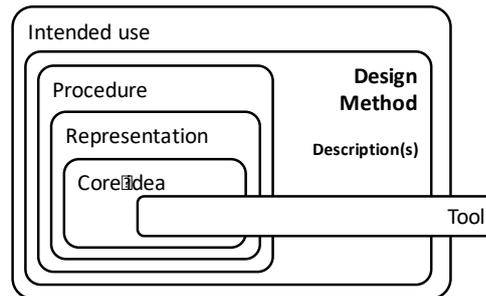


Figure 2. Elements of a method and relationship to its implementation in a tool

5 IMPLICATIONS

The understanding of the concept of method has a profound effect on how a method is validated and used. Validation is or should be crucial both for establishing trust in a method and establishing what trust is appropriate. As Barth et al. (2011) point out validation is a problematic area in design research with many papers offering no validation at all. Frey and Dym (2006) point to a comparison to medicine to draw lessons for the evaluation of design methods; however different elements of methods and methodologies embody different types of knowledge and should thus require different approaches to validation drawing on both natural and social sciences.

5.1 Implications for validation

Vermaas (2016) points out that many methods are formalised descriptions of expert behaviour augmented with tools and representations. This does not imply that other experts can apply the method successfully, as the expert behaviour includes assumptions about the nature of the problem and tacit skills in problem understanding that are not articulated. The method user's assumptions and skills need to fit the method. The formalized descriptions seldom give an indication of the scope, coverage or benefit of a method.

The different elements of a method (see Figure 2) affect how a method can or should be validated. To a certain extent they need to be validated separately. Eckert et al. (2003) propose that the empirical studies informing a method, the theory underlying a method, tools based on the theory, and the introduction of the theory in industry are evaluated separately according to the research methodology of the academic discipline that informed that particular aspect of the research. For example, that a computer tool needs to be validated with software engineering methods.

DRM (Blessing and Chakrabarti, 2009) provides guidance on how to validate research on design methods. However, the design research community is still lacking well-established research methods and consensus on how validation should be executed and what evidence needs to be provided to claim successful validation of a method.

Most design methods are published with illustrative examples while some have been applied in industry on a particular case, which gives no direct indication of the scope, the coverage, or the benefit of the method. Many research papers do not even attempt to validate their findings (Blessing and Chakrabarti, 2009). The main problem here is that academics need to publish papers both to communicate ideas and

to benefit their careers, but seldom have the opportunities they need to test methods on real industrial problems.

For successful methods, such as TRIZ or QFD, a picture emerges over multiple publications by the authors or other researchers of the scope, coverage and benefit of methods. However, in the absence of a culture of publishing failures, it is still not clear what lies outside the remit of the method. It is also often not clear to which extent methods have been deployed in full or whether just elements are used. For example, DSMs are widely used (Eppinger and Browning, 2012), but some applications just use a basic DSM as a convenient representation of relationships, whereas others make use of algorithms to analyse and modify the relationship between the elements or use dedicated DSM tools.

This makes the validation of design methods very different to the validation of engineering products designed by the potential application of methods, where companies take great care and effort to assure that a product works under multiple use and misuse conditions.

A validation of a method through a successful application can show the effect of a successful application, but if the application fails it gives little indication of which aspects of the method succeeded and which have failed, which can be any of the elements of Figure 2.

Even if the core idea of a method is sound and potentially helpful, without suitable accessible representations it can be difficult to use. Different users or user communities might well need their own representations. Understanding the procedure of a method and what each step contributes to the result is an important part of applying the method, because users need to see the merit of applying each of the steps, otherwise they cut corners and leave out parts that are required for the overall result. Understanding what each step contributes is also needed for customizing the method in sensible ways. Users of methods also need to be enabled to use the steps that they personally find useful.

As argued above, methods are often created for a particular context and purpose which the users need to understand. The intended use needs to be articulated to inform users about the suitability of a particular method in a specific context. Over claiming (or not explaining) the intended use is detrimental for the method's validity and uptake by industry. However, many methods have been applied completely or partially in totally different use contexts and thereby expanded the scope of the method. It is easier to expand the claimed scope, coverage and benefit of a method supported by empirical evidence afterwards, than justifying an overly broad claim right from the beginning.

Ideally, creators of methods would set up validation exercises for each element separately, working their way outwards from the core idea of the method. Similarly, tools can be seen as artefacts in their own right, which need to be validated for their multiple application contexts.

In conclusion, the validation of methods has to be an iterative process, whereby different aspects of the method need to be assessed separately. At each stage, it is necessary to look at the scope, coverage and potential benefits of a method. From an academic perspective, it is also important that the different methods are clearly related to existing literature as different methods can have common elements; for example, the idea of modelling flows or working surface pairs occurs in several methods, similarly DSMs are used as representations in multiple methods; and methods use common tools.

5.2 Implications for users in industry

An important question is, when can we (design researchers) say that a method is used in practice? What qualifies as method uptake by industry? As long as we do not have a consensus about this, we will continue to have the debate about our influence as a community on design practice. While, based on a strict interpretation, the application of a modified form of a method might be assessed as not successful, a more pragmatic or flexible interpretation would assess such an application as a successful implementation, understanding the adaptation as a matter of course instead as a proof that a method does not work in the way it was published. A clear articulation of the intended use complementing the method's description would ease the validation, as the target audience, required rigour, allowed adaptations and expected benefits would be clearly defined, thus validation would rely less on interpretation.

From an academic perspective, success consists in our methods being used in industry, whereas industry is most interested what they can achieve through the application of the methods. For industry, the application of methods - like most other activities - is a matter of cost benefit analysis. Very rigorous and time consuming methods only make sense to use when they guarantee to bring benefit or solve an immediate problem. Practitioners also need to see a clear benefit of going through all the stages.

Anecdotal evidence from practitioners (e.g. during MMEP SIG workshops) indicates that the use of methods is often abandoned in a number of situations:

- When the immediate problem has been resolved through the application of parts of the method.
- When the method does not deliver an obvious benefit.
- When they run into difficulties in applying the method.
- When the method becomes tedious, for example building a complete model of an entire product or product family.

The first point can be seen as a success of the method; while some methods are explicitly intended as ways to generate insights, this can also be the chief benefit of using methods intended as systematic procedures for generating formal problem descriptions or solutions.

While methods may simply be ineffective or not cost-effective in use, the second and third issues can point to problems in the descriptions of the intended use. If method users cannot see the benefit, this benefit might not have been explained properly to them. Difficulties in applying methods can arise from many sources, for example if it isn't clear which steps can be taken at any point, which could be dealt with in design guidelines. The fourth issue may arise if costs and benefits are distributed unequally or delayed too long: people have a strong and entirely rational aversion to putting in effort for which they get no reward, so getting people to accept effort-benefit mismatches requires strong commitment from management. Convincing people of the benefit of a method is even harder when the benefit would come in later stages of the project or in a following project.

Industry is also most persuaded by other industry using the methods. Therefore, being specific about how and where the method has been successfully applied might help.

6 CONCLUSION

Although design methods are crucially important to product development in industry and absorb a large amount of academic research effort, industrial adoption of academic efforts to improve the efficiency and effectiveness of engineering design practice is disappointing. One way in which academic methods researchers can improve the situation is by making clearer claims about the scope of new and existing methods, what results they produce, the benefits they should achieve, and how flexibly they can be stripped down or adapted to the needs of different projects.

The explicit adoption of a clear and consistent set of terms for method-related concepts will help with this, as will a more carefully differentiated set of concepts. This is important for the communication of research results to industrial engineers, including the management of expectations for what methods can achieve and the determination of appropriate ways to assess and validate new methods.

A longer-term objective for engineering education is to improve the understanding of methods research by developing a clear and consistent understanding of concepts and terminology among engineers.

Method users in academia and industry alike need, besides a clear description of the method itself, a description of the intended use and expected benefits - including explicit and tacit understanding as well as tangible outputs - otherwise methods might be used without creating the expected benefit, which could harm their reputation even though they would be useful in other contexts. Articulating the scope, coverage and benefit of methods provides a means for the research community to validate such claims individually and for industry to select suitable methods and to provide feedback.

As a community, we expect that research results such as new methods are carefully evaluated before being published. However, we are still struggling to find consensus about proper research methods for evaluation and qualifiers for uptake of methods in industry. A differentiation of the elements of methods provides a means to break down the validation of methods into smaller chunks, enabling the publication and communication of results without over claiming the maturity of the methods (that is, their readiness for use in industry).

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