Reflective Design Documentation

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ABSTRACT
Interaction design researchers doing research through design face not only the wicked problems in the practice of doing interaction design, but also the wicked problems that exist in the practice of doing *research*. In this paper we discuss the use of a tool developed for the specific purpose of documenting design projects and prompting reflection about design events as part of doing research through design. Based on cases lasting from nine to thirteen months we address specific benefits and challenges that we have encountered while employing the tool. Challenges concern *roles and responsibilities, lack of routines, determining what to document*, and *finding the right level of detail*. Benefits include *support of shared reflection and discussion in on-going projects*, the *development, refining, and reflection upon research questions, scaffolding longitudinal and cross-project studies.* Moreover, the benefits derived from entering design materials and other kinds of artefacts into a tool may not be achieved until must later, for instance when writing research publications.

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Design process, research-through-design

ACM Classification Keywords
H5.m. Information interfaces and presentation: Miscellaneous.

General Terms
Design, documentation, experimentation

INTRODUCTION
Interaction design processes can be messy and complicated affairs, especially when designers address so-called 'wicked problems' [13]. It should come as no surprise, then, that not only interaction design *practitioners*, but also interaction design *researchers*, face wicked problems, for the practice of doing research in this area is also highly complex. This is especially so in those cases in which researchers also participate in the design process, for instance, when they carry out research through design [20]. It may be said that researchers who adopt such an approach deal with multiple levels of 'wickedness', as they face not only the wicked problems in the practice of doing interaction design, but also the wicked problems that exist in the practice of doing research. Design research, such as exploring how a design event unfolds, pose a complexity beyond that of the design event, for instance, concerning how to gain access to the design event, how to collect and evaluate data, how to find the proper balance between acting as designers and acting as researchers, and more. One of the crucial aspects of conducting interaction design research is the establishment of reliable and structured ways of capturing and documenting the data generated by the research, so that it can be subjected to analysis and reflection. Documentation may serve the double role of supporting reflection, thereby serving as a source of insight, and providing evidence that supports the insight gained. Given the inherent complexities of design, this process of capturing and documenting design projects can be daunting, especially since there are few resources and tools developed for this particular purpose. In this paper, we will introduce and discuss a system developed for the specific purpose of documenting design projects and prompting reflection about design events, called the 'Project Reflection Tool' (PRT). Our main objective with this paper is not to present the system per se, but rather to present our experiences from the development and deployment of the system in a range of cases, as a catalyst for generating insights into and knowledge of the potential and challenges of systematic design documentation and reflection, as part of design research.

Several contributions to the field of interaction design have criticized the apparent lack of thorough, structured documentation of design processes, for instance [10,20]. Zimmerman, Stolterman, and Forlizzi [20] argue that such a lack of documentation may limit the value of research contributions, among other things because it makes it difficult to evaluate research findings, and renders comparisons across cases difficult. Our development of the PRT system has been motivated by these debates in the community, as well as our own previous experiences of conducting practice-based experimental design research. As such, our development of the PRT system and the discussions presented by this paper may be regarded as a response to calls for a more structured approach to research into the practice of design, as articulated by Wakkary [17], for instance, who states that 'it is by far more common to

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record interactions and real-time observations of "users" but not practitioners'. Indeed, the PRT system has been developed to record the ongoing work of practitioners during design processes, and invite reflection on this work. The design of the system has been inspired by Schön's [14] proposition that the design process may be construed as reflective conversation with materials and resources in the design situation, wherein the designer works with different media or materials, and experiments with various aspects of the design, in an ongoing and iterative process [14]. Thus, we have developed the PRT system to scaffold descriptions of design action, as well as prompt practitioners to continuously input reflection on design.

The structure of the paper is as follows: First, we present and discuss the thinking behind the design of the PRT in the light of related work, primarily touching upon the notions of reflective practice, design rationale, design process documentation, and research-through-design. Next, we offer a brief introduction to the PRT system, and outline four different cases in which it has been employed. With this in mind, we subsequently account for the specific benefits and challenges that we have encountered while employing the PRT system in practice; finally, we will extend our gaze, and offer a discussion of more general topics regarding documentation of design processes for use in research.

We consider these to be this paper's contributions 1) The presentation of the PRT system and the rationale behind its design; 2) The specific benefits and challenges of using a system like the PRT, including considerations of how to carry out similar work in practice; 3) The broader discussion of the potential of structured design process documentation and reflection.

RELATED WORK

According to Schön [14 p135], design processes may be understood as reflective conversation with materials, wherein the designer works with different media or materials, and experiments with various aspects of the design. Through an ongoing dialogue between the designer and the materials, he/she apprehends unanticipated problems and potential, in terms of a system of implications for further moves Schön [14 p101]. When it comes to researching how design processes unfold, this inherent complexity means that design researchers face a number of challenges. For instance, capturing and documenting a design process can be very time-consuming, and researchers often must determine a specific focus for their research, when they start documenting a process, in order to generate empirical data. Yet, if things unfold in unpredictable ways, as they often do when designing, the initial research focus may change during the process, meaning that initial data may be of less value, while aspects that have become pertinent have not been captured in sufficient detail.

When it comes to longitudinal design research, a pertinent question is how to assemble, condense, and make sense of the streams of data that are generated during the process. Since there are few studies and best practice examples of this type, design researchers often must develop their own systems and routines for capturing data and analysing it. This is likely one of the reasons why thorough documentation of design processes are rare, even in design research. The lack of established systems and shared routines for documenting design processes also leads to problems when it comes to comparing findings across different cases.

Another consideration is whether and how the ongoing documentation of a design process can lead to better informed design decisions during the process, if the data are collected primarily for subsequent analysis. Design researchers often assume a dual role, serving as both designers and researchers at different points in time during a process, especially if they adopt a research through design approach [19]. If we take a broader look at design documentation, Design Rationale has been a prominent area since the 1990s [1]. Design Rationale is an overarching term for a diverse set of practices in areas such as engineering, product design, and software engineering, and encompasses the body of knowledge that leads to the design of a specific product. Its basic idea is that a well-documented rationale may improve the quality of the product, as well as the design process. According to Lee [11 p78]:

Design rationales are important tools because they can include not only the reasons behind a design decision but also the justification for it, the other alternatives considered, the tradeoffs evaluated, and the argumentation that led to the decision.

Shipman and McCall [15] have identified three principal perspectives on design rationales. The argumentation perspective focuses on the reasons and considerations behind decisions made by individual designers or groups of designers. Its purpose is to identify flaws in the arguments for the design, with the goal of improving the quality of design decisions. The documentation perspective focuses on the design decision itself, together with information about who made the decisions, and when. The communication perspective focuses on documenting the communication throughout the process, by archiving e-mail messages, design documents, notes from telephone conversations, and so on. Across these three perspectives, Burge and Brown [3] mention eight aspects in which design rationales may be useful: design verification, design evaluation, design maintenance, design reuse, design teaching, design communication, design assistance, and design documentation.

In all cases, a design rationale approach is supported by some kind of software tool, but the strategy for constructing the design rationale varies in several respects [11 p78]. One

strategy is to have designers directly involved and responsible for constructing the design rationale, as opposed to having a dedicated person assigned the responsibility of collecting material and constructing the rationale, either as an ongoing activity throughout the design process, or at the end.

A design rationale system may support the construction of the design rationale, for instance, by automatically storing e-mail messages, video conference sessions, smart board snapshots, or by prompting the designer to answer questions concerning design material being stored.

Despite support by software tools, one faces several challenges when working with design rationales. Atwood and Horner [1] have noted that a significant portion of design activity occurs in informal situations, such as in corridors or around the coffee machine, and when the designer returns to his or her desk or computer, he or she may be more preoccupied with working on the design than documenting what was discussed a moment ago. Like other kinds of professional practice, tacit knowledge and knowing-in-action [14] play crucial roles, which inhibit designers' ability to explicitly formulate the rationale behind a design idea. Another challenge concerns the fact that one cannot document everything, and ultimately, designers are not surprisingly more preoccupied with designing, than with documenting. According to Burge [4], the limited success of the 'use design rationale' also stems from the circumstance of its requiring the collection of very large amounts of data, without the certainty of its utility or a clear benefit.

Our agenda in this paper is not to promote or discuss design rationale systems, which are developed in order to scaffold *design*; rather, we focus on *design research*. Our motivation for bringing design rationale into play is that this field is concerned with developing systems and routines for systematic capture of design events. What we take from Design Rationale is not the assumption that a clear presentation of design reasoning leads to better products, but the insights and experiences from using software tools for capturing salient aspects and events of the design process in a systematic way.

In the area of interaction design research, Dalsgaard et al. [5] report on the experience of using so-called maps, which are sets of artefacts intended to support design researchers to capture, analyse, and reflect on design processes, with a particular focus on sources of inspiration, transformation of design ideas, and design materials. The authors distinguish between three kind of maps: *Overview*, *Strand*, and *Focal Maps.* Overview maps have the form of a timeline, along which the emergence and interrelation of project conditions, sources of inspiration, and design ideas are organized. Strand maps are graphical representations of the design events and activities leading to one particular design idea. Focal maps capture a single design event in a descriptive and a reflective part. The appearance of the maps is not determined by a dedicated software tool, but they are produced as images, using standard graphical software.

In our research lab, [9], much of our work can be characterized as research-through-design. We actively engage in real-life design projects, which serve as catalysts for knowledge generation. One of our main interests is improving the understanding of interaction design processes. Faced with the problem of not having a shared tool for thorough, systematic design documentation that could serve as a source of data for analysis, and informed by the work on maps for design reflection, we recently developed a dedicated online platform, the Process Reflection Tool (PRT), for capturing and reflecting on design processes. In the following section, we present the basic structure and functionality of this system.

THE TOOL

The Process Reflection Tool is organized around documenting the design process in terms of *events*, *sub-events* and *notes* using time as the organizing principle, figure 1. Each of the three elements of the tool has a descriptive part, which describe what happened during a process. In addition to the descriptive element, the tool supports the addition of reflections on the process. PRT is a web-based system, making it a shared resource for all project participants. Figure 2 shows a screenshot of the front page of a specific project, Expo 2010, with five highlighted content areas: 1. Cross-project navigation, administration and search, 2. Project navigation, key functions and timeline, 3. General project information, 4. Most recent event (more events follow further down the page), 5. Overview of all events and notes in the project.

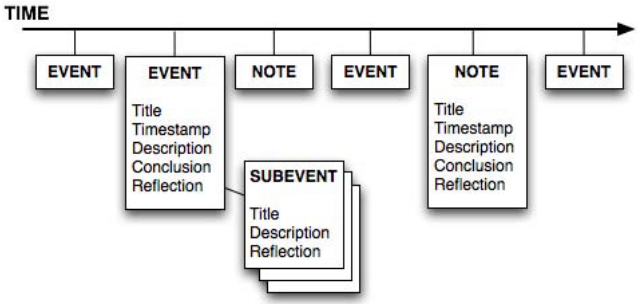

Figure 1: Key elements of the Process Reflection Tool

In the following, we will describe the key elements of PRT in more detail.

Events

An *event* denotes a distinct activity in the design process, such as a meeting, a workshop, an experiment, or a field study. An event is something that has a well-defined purpose in the process, a beginning, and well-defined end.

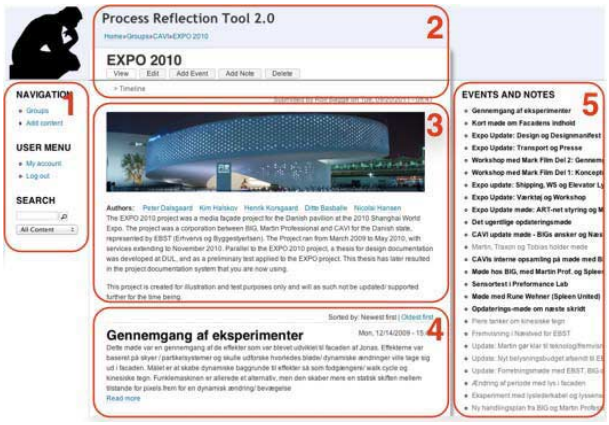

Figure 2: Screenshot of the front page for the Expo 2010 project in PRT with five highlighted main content areas

That is, it is not something regarded as open-ended, but should be finished in a day. If an event extends over several days, it should be split into individual events, in order to keep each event well-defined, and provide a clear overview process. Each event is documented in terms of the following text fields, see also figure 3.

Title: The title of the event, for instance 'Design workshop with the users'.

Timestamp: The time and date of the initial creation of the event. The timestamp is automatically generated, but may be edited, if the event is entered after it has occurred.

Information: General information about the event, such as location, participants, and other relevant facts.

Conclusion: This field is for concluding and summing up the event, for instance, in terms of what insight was gained, or what decision was made about the next step in the process.

Description: This is a description of the event that captures a certain level of detail of what happened during the event.

Associated with each event, PRT supports the upload of still images, video footage, and documents.

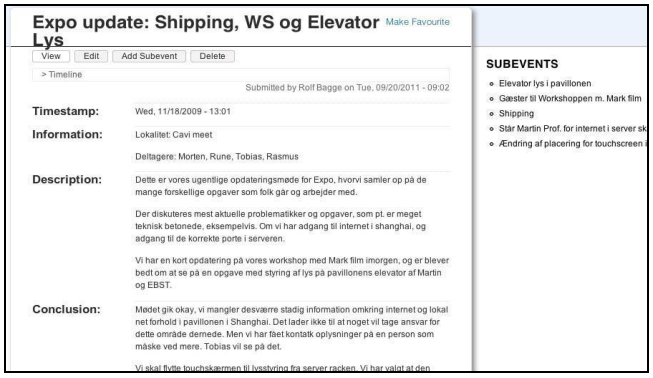

Figure 3: Screenshot of a specific event with sub-events listed to the right

Sub-events

Events may be quite complex, and in order to provide a better overview and structure, it is possible to add *sub-events* to events. For instance, an individual item on the agenda of a design meeting, or a single design experiment of a design workshop may be documented as an individual sub-event.

Sub-events are documented by a title and a description, together with the same kinds of media files possible for events.

Notes

Events and sub-events were the original item types available in PRT, but our initial use of the tool made evident the need to document more informal parts of the design processes, for instance e-mail messages, telephone conversations, discussions around the coffee machine, or the like. For such unscheduled or otherwise informal parts of the process, PRT has *note* items, which are documented with a time stamp and a text field, together with media files.

Timeline

In addition to the standard view, in which events, sub-events and notes are presented in reverse chronological order, a timeline view can be activated at the top of all pages. The timeline shows all events, subevents and notes listed from left to right on a timeline. Users can zoom in and out and select/deselect the view of events, subevents and notes. Clicking on an event, subevent or note will reveal more information about it and provide a link to the full information on the event or note. The timeline allows users to quickly gain an overview of how the project has progressed, get brief information, and delve deeper into specific information if requited. Figure 4 shows a part of the timeline for the Expo 2010 project with selection options for zoom and selection on top, main timeline content in the middle, and timeline navigation at the bottom.

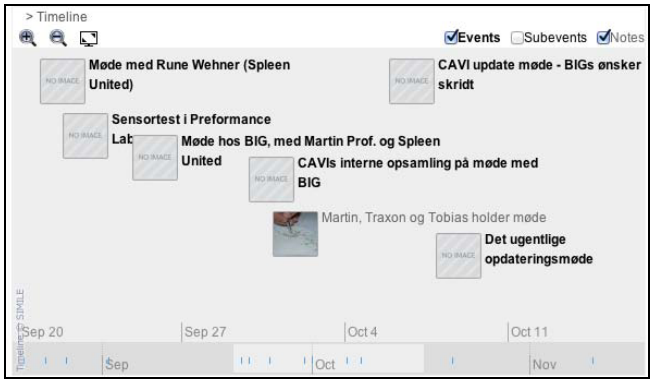

Figure 4: Screenshot of the timeline

Reflection

Working with PRT can be separated into two distinct modes: The documentation of a design process in terms of

events, sub-events, and notes, and reflection on the process. To facilitate reflection, users of PRT can add one ore more reflections to each of the documentation elements (events, sub-events, and notes). The PRT supports Schön' [14] concepts' of reflection-in-action and reflection-on-action, in the sense that reflections may be added as an ongoing activity throughout the design process, or as a separate activity at the end of the process. We have extended Schön's concept of design as a reflective conversation with material – which, in Schön's the original conception is about *design* materials – to also include reflective conversation with materials from a *research* perspective.

To provide an overview of the process the PRT provides a list of all events (in bold) and each sub-event. Moreover, the current version of the tool has a prototype version of a timeline, with thumbnails representing events, sub-events, and notes, where, via radio buttons, it is possible to individually select and deselect each of the three categories.

Basic design principles

The design of the PRT tool itself has been driven by the principle of having a simple interface with few rules for documenting and reflecting on the process incorporated into the tool. The tool is intended to help guide and structure work processes in ways determined by those using the PRT. As an example, events have a 'description' field, but the description of the process is in the hands of the user of the tool.

The basic idea is that mapping comments, reflections, insights, and actions when they occur makes the design process observable, which provides a better platform for analysing the process, and providing empirical data and evidence of research findings. Among our motivations for developing the tool is the desire to support stronger connections between research and design, by inviting reflection on an ongoing basis. Our experience as design researchers doing research through design is that we have a tendency to focus on either the design agenda (during the design process) or the research agenda (when analysing the projects, afterwards). This tool may help us to bridge the two agendas while entrenched in the design phase.

CASES AND MATERIAL

Our research laboratory [9] has used the PRT throughout several of our recent research projects, and for this paper we focus on three of them, and on the use of PRT in our interaction design teaching.

EXPO 2010

The EXPO 2010 case was one of the very first cases where we used the PRT. The project concerned the design and implementation of the media facade of the Danish pavilion at Expo 2010, in Shanghai. The commission for the Danish pavilion at Expo 2010 was awarded to the Danish architectural firm, BIG. The interior of the helical building acted as a three-hundred-metre-long exhibition area, and the outer facade of the pavilion is perforated with almost four thousand holes of various sizes and configurations. Because of the double-loop structure of the building, the facade is almost three hundred metres long, and from some angles appears as two bands, one above the other.

Our research laboratory became involved in the project after the design of the building was already determined; the original idea was that the holes would simply be plain holes, but since we had previously collaborated with BIG in the field of media facades, we suggested to them the idea of turning the perforated facade into a media facade. The design for the media facade evolved over a thirteen-month period, through a series of design experiments involving full-scale mock-ups, a custom-made design visualization tool, and a mixed reality, three-dimensional model. The design tools each addressed different aspects of spatiality, scale, pixel form, and picture formation in their own way. Our principal collaborating partners were BIG and the Danish lighting manufacturer, Martin Professional.

The process was documented in PRT in terms of twenty-three events and thirteen notes, and included a large number of media files documenting design experiments via video and still images, for instance of a full-scale, wood model of a section of the facade (figure 5) and test of light sources for the individual pixels.

Figure 5: full-scale, wood model of a section of the facade

Holger the Dane

The Holger the Dane case was a cultural heritage project that centred on a white concrete statue of the legendary warrior, Holger the Dane, located in a casemate in Denmark's Kronborg Castle. For this project, our research laboratory used 3D projection to add a digital layer directly to the statue, bringing to life for the audience elements of the legends told about Holger the Dane. The project was a direct collaboration with Kronborg Castle, and included three of our PhD students from our research laboratory, together with a project manager, two of our software people, and our designer of 3D models and animations.

Figure 6: Design artefact for design workshop exploring the design potential of the statue in the casemate.

The main part of the design process evolved over a one-year period, and the process has been documented in PRT as eighteen events, most of which have, in turn, been described in greater detail by between two and ten sub-events. Figure 6 shows an image from PRT of one of the design artefacts used.

Tangible 3D Tabletop

The tangible 3D tabletop combines tangible tabletop interaction with 3D projection in such a way that the tangible objects may be augmented with visual data corresponding to their physical shape, position, and orientation on the tabletop, figure 7.

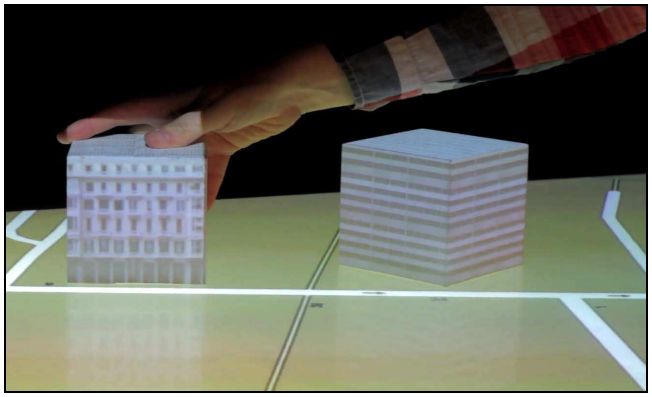

Figure 7: Displaying 3D building facades onto tangibles placed on a map.

Over a nine-month period, we and our partners from a design firm have been exploring the design potential for this particular kind of interface. A large number of design experiments have been documented in PRT, in terms of four events, with between three and eight sub-events, and six notes.

Reflective Design Practicum

The fourth case differs from the aforementioned three, in that it encompasses a number of semester-long projects carried out by groups of design students. The framework for these projects is based upon Schön's notion of *the reflective practicum*, described as 'a setting designed for the task of learning a practice' [14]. The goal is to establish a learning environment in which students are faced with tasks that approximate real world design problems. In these two courses, the students were given the open task of developing an interactive system for municipal libraries and civic services; they then had to carry out a full-time design process from initial field studies through ideation and concept development, working towards a prototype of the project within the space of four months.

The PRT system was employed as the core tool for project documentation in two classes of eighteen and eight design groups, each group consisting of three to five design students. The two courses ran in parallel, providing us with the opportunity to engage in comparative studies of how the use of PRT unfolded. We have chosen to include the projects in the *Reflective Design Practicum* case, because they gave us access to a series of relatively comparable design projects, the design challenges and processes approximated real world design challenges, we could make it mandatory for the student designers to carry out reflective exercises, had constant access to their documentation, and carried out interviews and focus group studies. These twenty-six projects are not design research projects in the same sense as the first three cases, but they share a number of key characteristics: The students carried out extensive studies and thoroughly documented their ongoing work, they were prompted to enter their ongoing reflections as part of their coursework, and they subsequently analysed their documentation in their exam papers. The case is described in more detail in [18].

While the students' use of PRT was clearly influenced by the course framework, the *Reflective Design Practicum* case nevertheless provided us with a number of insights into the benefits and drawbacks of the PRT system, as well as how prospective design researchers, outside of our own research group, perceive the system's potential in practice.

FINDINGS: CHALLENGES AND BENEFITS OF REFLECTIVE DESIGN DOCUMENTATION

We will next outline the main findings that emerged from employing the PRT system in practice. We have chosen to structure these findings under the headings of 'challenges' and 'benefits' of reflective design documentation. While we acknowledge that several of the aspects we address may be construed as both beneficial and challenging, depending on the context of use, we have opted for this structure for the sake of clarity, and because our studies of the PRT system in the range of cases outlined above suggest recurrent aspects that help or hinder systematic documentation and reflection. We also strive to discuss aspects that we deem generalizable beyond these specific cases, based on our own experience, as well as surveys of the literature presented in the 'Related Work' section.

Challenges

System limitations: At a very concrete level, several of facets of the PRT system would benefit from further development, primarily with regard to the immediate capture of information throughout the design process. While we have iteratively improved upon the system, based on ongoing evaluation of use patterns, the PRT system is still a work in progress. The most prevalent finding from user feedback is that information capture must be very straightforward and fast, so that a) it does not interrupt design practice, or that b) the information captured may immediately benefit the design task at hand. With regard to a), the current system facilitates relatively fast text input and uploads of media files from a browser. However, this mode of data entry means that media files such as photos and videos must be transferred to a computer, and then uploaded as part of the documentation process. In practice, this often results in one person having to assemble all the notes, photos, and videos from the event, and enter them into the system. When we did joint evaluations in the *Reflective Design Practicum*, a number of users suggested that the software could be developed to make such actions more straightforward, for instance by directly uploading text, images, and video from smartphones to a project's media archive, which could then be sorted and annotated later on. This mirrors our findings from the *Tangible 3D Tabletop* case, in which we would often took images and videos of design experiments followed by subsequent discussions in which it would be beneficial to have immediate access to the files in a shared system. With regards to b), we are using a current design project to explore how information captured during a design event can feed directly into that event, and inform the ongoing process. An example of this would be photographing sketches from a collaborative ideation event, and displaying them on shared peripheral displays, which could serve as points of reference in the ongoing ideation process, and might be further annotated throughout the event, to highlight particularly interesting or troublesome features.

Resources, roles, and responsibilities: No matter how well a system may function theory, what really matters is how it functions in practice. With regard to PRT use patterns, we identified a series of interrelated challenges related to resources, roles, and responsibilities. Even with the most usable of systems, it takes time to document and reflect upon a design process, and in practice, the design agenda often prevails over the research agenda. On the surface of things, this points to the recurrent work vs. benefit disparity identified by Grudin [7]: There must be a perceived benefit from doing the extra work required for documenting the design process. We observed this challenge in many of the design student projects, as well as in projects in which we, as researchers, were part of the design team. In many projects we have participated in the dual roles of designers and researchers. Even witha relatively straightforward system in place for documenting the design process and a clear motivation for doing so, in terms of our research agenda, we still encountered the problem of deliberately or unconsciously postponing this, in favour of moving ahead with events and activities that move the design process forward.

There may be a number of relevant reasons for advancing with the design project at the cost of research, such as responsibilities to project partners, time constraints, and deadlines, and in the end it may boil down to the fact that, if the design project collapses, it is hard to conduct design research. *Expo 2010* was initiated as a pure research project, but the ideas and design developed were so well received that our research laboratory was offered the opportunity to be part of a consortium that got the contract to implement the design, leading to a formal contract, which increased the pressure on us to commit to documenting the process. However, neglecting documentation efforts can potentially undermine the accuracy and validity of a research project, and the fact that both designers and researchers sometimes do so indicates that this is a major challenge. Part of this may be ascribed to a lack of routine: it takes time to establish new patterns, such as rigorous data capture and reflection on the design process. Thus, one way of addressing these issues is to assign clear roles and responsibilities, with regard to who documents given types of events and activities. In the *Expo 2010* and *Holger The Dane* projects, a member of the research team was assigned the role of managing the ongoing project documentation; in turn, this documentation manager could delegate the responsibility for certain tasks to other project members, for instance, recording and uploading video footage of specific events, or subsequently adding commentary to various activities. In the case of the *Tangible 3D Tabletop*, a team of two researchers, who also had an interest in PRT, led the project, but despite a strong commitment to using PRT, it proved challenging for them to find the time to document and reflect on the process as it unfolded. As a strategy for pushing the use of PRT dedicated time for documentation and reflection was scheduled at the end of each design event, which actually intensified the use of the PRT. In the *Tangible 3D Tabletop* project, we collaborated with partners from a design firm, and since one of them had previously graduated from our department, he contributed to the documentation of the process by sending video footage and images of design experiments.

Documentation focus and detail: When it comes to the actual work of documenting the design process, we have encountered two major issues in our cases: determining what to document, and finding the right level of detail. As described in 'The Tool' section, we have deliberately kept the system generic and open, meaning that it is up to users to establish their specific documentation and reflection approach. Our initial version of the PRT system had more detailed templates for data entry, but we soon discovered that unless we wanted to develop a custom system for

addressing a particular facet of design, these templates would be too constraining for many projects. The current generic system places demands on researchers, when it comes to the initial planning of research efforts. Since documenting a design process can be very time-consuming, researchers must determine a specific focus when they start documenting a process, in order to generate usable data. In the case of *Expo 2010*, one of the focal points was the set of visualization tools and design experiments conducted when designing media architecture, see figure 5, and in the case of *Holger the Dane*, the focal point derived from the research focus of the PhD students involved. The research focus of one of the PhD students was 'space' as a resource in interaction design, which directed the focus on what to document, for instance, design artefacts related to the physical space, figure 6. Had the research focus been different, for instance, related to participatory design or collaboration in a design project, different aspects of the process would have been documented. In the cases in which we have been involved, examples of other focal points include how design concepts emerge, how concepts are expressed in various physical forms throughout the process, and how sources of inspiration inform the design process; these focal points are fully dependent on the research agenda in question.

In our own experience, this initial process of determining what to document and how to establish routines for securing the needed data can be a very fruitful part of the research phase. Since design research is not a 'normal science', in Kuhn's terminology (1962), few (if any) design research efforts are questions of applying a specific, predetermined method. Rather, each research undertaking requires considerable initial methodological consideration, which, when using the PRT, includes reflection on which aspects to document, and how to set up suitable routines for doing so. Even with careful initial deliberation, our experience from the cases is that if things unfold in unpredictable ways, as they often do in design work, the initial research focus may change during the process. In some cases, the research interest is decided *after* the design process has ended, as was the circumstance when we decided to use *Holger the Dane* for our research into the interplay between research and design, as part of our interest in research-through-design [2]. In this particular situation, we did not find the material in PRT sufficient, leading to a need for collecting additional information about the process. Hence, PRT data may have less value than initially desired, because aspects emerge as pertinent may not have been captured in sufficient detail. However, this may be an unavoidable consequence of addressing wicked problems in design research. Our best advice for pre-empting this concern would be to employ methods of data capture that allow for more detailed subsequent analysis, should the need arise. In some cases, for instance, *EXPO 2010*, we found that detailed video recordings of ideation events, which were initially carried out to document how sources of inspiration were brought into play by workshop participants, could also be used to study how physical materials played a role in the formation of design concepts.

Benefits

Supporting shared reflection and discussion in ongoing projects: One of the immediate advantages of the PRT system is that it supports a shared focus on ongoing research and reflection among the parties involved in a design project. While the existence of these aspects at the core of a design research project may seem self-evident, we have found that the presence of a shared, light-weight system throughout the process helps establish a shared platform for the researchers involved to discuss and develop their research agenda. At a concrete level, the system serves as a repository for empirical data and notes, but our studies of the cases also suggest that having this data constantly available and at hand invites reflection and discussion among researchers and practitioners; this is supported by the interface, in which we have designed the presentation of information and input fields to prompt ongoing reflection. We have found that these joint discussions addressed topics ranging from specific design experiments and decisions, to discussions of research agendas. As an example of discussions between designers and researchers, we conducted a joint ideation event with a partnering design company, in the *Tangible 3D Projection Table* case. The various concepts from the event were captured in the PRT system, and both the architects and the design research group subsequently used the system to comment on the rationale behind various concepts, and their motivations for exploring some of them during the subsequent stages of the process. Thus the system can prompt reflection from participants, and help maintain a focus on the research agenda, which may at times be overlooked because of pressing design issues, as discussed in the section above.

From our use of the PRT as part of the *Reflective Design Practicum*, we have clear evidence that the system supports design students' reflection on how they plan design activities in their project team and how they reflect on the way in which design activities unfold.

Developing, refining, and reflecting upon research questions: Just as the use of the PRT may invite discussions of overarching research agendas, we have found it to serve as the nexus for the development and refinement of specific research questions in the four design cases. When it comes to the development of research questions, it appears that the initial strategy for capturing data influences how research discussions unfold. A strategy for data capture that focuses on specific and well-defined questions most often seems to prompt relatively restricted discussions of the existing research questions. In contrast, more open-ended strategies for capturing diverse aspects of design often led to discussions of how more specific research questions may be defined; this is likely a combination of two factors, one being that the research group develops an understanding of

particularly salient topics, the other being the very practical point that design documentation is labour-intensive, and in most cases it is only possible to capture part of the process. For example, when we started the *EXPO 2010* project, we had a general interest in studying the design process, and as the process unfolded, we zeroed in on understanding the tools and design experiments applied, in order to understand the design potential of the curvilinear display using a unique kind of pixel [6].

In addition to supporting reflection on ongoing projects, we find the PRT a valuable resource, once a design project is concluded. For example, our research group is interested in understanding research-through-design as a research approach, and for a recent paper [2] we used the *Holger the Dane* project as the principal case. Although research-through-design was not defined as an area of research at the start of that project, we found that having the project events available in the PRT was extremely valuable as a starting point for reflecting on the interplay between research and design.

Scaffolding longitudinal and cross-project studies: In addition to offering a shared platform for capturing current activities and discussions in an ongoing project, we consider the main benefit of employing a system such as the PRT to be that it scaffolds longitudinal and cross-project studies. Some design research projects extend over long periods of time, and our experience is that such projects present researchers with certain pitfalls. One of the practical pitfalls is that details and data may be lost over the course of time; this may be remedied by rigorous data collection. Another pitfall, which exists at a more conceptual level, is that the accounts of what has happened during a design process, and why, has a tendency to change over the course of time: Design decisions and moves are often re-interpreted retrospectively, in light of insights that were not available at the actual time that said decisions and moves occurred. From a research perspective, this may result in unintentionally skewed accounts. One of the reasons for developing the PRT system was to counter this tendency, by prompting users of the system to document not only descriptions of design events, but also the intentions and reflections at that point in time. While it may seem burdensome extra effort at the time of entry, this provides a more reliable frame of reference for subsequent analyses.

Another benefit of employing the PRT or a similar system is that allows for studies of aspects of design across cases, provided that the strategies for documenting cases have been comparable. Such cross-case studies, which are exceedingly difficult to carry out and/or may become speculative if not properly documented, may concern both overall developments of the design process, or more specific aspects, such as the outcomes of a given design technique. As an example of overall design process development, in the *Design Practicum* case we conducted a study of phases of convergence and divergence during the design process [12], combined with design-group interviews and process visualization exercises, in order to examine when different groups of students experienced so-called 'moments of insight', that is, development breakthroughs, as reported in [18]. As an example of studying a specific aspect across a series of cases, we are currently examining the impact of a particular co-design technique [8] in a series of projects in which the technique has been employed in the ideation phase, in order to improve understanding of how the technique can be developed and adapted to suit a given project.

6. DISCUSSION: RESEARCH AND DESIGN

We started from the call for thorough, structured documentation of design processes, something broached by several researchers in the field [10,20], who have argued that the lack of this kind of information may limit the quality of research contributions. We have used the PRT system to address benefits and challenges when capturing and reflecting on design processes based on our experiences with several projects. Importantly, we do not claim that the PRT is the ultimate tool for supporting reflection on design processes, but have simply used it as a resource for exploring how to support research-through-design. We have developed PRT to fit our specific needs, and an obvious avenue for future research is to explore how other systems, including off-the-shelf software, could be employed to support reflective design documentation.

The design of PRT has been inspired by research into design rationale. It is important to point out that our system differs from design rationale systems in a very important respect, namely that the objective of the system is to capture data from the design process for use in design research, rather than to serve as a tool for improving the result of the design process. While we speculate that PRT might be employed as an active tool in the design process in order to support design decisions, we have not yet explored this aspect in depth. Given the inspiration from design rationale systems and our own prior experiences from capturing design processes for research purposes [5], we have designed PRT primarily on the principle that it should be simple and easy to use, without any strict, built-in procedure for using the tool. For instance, we have limited the number of required fields to be filled in, and do not require that reflections be added at particular points during the process. The key to successfully using the tool lies not in the tool itself, but in the practices established for its use. One particular issue we would like to emphasize relates to one of the challenges in designing groupware addressed by Grudin [7 p97]: 'Disparity in work and benefit. Groupware applications require additional work from individuals who do not perceive a direct benefit from the use of the application', which may also be the case when documenting design processes for research purposes. But, perhaps even more crucially, the benefits derived from entering design materials and other kinds of artefacts into a tool such as the

PRT may not be achieved until must later, for instance when writing research publications.

We have extended Schön's [14] concept of reflection in and on design processes to include reflection in and on research processes. However, the approach we take is not limited to a specific theoretical understanding of the design process, but may support a grounded theory approach, in which theory emerges from ongoing data analysis and coding, as well as more traditional hypothesis-evaluating research efforts. In both cases, capturing empirical data and providing evidence for research publications are essential.

While it is often advantageous for researchers to determine a specific focus for their research when they start documenting a process, in order to generate relevant and focused empirical data, the unpredictability of the design process may in turn affect the research questions. In the introduction, we touched upon the concept of 'multiple levels of wickedness', and this is one of the ways in which the 'wicked problems' of design practice and design research conflate. If things unfold in unforeseen ways, the initial research focus may change during the process, meaning that preliminary data may be less valuable, while aspects that later become relevant have not been captured in sufficient detail. On the surface of things, this may argue against thorough and systematic documentation. However, we will argue that quite the opposite is true. First, systematic process documentation can help researchers to identify the factors that have changed, and, by extension, may provide a better basis for developing research questions to be addressed within the framework of the project. Secondly, accounts of how and why research questions change over the course of complex projects may be extremely valuable to the design research community, since it can feed into the ongoing discourse on the nature of design research [16].

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