In Search for the Right Tools to fix the Right Problem: A Look into the Challenges of Collaborative Design

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Abstract

Problem solving and design tasks are quite common across industries; as problems grow more complex and systems grow larger, design becomes increasingly a collaborative task. Design in itself already is challenging but collaboration adds its own challenges to the mix. In this paper, we explore the challenges of collaborative design. We approach the research question through design research framework as we synthesize the knowledge base and expert experiences to propositions about the challenges of collaborative design. We contribute to the discussion on collaborative design and we enable further research on how to support collaborative design activities.

1. Introduction

As systems become increasingly complex, their design requires collaboration between various domain, process and technical experts. Also the rise of stakeholder-thinking has propelled collaborative design [2][20][33], and in the interest of including different viewpoints, often policy officials and experts, as well as members of operation crew, management and economic experts and investors can be included in the process. Especially in information systems, it is also critical to involve the user and customer in the formulation of sound requirements and functional specification [3].

Design as such is a challenging activity. Starting from the beginning of design cycle, finding the real problem and a representation to make it transparent for all parties concerned is a challenge in itself [12][29]. Generation of the solution or artifact is not a task to be taken lightly, especially when the design deals with complex systems [32]. Scientific aspects of design, such as validation of the artifact, and theory building, offer another source of methodological and conceptual challenges [19]. In addition to design challenges, group work and collaboration themselves tend to be difficult. Collaboration requires additional organization, negotiation and building of shared understanding on the issues concerning the design. Further, design is also frequently supported with tools and environments, which have not been developed for collaborative work.

The contribution of this paper is to enhance understanding of collaborative design and the specific management challenges associated with it. The paper provides a base for developing means and practices to achieve better design results. We aim to address the problem by seeking answer to the question “What are the challenges in collaborative design?”

We approach the subject through the design research framework presented by Hevner et al. [19]. The framework prescribes that design research should be attached to both the surrounding environment and previous knowledge, as described in section two. In the third section, we establish a knowledge base through a literature survey. In the fourth section, we tie our research to the surrounding environment through interviews with expert designers and researchers on collaborative design. Following this groundwork, we analyze and interpret the result, and forge our proposition about the challenges of collaborative design.

2. Research design

Our research objective as stated in the introduction is to understand the challenges of collaborative design better. We aim to use this understanding to provide a base for designing tools to facilitate collaborative design. We position ourselves to design research, even though this study is an intermediate, descriptive, step and does not result in a concrete artifact. Design science can be characterized as formulation of valid prescriptions on how to develop methods [24], design theories [25] or classes of artifacts [24] (including constructs, models, methods, or instantiations). In our case, the product will be closest to a conceptual model.

Hevner et al. [19] presented a framework for design research, in which they aim to combine rigor and relevance by proposing that (design) research should
be firmly grounded in the knowledge base, as well as in the environment. We understand the knowledge base as accumulated literature, theories and established ways of conducting research within a discipline. Using these resources, the designer ensures the rigor of his or her design. We understand the environment as the business world, and the experiences ‘the field’ has accumulated over the years. The field is the other facet of design research, and enables the grounding of the research to the reality faced by practitioner in their routines. This ensures the relevance of the research. Both are important for design, as design as scientific activity is not only problem solving, but it is also about applying existing knowledge through a structured methodology to solve an existing problem as Cross [9] puts it.

In this paper, we will examine the body of knowledge through a literature survey, and conduct interviews to examine the environment, and analyze and cross-evaluate the findings to forge our propositions. Although we will contribute to the knowledge base, our research is a step forward to design concrete artifacts to support collaborative design. We propose that that our results can be used in building a tool set for collaborative design, as we do describe the phenomenon of collaborative design and the challenges therein, and assert some basic inference between the described challenges and previous findings.

We started the search for challenges in collaborative design by surveying literature on design. To conduct our analysis we made a query to the ISI Web of Knowledge (www.isiknowledge.com) database to retrieve a dataset for analysis. We chose the ISI Web of Knowledge as it represents a reasonable cross-section of ‘high-quality’ journals, and it interfaces with the tools we used for further analysis. The dataset was retrieved with the keywords “design science” OR “Design research” OR “design theory” in topic, keyword or abstract. Before exporting the citation data, the dataset was narrowed down by concentrating on social, information and computer sciences, excluding sociological and political studies, as well as medical and life sciences. The resulting initial dataset was 189 articles with over 2000 references.

We used the surveyed dataset to recognize a set of most influential works on design and choose a set of 45 articles with 5 or more citation to further analysis. The survey results acted as a base, where we selected some publications and continued to snowball more literature as the coding proceeded. To find emerging patterns, we started coding the literature. In this meta-analysis we employ a basic content analysis technique, where we gather constructs from the literature to an existing classification to systematic reduce the textual material [23][36]. The basic coding of the literature was done by one of the authors, inspected by others, and the subsequent analysis and conclusions were based on the coding and discussions between the authors. The question we posed to analyze the data, was “what are the challenges of collaborative design?”

To tap into the experiences in the field, we chose to interview design experts. The secondary benefit from the interviews is that a literature study is by nature a description of past, while the interviews give a better view of the current challenges. The interview subjects were chosen among people who were known to have experience on design as researcher, practitioner or both. After the selection of initial interviews we continued by snowball sampling, by asking the interviewees who they think would be appropriate. The interviews were also administered by one of the authors and recorded or noted. To enable comparison and cross-evaluation of the results, we use the same methodology and coding to aggregate and analyze the interviews. In this stage of the research, we did not transcribe the interviews, but coded them straight from the tapes or notes instead.

3. The knowledge base

Group work has many forms, and the level of commitment can vary substantially between settings, depending on the motivation, goal congruence between the members, and general level of interest and invested stakes. Wood and Gray [37] emphasize shared rules in collaboration as they write “Collaboration occurs when a group of autonomous stakeholders of a problem domain engage in an interactive process, using shared rules, norms, and structures, to act or decide on issues related to that domain.” Elliot’s [14] definition is more oriented toward shared understanding “the process of two or more people collectively creating emergent, shared representations of a process and or outcome that reflects the input of the total body of contributors.”

Design can be also defined through the process or the product, just as the two definitions of collaboration represent two slightly different perspectives. Design in general is about creating an understanding and definition of a problem and solving through a process of generating solutions and testing them to find the most suitable (e.g. Simon [32] for general discussion).

Thus collaborative design can be described as ‘the process of two or more people collectively creating shared representations of a problem and alternative solutions that reflect the input of the total body of contributors in a interactive process, using shared rules, norms, and structures, to act or decide on issues related to searching for solutions, building artifacts and
validating them.’ We therefore define collaborative design generally as “purposeful joint effort to create a solution to a problem”.

Beside design, collaboration as such contains a myriad of challenges [26]. Different experts who collaborate might represent different stakeholders in the market, and thus conflict can arise, but it is still important that the opinion and knowledge of each of these stakeholders is taken into account. Further, shared understanding in general is a problem when expertise among participants is non-overlapping [35]. On the other side of the spectrum, groups with a shared objective can get a tunnel vision of a problem when people are not critical but confirmative, resulting in a phenomenon described by Janis [21] as ‘Groupthink’ which can be defined as a state where the group’s strive for unanimity and consensus impedes critical consideration of alternative solutions.

Another key challenge in collaboration is information overload. When more expertise is added to the collaborative task, more perspectives are accommodated; and more information needs to be assimilated by the participants. While structure and summarizing can resolve such overload, groups do not always have sufficient shared understanding to agree easily on the use of a framework or structure for their collaborative effort.

An additional set of challenges occurs when groups do not only have to perform a task jointly but also have to make decisions or choices. Decision making in groups can be challenging, as both rational arguments and preferences of stakeholders can be different given their different stakes, expertise and role in the collaborative task. Consensus building in groups is challenging as actual disagreements can be obscured by differences in understanding, knowledge and mental models around the different proposals that the group has to consider [7].

3.1. Analysis of literature

We use a two dimensional classification to code the knowledge base. The first dimension relates the challenges to different phases of a general design process. Literature describes or prescribes a number of design processes, e.g. [1][13], which can be summarized as being (1) problem definition (including problem definition and analysis), (2) generating an artifact or multiple artifacts, for (3) testing and validation, after which (4) implementation and sustained use in the target system or organization needs to be supported.

We have supplemented the sequential division to design process phases with classification built on the levels of design presented by Dorst [11], who discussed the different perspectives to design and outlined the basic levels of analysis concerning the science of design. The levels are (1) the object or artifact that is designed, (2) the context to which the object is designed and where it is supposed to function, (3) the actor or actors who design, and finally (4) the process and methodology for design.

The remainder of the section is structured around the process phases and each sub-section underlines the challenges we identified from the literature.

3.2. Problem definition

The problem definition phase defines the design process and the subsequent content. Many of the challenges pertain to understanding the problem and developing a representation upon which all involved parties can agree. In fact, the main theme even at this stage of the process is to develop a shared understanding and a common language for the rest of the process.

1) Object of design: The major challenges in relation to the object of design are to find a joint and mutually acceptable problem definition. For this, it is necessary to create a shared understanding about the problem and integrate multiple perspectives. These challenges become visible in shifting, evolving goals [32], the notion of a holistic outlook on the problem [2] and the problem in finding the users as well as identifying their needs [25].

2) Context of design: A great challenge which relates to the context is the ambiguous, wicked, nature of problems [29][32]. The complexity of the situation makes it hard to identify the real problem owner [32] and often results in conflicts of interest, difficulties in developing a consensus on the problem and goals [8][29]. Finding the limiting resource and other design constraint [32] is a challenge which associates with framing the problem and finding the stakeholders.

3) Actors who design: Especially when considering collaborative design, developing a strong client/stakeholder orientation [2] plays a key role on later commitment and ownership to for the design [4]. Different interpretations of the design problem or specification [12] can be linked with misunderstandings because of insufficient overlap in experience and lack of shared context and language.

4) Design process and methodology: Considering the challenges above, a key issue in the process is focus in establishing the right specification [2] from the start. Developing the specification may require developing representations for design object and methodology [19][28][32][34]. While developing the problem representation, there is also the trade-off between achieving representational simplicity and
usability, and oversimplifying things, ‘assuming away’ aspects of the problem [19]. Beside the conceptual challenges, there is the practical challenge of involving stakeholders in the design and problem definition [2][4]. Following the specification there is a need for design strategy for the rest of the process and criteria for design iterations [22].

3.3. Artifact construction

During construction of a solution to the previously defined problem, the challenges continue on the same track. Many challenges encompass the need to balance the different needs expressed by the stakeholders, and to develop a solution which can be implemented with confidence that the intended effect is achieved.

1) Object of design: An important challenge is addressing the effect of the design to the behavior of the user [4] and the ripple effect of the design to surrounding systems [32] through interfaces and interdependencies between systems and components. The interface effect [16] can also cause a gap between the designed function and actual behavior of a system. Also, orchestrating the design of a large scale system with sub-systems [32] is a demanding task.

2) Context of design: The context presents concrete challenges when abstracting the environment and finding criteria for satisfying solutions [19] and prioritization of different stakeholders’ needs [12]. Finding proper kernel theories and other foundations for the design [19][25] is an important part of design where context also has a role. Goal shift often the shift continues after the initial specification is locked, and poses challenges for constructing the artifact.

3) Actors who design: The most apparent challenge is to manage co-evolution of the problem (interpretation) and artifact [12] while maintaining adherence to the original specification. Also the human condition poses challenges in finding the solution, and often designers failure to develop multiple alternatives, and stick to favorite theories or “marry the first option” [2][16].

4) Design process and methodology: Methodological challenges mirror the other levels of analysis, as the method is supposed to enable establishing logical linkage between design features and requirements [22]. Proper decomposition of the problem representation and choice of proper means to support the design is also an important challenge [19]. The means can include development of sufficient representation to implement the artifact as intended [2] and effective (ad-hoc) search heuristics for solutions [12][19].

3.4. Testing and validation

The testing phase is for testing the solution or artifact for completeness and ability to solve the problem. The challenges in this phase are more technical in nature when compared to the conceptual challenges in previous phases. The challenge amounts largely to collecting enough data to pre-validate the artifact and to do the testing in a rational manner without playing favorites between possible alternative solutions. Compared to testing, validation is a more formal and stringent evaluation, to ensure the artifact lives up to the specification in terms of features and performance. Here conceptual challenges are rare, and concern mainly the question whether the artifact represents the design accurately or not. The practical challenges deal with finding proper techniques for validation as well as finding criteria and metrics to judge whether the artifact is valid.

1) & 2) Object and context of design: The first challenge is ensuring that the artifact embodies the problem representation and the chosen kernel and design theories sufficiently and that the context for validation is realistic enough [19]. A large challenge in testing is to encourage users to use the system long enough to gather data for testing and validation [25]. Equally important is to create consensus on the validation before the fact and to choose proper metrics and methods to evaluate/validate the artifact [19].

3) Actors who design: Just as well as rationality may fail in elucidating and interpreting the requirements, failure may occur while evaluating the solution [2] especially if they have some favorite feats of some of the collaborators. The same need to overcome bounded rationality is associated with assessing the effects of the design [32].

4) Design process and methodology: On methodology level, the main challenge is the selection and application of proper methodologies to validation [19], as well as developing a set of performance and evaluation criteria to judge the success of the design [2] in a way the collaborators can agree upon. The methodological challenges again are associated with the other levels, like developing performance and evaluation criteria to judge the success of the design [2] to support rational evaluation of the solution. Also ordering design iteration if performance objectives or behavioral patterns shift from expected [22] may prove to be a challenge.

3.5. Implementation and sustained use

The last phase is the least documented in the examined literature. The challenges are nevertheless quite important considering the sustainability of the solution or artifact. Starting from the challenge of implementing
the artifact in a way that ensures the intended features will emerge might be a major challenge in practice. Overcoming resistance to change may also connect to other challenges, as ownership and general willingness to use the artifact can conceivably influence the behavior of the artifact.

1) Object of design: In implementation and use the main challenge is to specify the artifact and its implementation in such a representation and with a degree of detail in design specification for the intended features to emerge [2][19].

2) Context of design: Here, the challenge is to ensure that the realized artifact resembles the design [2]. Traditionally, resistance to change in the target organization [8][25] has been a major challenge and important aspect is getting commitment to the artifact so that the organization can “learn to perform” [2] and adapt its structures to accommodate the new artifact. Resistance to change and inaccuracies in representation can also cause deviation between designed function and the systems behavior [16]. The interface issues mentioned above can be realized in implementation, when the artifact has to interact with the existing organizations and systems.

3) Design process and methodology: The challenge of building ownership for the design [4] can be also seen as a challenge for the process. Also creating consensus behind implementation decision and methods is an important challenge.

4) Creating understanding: ensuring shared understanding and mental models of the problem, current state of the system, and envisioned solution.

5) Satisfying quality: balancing individual requirements and joint quality constraints while making design choices

6) Balancing rigor and relevance: using methods that support both stakeholder involvement and design discipline.

7) Organizing interaction: effective organization beyond project management, facilitating interaction between the actors, achieving rationality in the process and finding ways and means to work effectively

8) Ensuring ownership: implementation of the design to an organization, and transfer of ownership.
4. Tapping into the environment

To collect insights from the environment and learn about the experienced challenges in design we interviewed 5 experts in design and design research. We prepared a list of themes and reserved an hour for the interview. In practice, the interviews lasted between 25 and 45 minutes. Details of the interviewees are as follows:

1. An experienced researcher with background in plant design
2. An experienced practitioner with experience in an engineering company turned researcher
3. An experienced researcher with a background in design research
4. A researcher with experience in collaborative modeling
5. A researcher focused on distributed design collaboration

The interviews were recorded, bar one of them, and interpretations of the interviewee statements were coded from tapes or notes straight to the 2-dimensional framework presented for the literature study. Next, we present the interviews in the same format as above. To distinguish from literature citations, we indicate refer to the interviewees by number in parentheses. We elected to use interview quotes to illustrate the challenges.

4.1. Problem definition

The general outlook to the challenges is similar to the literature analysis, but the interviewees seem to be more stakeholder-oriented. The first phase of the process receives less attention as perhaps expected.

1) & 2) Object and context of design: One interviewee (4) in particular stressed the importance of holistic problem definition in modeling context when saying “...an enterprise is a combination or a network of many functions enterprise processes are crossing boundaries of several units and functions ... to truly capture the details of workflows, of business processes you have to involve many of these users from different departments...”.

3) & 4) Actors and design process: Considering actors, the main challenges are involving the stakeholders (4) and organizing the design workflow (2) and the meetings (4). One aspect is that collaboration may be quite superficial if the collaborators do not have common interest or other incentive to contribute (5). The challenge of finding a common language and problem representation arises in the actor level again in modeling context (4). On the process level, the basic challenges are agreeing on how to organize the process (1), arrange for and facilitate meetings (4) and which design approach or tools to use (5). The challenge of tutoring people in the use of tools and possible modeling expressions (4) also mirrors the general challenge of establishing common language.

4.2. Artifact construction

Considering challenges in constructing the artifact, the interviewees’ outlook was perhaps more practical and process oriented than the literature. Much of the identified challenges can be characterized as organizational, management and communication challenges.

1) & 2) Object and context of design: The first challenge that pertains specifically to the object is the division of the holistic description to manageable sub-problems (2) to be solved by individual designers. A challenge specific to large scale design is that the design in fact may have effect on the environment to the same degree the environment affects the design (1) which also relates to assuming a holistic outlook to the problems.

3) & 4) Actors and design process: In real-world design, trust building is important to get the stakeholders to share important information (1) “I think the main challenge [in collaboration] would be to have enough trust between the participants that will make them share enough information to create a design...” A formal part of this trust building is agreement on confidentiality and privacy measures (1). Not to forget equal treatment and possible ego issues in negotiations (2). One interviewee also pointed out that in some cases the properties of the artifact can depend completely on negotiation between stakeholders and the scale of the project may prohibit comprehensive redesign (1) “…typically you would talk to stakeholders at the beginning ... get their requirements in ... and get back to then with your conceptual design or your first prototype ... it’s impossible for these large scale things ... it totally depends on their behavior what type of technical structure emerges. It’s impossible to go back to the drawing board to create the design.” On the process level, the designers also face the challenge to remain open for new ideas and ways of working instead of sticking to the routines and recycling old solutions (5). A more practical challenge is integration of the processes and systems of design collaborators (1) and establishing workflows to use the tools effectively (2). The issue of workflows arises especially in collaborative context, as the tools are often not designed for collaboration and especially the more complete design methodologies can be perceived as restricting by the designers (3). The individual designers collaborate and communicate with different
intensities during the process, and the design approach or toolset should support these different modes (5) “[the challenge is] to facilitate that designers can use design methodology more effectively during the design process, but the problem is that the moment when designers need … or would need methods, they are kind of unpredictable as well. … Even when people make kind of a plan for [design methodology] designers deviate from these plans, every moment they think they have kind of a quicker route to somewhere.” A challenge common to actor and context levels is choosing representation and illustration of the design so that the stakeholders will understand the features and are able to evaluate the design (2) “…large [challenge] would be that people experience things differently about how to solve a problem, and you have to convince them that a certain way is the best way … in our case we could provide them with animation with measured data to show to show impossibilities… ”. Choosing tools and methods is especially challenging, as people tend to make decisions and design iteration outside formal processes and may actively seek shortcuts to the process to achieve the goal quicker and easier (5) “... the problem in practice would be that it is pretty unpredictable … when these [collaborative decision making] situations occur and I also think it is hard to identify when they occur … because a lot of these decisions are not made in a formal meeting … Usually it happens over a little bit longer period when people just meet informally …”.

4.3. Observations and summary of the interviews

Consistent with the literature, the challenges in the interviews seem to be concentrated mainly, almost solely, on the first phases of design. This might be an indication of a ‘researcher bias’, that is, given their role, interviewees did not have broad experiences in validation and implementation.

In particular one of the interviewees illustrated the benefits of collaborative design with an example how development of an enterprise model took several research visits and iterations during a lengthy period of time, while almost the same result could be achieved through a workshop involving the problem owner and stakeholders. The modeling example also illustrates the importance of shared language between the participants. According to the interviewee, the experience is that the collaborative modeling effort takes some orientation time for the people to get used to the ways of working, but also to be able to express their ideas through modeling expressions.

A fresh perspective to the process came from a design scholar who pointed out that in practice many design tasks are collaborative at least to some extent, so the methodologies and tools need to support different modes of working. A major challenge for management of the design process is that designers tend to look for shortcuts to achieve the design, and use familiar methods, which creates an element of informality in the practical design processes. The ensuing challenge is that too rigorous design methodologies may be detrimental to achieving project goals. Therefore, the choice of design tools requires satisficing, finding a way of working which does not obstruct creativity but does support timely completion of the project.

A phenomenon that we only found in interviews is that decisions tend to shape in peoples’ minds and in informal settings. This can create a paradox as key decisions are often formally made in structured meetings, but instead the meetings may be seen as venues to broadcast the decision and to justify it after the fact. This makes it hard to predict the need for support tools in a given process. Further, tools and methods for design can be regarded as restricting to creativity, cumbersome, not well suited for group work or collaboration and not flexible in terms of workflows. As a specific requirement, this might mean that there is a need to support continuous collaboration and communication in a more general way, besides the GSS-type tools which are often used to accomplish a specific task by specific people in a given time [6].

Where the literature was perhaps more problem oriented, much of the challenges indicated by practitioners have to do with keeping the design effort purposeful and collaborative, to borrow wording from the definition. To summarize the interviews in similar themes as the literature, we present the following list:

1) Organization and management of design, choice of tools and facilitation to support different modes of working.
2) Assuming a holistic outlook to the problem and the interaction between the artifact and its environment, keeping in mind that redesign might not always be possible
3) Choosing representation and illustrating the problem as well as the artifacts properties so that all stakeholders understand

5. Synthesis of the design challenges and discussions

The first observation we can make from the literature is that design science does not discuss collaborative design explicitly, although the same themes found in collaboration literature are present in many places. The interviews give a different picture and it seems that
modern industrial design practice makes use of collaboration increasingly. It seems that especially in construction and plant design modern regulation has practically forced collaborative design on the designers. It seems that many projects are so complex and involve so many stakeholders and regulators that collaboration is the most straightforward way to proceed. In this sense, it seems that the literature is slightly behind on current developments.

The second observation is the emphasis in both interviews and literature on the first phases of design. We do not believe that other phases of the design process are less challenging, but they are less studied and less discussed. In fact, one might suggest that one of most challenging aspects would be to ensure the organization adopts the artifact, learns to perform quickly, and develops ownership. The front-end of the process may help adoption, but arguably achieving sustained use is one of most demanding tests for an artifact. While extensive studies exist around technology transition, deployment, adoption and use, e.g. [5][27], they are not strongly related to design.

If we compare the challenges from the knowledge base and experience side-by-side, the main themes seem to be similar as far as the first phases of design process are concerned. For instance, both revealed the challenge of creating shared understanding, and the balance between different approaches and perspectives to design. Also the challenges for organizing and managing the design are similar in the literature and interviews. The remaining themes in the literature that did not emerge from the interviews are ensuring ownership and the quality aspects. On the other hand, a theme that emerged from the interviews more strongly than from the literature was assuming a holistic outlook to the problem and the interaction between the artifact and its surrounding. The interviewees did seem to have the perspective of a professional designer instead of a collaborator, so ownership was probably not high on their list. As for quality and balancing the requirements, we would like to interpret that balance is embedded in the concerns of seeking good representation and shared understanding. Overall, we would like to integrate the results to the following proposition for overall design challenges:

1) **Finding the right problem**: Assuming a holistic outlook to the problem and accounting the interplay between the artifact and its environment as well as finding satisfying balance between individual requirements
2) **Ensuring understanding**: Choosing a representation to support mutual understanding of the problem and the artifact, and to support emergence of the intended behavior of the artifact
3) **Finding the right tools**: Organizing collaboration and communication using methods and tools to support stakeholder involvement and flexible collaboration, while maintaining structure and rationality in the process
4) **Ensuring ownership**: transfer of ownership to target organization and helping the owners learn to perform and adapt the existing structures to accommodate the artifact

We have briefly tried to tie the challenges to the definition of collaborative design, and it seems that the main interfaces are finding the problem and then keeping the effort of solving it purposeful. The challenges seem also to relate to the challenges of collaboration discussed above. Starting from the problem definition, it is obvious that it can be challenging to extract the real stakeholder demands from a group of people [2][4][12], whether there are real conflicts of interest or just challenges in collaboration. Information overload can be seen as a real danger when considering large scale designs, which can influence their environment as much as the environment influences the design [32] or otherwise ambiguous or wicked problems [29]. The collaborators or designers have to make a choice on design features [19], have to agree upon the set of evaluation and validation criteria for the artifact [2] and have to decide whether further design is needed [22] and whether the artifact passes validation and is ready to implementation.

Collaboration literature suggests that when confronted with complex and knowledge intensive tasks, groups are often not able to detect and overcome such challenges without support or training [26][31]. Even if groups are able to accomplish their goals, they can often collaborate more efficiently and effectively using collaboration support [18][26]. Collaboration support can consist of tools and technology, processes and services, such as facilitation and training, which support groups in their joint effort [10].

Though designing collaboration support is a challenge on its own, existing research already offers powerful means in form of design patterns to overcome this challenge. Design patterns are already considered a ‘lingua franca’ for design [15]. Design patterns can capture best practices for a specific domain, as e.g. computer-mediated interaction [30] or group facilitation tools and techniques [35].

We used the Hevner et al. [19] framework to structure our study. Our knowledge base is based on a well structured review and analysis of literature and interviews ground the propositions to the environment. Both, the knowledge base and environment have significant overlap, but together they form a richer
picture which in our view raises the validity of our claims. Based on our analysis we found clear patterns in collaborative design, which we call propositions for understanding collaborative design.

There are three major limitations concerning our conclusions. The first is that we have examined only second hand accounts on the engineering design methodology books included in the dataset. Whether this will affect the conclusion is hard to say, but judging by the review by Finger and Dixon [17][16] and Joseph [22], the literature is centered around the same problems, particularly representation and theoretical challenges of design. Another one is the possible ‘researcher bias’ concerning the interviews. It would seem that this bias is manifested in the fact that most challenges identified by the interviewees concern the actual design phase. The third possible bias concerns the coding of the textual materials, which was executed mainly by one of the authors.

Our research has not explicitly differentiated between challenges of design in complex and simple projects. While added complexity will require more and different types of expertise, we expect that this will enlarge but not change the challenges we identified.

When asked about tools and practices interviewees use to facilitate collaborative design, mostly communication technologies like e-mail, document sharing, phone and Skype conversations, meetings, presentations and in more rare cases structured workshops to facilitate group work, and the normal design and engineering software were mentioned. In terms of engineering systems or design methodologies, the interviewees pointed out in-house accumulated best practices and templates and in some cases analysis frameworks.

We will continue our research in the challenges to supplement the limited sample from the vast field of experience which is waiting to be tapped. In terms of further research, our research continues by including more practitioners to the sample and paying attention to the whole design process to gain a more complete picture of the phenomenon and to compose a more complete conceptual model. Especially answering the question how well present theories and methods fare in the “real world” would be a valuable insight for future designers. The findings highlight that structuring creative activity like design is not straightforward, and past rational design theories seem to have run into challenges in the social dimension of collaborative design, that is, creating a purposeful joint effort to solve the design problem. Using our findings, we aim to develop collaboration support method and techniques, based on best practices, and to capture these as design patterns for collaborative design.

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